

FISH BIODIVERSITY AND DISTRIBUTION IN SUNKOSH RIVER TRIBUTARIES, BHUTAN: A BASELINE ASSESSMENT

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ABSTRACT: *Baseline information on freshwater fish biodiversity is essential for effective Environmental Impact Assessment (EIA) and sustainable land-use planning. However, biodiversity data in Bhutan remain limited due to diverse reasons. This study assessed fish species composition and spatial distribution in selected tributaries of the Sunkosh River Basin in Tsirang District of Bhutan. Field surveys were conducted from 21 April to 10 May 2025 using a stratified, site-based sampling, by means of electrofishing and cast nets. A total of 274 fish individuals representing 17 species, 13 genera, four families, and two orders were recorded. Species richness varied markedly among sites, ranging from three species in Katley Khola to eleven species at the Kali Khola-Sunkosh confluence. This pattern indicates pronounced habitat heterogeneity and strong ecological connectivity. *Neolissochilus hexagonolepis* or commonly Chocolate Mahseer or Katley (in Bhutanese usage) was the most abundant species, followed by *Ptychobarbus* spp. (Snow trout/Snow carp) and *Aborichthys* spp., (Torrent loaches) while *Garra* spp. (Stone suckers or Sucker fish) showed wide spatial distribution across river systems. Notably, *Tor putitora* (Golden Mahseer or Sernya in locally), *Semiplotus semiplotus* (Kharpata or Assam carp), and *Pterocryptis barakensis* (Barak catfish) were recorded exclusively at the confluence zone, underscoring its conservation significance. One-way ANOVA revealed significant spatial variation in fish abundance among sampling sites for electrofishing and cast-net sampling ($F_{7,16} = 4.37, p < 0.05$), while diversity analysis using the Shannon-Wiener diversity index and Simpson diversity index indicated moderate to high fish diversity (Shannon: 0.76–2.23; Simpson: 0.44–0.89), with greater diversity in downstream and confluence habitat of sampling stations 4 to 5 (S4–S5) and lower diversity at sampling station 1 (S1) reflecting limited habitat complexity in the smaller Katley Khola stream. The study provides critical baseline data to support environmental clearance, impact mitigation, and long-term biodiversity monitoring under a broader rehabilitation and environmental management framework known as Model Rehabilitation Programme, MRP. The findings emphasise the need for prioritizing ecologically sensitive zones and conducting additional seasonal surveys to capture undetected species and temporal variation.*

Keywords: Species richness; Environmental impact assessment; Lotic ecosystems; Bhutan; Himalayan rivers; Model rehabilitation program; Livelihood transformation.

1. INTRODUCTION

Agriculture continues to underpin Bhutan's rural livelihoods, accounting for approximately 43.5% of national employment, while contributing a comparatively smaller share (14.67%) to the country's Gross Domestic Product (Royal Government of Bhutan 2023). This structural imbalance reflects enduring challenges such as fragmented land tenure, insufficient production and market infrastructure, limited mechanization, and constrained access to financial services,

which collectively restrict productivity and commercial growth (Ministry of Agriculture and Forests 2022). Strengthening livestock and agricultural systems therefore requires integrated interventions that enhance economic performance while safeguarding environmental resources (National Statistics Bureau 2024).

The Model Rehabilitation Program (MRP) represents a strategic response to these challenges by emphasising land-use

optimisation and livelihood transformation within the policy framework of Bhutan's 13th Five-Year Plan. It aims to substantially improve agricultural sector performance by increasing agricultural GDP from Nu. 36.48 billion in 2023 to Nu. 58 billion by 2029, thereby supporting national aspirations for a high-income Gross National Happiness economy by 2034 (Gross National Happiness Commission 2023). Key elements of the MRP include cluster-based livestock development, enhanced value-chain integration, and diversification of production systems.

The Sunkosh River Basin (*Puna Tsang Chu* in Dzongkha, Bhutan's official language) is one of Bhutan's major river systems, draining from the high Himalayas into India. Its tributaries, including Katley Khola, Kalikhola, and Dhanasey Chu, support rich riverine biodiversity and provide critical spawning and nursery habitats for native fish species (Tenzin et al. 2025; Royal Government of Bhutan 2000). Because these tributaries are vital for local livelihoods and ecosystem connectivity, fish biodiversity surveys and ecological baseline assessments are essential components of Environmental Impact Assessments (EIAs) for proposed developments under the MRP to ensure sustainable land and water resource management (National Environment Commission [NEC], 2000).

Notwithstanding these development objectives, large-scale livestock and agricultural interventions have the potential to influence surrounding natural systems if ecological considerations are insufficiently addressed (Shanmugam et al. 2024; Royal Government of Bhutan 2025). Bhutan's increasing pressure from unplanned urban expansion has further intensified concerns related to land-use efficiency and natural resource management (Ministry of Infrastructure and Transport 2019; Water Research Bhutan 2023). Urban growth often leads to increased impervious surfaces, wastewater discharge, and habitat

fragmentation, while intensified agriculture contributes nutrient runoff, sedimentation, and pesticide exposure. Together, these processes interact synergistically, compounding stress on aquatic habitats and amplifying risks to native fish populations (Pradhan and Mandal 2008; Sharma et al. 2022). These dynamics highlight the importance of embedding environmental safeguards within land-use and livestock development planning processes.

Careful monitoring is necessary because hydropower development and land-use changes can significantly affect freshwater biodiversity. For instance, in Bhutan, studies on the Wang Chhu and Puna Tsang Chhu basins have documented declines in native fish abundance following dam construction (Dorji et al. 2018; Wangchuk and Tshering, 2020). In neighboring Nepal, hydropower projects on the Trishuli and Marshyangdi Rivers have similarly altered fish community composition (Shrestha and Khadka 2019). These examples highlight the potential ecological consequences if mitigation measures are not effectively implemented

Lotic ecosystem¹ are particularly responsive to landscape-level changes, and fish community structure is widely used to infer ecological condition and habitat integrity (Allan 2004; Karr 1981). Himalayan river systems support diverse native fish fauna of ecological and socio-economic significance, yet systematic baseline assessments remain limited in many areas (Gurung and Thoni 2019). Riverine fish biodiversity in Bhutan is sensitive to climate variation and changing flow regimes, and there is a growing need for standardized long-term monitoring to support conservation planning (Wangchuk and Wangmo, 2022). In accordance with national environmental regulations, fish biodiversity surveys form a

¹A lotic ecosystem refers to a freshwater environment characterized by flowing water, such as rivers, streams, and creeks.

mandatory component of Environmental Impact Assessments (EIA) for livestock commodity farms and associated infrastructure proposed under the MRP (National Environment Commission [NEC], 2000).

Fish biodiversity surveys and ecological baseline assessments are conducted under the MRP area to ensure sustainable land and water resource management. Unlike previous programs² the MRP integrates systematic ecological monitoring with targeted habitat restoration, emphasizing evidence-based decision-making and proactive environmental safeguards, thereby representing a more innovative and comprehensive approach to river basin rehabilitation.

Fish biodiversity surveys and ecological baseline assessments are required under the MRP areas to inform Environmental Impact Assessments (EIAs). These surveys follow standardized protocols for key indicators, including species composition, abundance, and habitat quality; however, some survey components may be adapted to the scale of specific development projects, ensuring both regulatory compliance and practical feasibility.

This study was undertaken to establish baseline information on fish species composition and distribution within selected river systems in the MRP intervention area. It aims to assess fish biodiversity and ecological conditions in tributaries of the Sunkosh River Basin; Katley Khola, Kali Khola and Dhanasey Chhu addressing a critical research gap as these tributaries have not yet been covered by any comprehensive

baseline studies or systematic ecological assessments. The results provide essential reference data for environmental clearance processes, facilitate impact evaluation, and support long-term monitoring and evidence-based decision-making for environmentally responsible implementation of the MRP. Beyond its immediate relevance to MRP, the findings will also contribute important baseline ecological insights that may support national freshwater biodiversity conservation, evidence-based fisheries management, and environmentally responsible rural development planning in Bhutan.

2. MATERIALS AND METHODS

2.1 Study area

The study was conducted in three river systems geographically located at; Katley Khola (26.550495° N, 90.849540° E), Kali Khola (26.540782° N, 90.064125° E), and Upper Danasey, lower-end (26.511946° N, 90.053094° E), and Lower, lower-end Danasey (26.510550° N, 90.025839° E), under Tsirang Dzongkhag, Bhutan (Figure 1&2; Table 1). These rivers form part of the Sunkosh River Basin and represent varying hydrological, ecological, and anthropogenic conditions. They represent riverine habitats distributed along an altitudinal gradient ranging from 474 to 1,072 m above mean sea level (amsl). Katleykhola/Tsakaling is situated at approximately 1,072 m amsl, Kalikhola at 474 m amsl, Upper Danasey at 792 m amsl, and Lower Danasey at 499 m amsl. The variation in elevation and stream characteristics across the sites provides heterogeneous aquatic habitats that influence freshwater fish assemblages and biodiversity patterns within the study area.

Katley Khola (Zone 1) was represented by a single sampling site selected to characterize the general ecological and physicochemical conditions of the river. Kali Khola (Zone 2) comprised three sampling sites distributed across the upstream, midstream, and downstream reaches to capture longitudinal variation in habitat structure and water

²Previous programs refer to earlier river or watershed management efforts that were typically fragmented, project-based, and development-focused, with limited long-term ecological monitoring and integrated restoration planning.

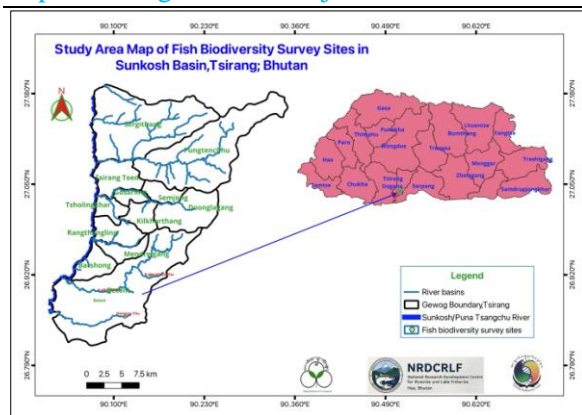


Figure 1: Fish biodiversity survey sites within the Sunkosh River Basin in Tsirang District, Bhutan.

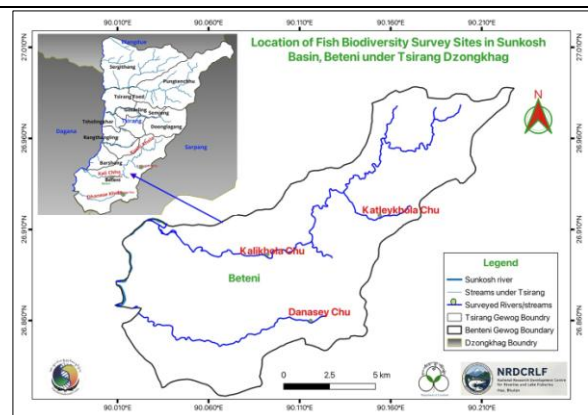


Figure 2: Location of fish biodiversity survey and sampling sites within the Sunkosh River Basin, including Dhanasey Chhu, Kali Khola, and Katley Khola, under Tsirang District, Bhutan.

Table 1: Geographic location, elevation, and habitat characteristics of fish sampling sites in Katley Khola, Kali Khola, and Dhanasey Chhu, Tsirang District, Bhutan.

Zone (River)	Sampling site	Site ID	Starting Point			End Point			Sampling Distance (m)
			Lat.	Long.	Altitude (m)	Lat.	Long.	Altitude (m)	
Katley Khola	Tsakaling Katley	S1	26.550495	90.84954	1072	26.91543	90.14984	1100	553
	Malbasey Proper	S2	26.540782	90.064125	474	26.543023	90.065575	512	1258
	Malbasey Mid	S3	26.53503	90.042259	372	26.534509	90.050453	400	1203
Kali Khola	Kali Khola-Sunkosh Confluence	S4	26.544023	90.02001	277	26.542349	90.02356	325	1327
Upper Dhanasey	Lower end	S5	26.511946	90.053094	792	26.513374	90.055029	842	777
	Upper end	S6	26.514198	90.061058	848	26.51424	90.062015	853	267
Lower Dhanasey	Lower end	S7	26.510555	90.025839	499	26.510135	90.031644	551	619
	Upper end	S8	26.505635	90.034353	582	26.50537	90.035463	599	332

quality. Dhanasey Chhu (Zone 3) included four sampling sites, subdivided into two sites in the upper reach, representing relatively undisturbed headwater conditions, and two sites in the lower reach, where channel width increases and human influence is more pronounced. This spatial stratification ensured representative coverage of all river sections and facilitated comparative assessment among systems.

Fish habitats surveyed encompassed a range of freshwater microhabitats, including riffles, runs, and pools. Substrate composition ranged from boulders and cobbles in upper reaches to sandy and silty substrates downstream. Riparian vegetation was dense along Katley Khola and the upper Dhanasey Chhu, resulting in shaded channel conditions, whereas sections of Kali Khola, particularly near the confluence, exhibited more open canopies and deeper pools. Such habitat heterogeneity was expected to influence fish assemblage structure and distribution across sampling sites.

Sampling sites within the MRP intervention landscape were selected to represent ecologically relevant and accessible stream habitats, enabling assessment of fish biodiversity and generation of baseline data for environmental planning and management.

Although the broader landscape is influenced by anthropogenic activities such as small-scale agriculture, livestock grazing, and scattered settlements associated with the MRP intervention area, most sampling sites were located in relatively undisturbed stream sections. These locations were intentionally selected to capture fish assemblages under largely natural habitat conditions and to provide baseline ecological information prior to potential and-use intensification resulting from settlement and agricultural development.

2.2 Sampling design

A stratified sampling design was adopted, with each river treated as a distinct sampling zone and further subdivided into non-overlapping sampling sites (Table 1). Sampling sites were established along the stream at intervals ranging from approximately 267 m to 1,327 m. The variation in site spacing was influenced by accessibility and local geographic conditions such as terrain, stream morphology, and safe sampling points within the study area. This spatial arrangement enabled coverage of representative habitat sections within the MRP- intervention landscape while maintaining sufficient separation among sites to reduce sampling overlap and support comparative assessment of fish biodiversity.

This sampling approach is consistent with methods that reduce within-site variability and enhance the representativeness of fish biodiversity estimates across spatial gradients (Chaudhuri and Stenger 1992). The survey design followed established principles of representative sampling to minimize bias and improve reliability of estimates (Chaudhuri and Stenger 1992; Barnett 1991). A uniform sampling protocol was applied across all sites to ensure methodological consistency and comparability, following established environmental sampling design principles (Green 1979). In total, eight sampling sites were surveyed: one in Katley Khola, three in Kali Khola, and four in Dhanasey Chhu (two in the upper reach and two in the lower reach).

2.3 Sample collection

Fish sampling was conducted between 21 April and 10 May 2025, corresponding to the spring season (April-May), a biologically active period characterized by moderate water temperatures, increasing discharge from snowmelt, and early pre-monsoon rainfall. These conditions facilitated access to sampling sites and supported diverse aquatic habitats.

Sampling was conducted during the selected season to ensure favorable field conditions and effective sampling efficiency. However, seasonal timing may influence species detectability, as several native Himalayan stream fishes in Bhutan, including *Schizothorax* and *Garra* species, exhibit seasonal habitat shifts or upstream movements associated with spawning, which may alter their spatial distribution and capture probability during the sampling period (Khanal et al. 2023; Wangchuk and Wangmo 2022).

Fish were collected using a portable electrofisher and a cast net, selected based on habitat characteristics and in accordance with standard sample-based fisheries assessment procedures. Catch per unit effort (CPUE) was computed following established protocols (Sparre 2000). Electrofishing was carried out using a portable unit powered by a 12 V, 14 Ah lithium-ion battery coupled with a digital inverter producing 230 V at 50 Hz (200 VA output). This configuration was maintained consistently across all sampling sites to standardize the electrical output and ensure comparability of sampling effort. Captured individuals were measured for total length (mm) and body weight (g) and subsequently released at the capture site. Representative specimens were preserved in 10% formalin for laboratory-based taxonomic identification according to morphological keys outlined for Bhutanese fishes of western and eastern Bhutan (NRDCR&LF, 2017; NRDCR&LF, 2020). The specimens were then preserved and deposited in the centre's repository laboratory for future reference. Each preserved specimens were labeled with site name, GPS coordinates, date of collection, and collector details.

At each sampling site, water quality parameters including dissolved oxygen (DO), pH, temperature, and total dissolved solids (TDS) were recorded in triplicates at both the upstream and downstream ends

using a multi-parameter probe (Model 98194, Hanna Instruments, Romania).

2.4 Survey effort

Sampling was conducted over 20 field days across the eight sites. At each site, electrofishing was performed for approximately 1-2 hours, targeting shallow and mid-depth habitats, while cast netting was conducted for approximately 1 hour, focusing on deeper pools and open-water sections³. The two gear types were deployed with standardized effort across all sites, with each site being sampled for approximately 1-2 hours (electrofishing) or 3-5 net throws (cast netting), ensuring CPUE comparisons reflect actual differences in fish abundance rather than sampling effort. The average effective sampling time per site was 67 minutes, adjusted according to accessibility and habitat complexity, following established methodologies for assessing exploited fisheries in Indian waters (Banerji 1973). Catch per unit effort (CPUE) was recorded for each gear type. Field activities were carried out by a team of six trained personnel, including a fisher.

2.5 Data analysis

Data analysis focused on species richness, relative abundance, and CPUE. Species richness was defined as the total number of fish species recorded per site and river system. Relative abundance was calculated as the proportion of individuals of each species relative to the total catch. Gear-specific CPUE was used as an indirect indicator of fish abundance and was calculated as the total catch weight divided by fishing duration (hours) for each sampling method.

³These methods were selected to maximize species detection across different habitats, as electrofishing temporarily stuns fish allowing live capture and identification, while cast netting complements sampling in deeper areas. Both methods are widely used in Bhutanese freshwater biodiversity studies (Tenzin, Tobgay, and Gurung, 2025; NEC, 2000).

Furthermore, species diversity was assessed using the Shannon-Wiener diversity index (H') and Simpson's diversity index (D) to evaluate community diversity and dominance patterns. The Shannon-Wiener diversity index (H') was calculated using the formula:

$$H' = -\sum(p_i \ln p_i)$$

where p_n represents the proportion of individuals belonging to the i th species relative to the total number of individuals recorded. This index accounts for both species richness (number of species) and evenness (distribution of individuals among species). Higher values of H' indicate greater diversity, reflecting a more even distribution of individuals among species, whereas lower values suggest dominance by a few species.

The Simpson diversity index (D) was calculated using the formula:

$$D = 1 - \sum(p_i^2)$$

where p_n represents the proportional abundance of each species. This index measures the probability that two individuals randomly selected from a sample belong to different species. Values of the index range from 0 to 1, with values closer to 1 indicating higher diversity and lower dominance by a single species.

Spatial differences in CPUE and fish abundance among sampling sites were examined using one-way analysis of variance (ANOVA). Separate analyses were conducted for CPUE obtained from electrofishing (g hr^{-1}) and cast net sampling (g min^{-1}). Prior to analysis, data were checked for normality and homogeneity of variance. Statistical significance was determined at $\alpha = 0.05$. All statistical analyses were performed using standard statistical procedures following methodologies commonly applied in fisheries stock assessment studies.

3. RESULTS AND DISCUSSION

3.1 Basic water quality

Basic water quality parameters were recorded to characterize habitat conditions and establish baseline environmental conditions across the study sites (Table 2). DO concentrations ranged from 6.6 to 8.0 ppm, while pH values varied between 8.4 and 8.9 across all sampling locations. These values fall within ranges considered suitable for freshwater fish and aquatic fauna under Class D water quality standards (Central Pollution Control Board 2008) which were used as a comparative benchmark for fisheries-supporting waters in the absence of detailed Bhutan-specific classification thresholds.

TDS ranged from 67 to 138 ppm, remaining well below thresholds reported to support productive freshwater ecosystems (Boyd 2020) and are consistent with typical ranges observed in Himalayan river systems.

Water temperature varied from 20.8 to 24.3°C, with slightly higher values observed in mid- and downstream reaches. Mean water depth ranged from 34 to 43 cm, while water velocity varied from 0.1 to 1.2 m s^{-1} , reflecting differences in channel morphology and flow conditions among sites. Overall, the measured physicochemical parameters indicated generally favorable habitat conditions for freshwater fish assemblages across all three river systems (Allan and Castillo 2007; Boyd 1998). These conditions corresponded with higher species richness in moderately deep and flowing reaches, highlighting habitat-driven patterns in freshwater fish assemblages.

3.2 Species richness and composition

A total of 274 individual fish specimens, representing 2 orders, 4 families, 13 genera, and 17 species, were recorded across the study area. Their conservation status is presented according to the IUCN Red List (Table 3; Figure 3).

Table 2: Physicochemical water quality parameters recorded across sampling sites during the study period (April–May 2025).

Zone (River)	Sampling site	Site ID	DO (ppm)	pH	Temperature (°C)	TDS (ppm)	Water depth (cm)	Water velocity (m/s)
Katley Khola	Tsakaling Katley	S1	6.9	8.4	21.8	120.5	43	0.1
	Malbasey Proper	S2	7	8.4	22.3	76	36	0.7
Kali Khola	Malbasey Mid	S3	7.7	8.8	24.3	68	34	0.8
	Kali Khola-Sunkosh Confluence	S4	8	8.9	23.2	67	41	1.2
Upper Dhanasey	Lower end	S5	6.6	8.5	21.3	127	39	0.3
	Upper end	S6	7	8.8	20.8	138	42	0.4
Lower Dhanasey	Lower end	S7	7.9	8.6	22.7	89	40	1
	Upper end	S8	8	8.9	23.5	85	41	1.2

Table 3: Checklist of fish species recorded from the Sunkosh River tributaries and their IUCN red listed, Tsirang District, Bhutan.

Order	Family	Genus	Species	IUCN Status	
Cypriniformes	Cyprinidae	<i>Barilius</i>	<i>Barilius barna</i>	Least concern	
		<i>Devario</i>	<i>Devario aequipinnatus</i>	Least concern	
			<i>Devario assamensis</i>	Vulnerable	
		<i>Tor</i>	<i>Tor putitora</i>	Endangered	
		<i>Neolissochilus</i>	<i>Neolissochilus hexagonolepis</i>	Near threatened	
		<i>Semiplotus</i>	<i>Semiplotus</i>	Data deficient	
		<i>Ptychobarbus</i>	<i>Ptychobarbus sps</i>	Least concern	
		<i>Schizothorax</i>	<i>Schizothorax sps</i>	Data deficient	
		<i>Garra</i>	<i>Garra annandalei</i>	Least concern	
			<i>Garra gotyla</i>	Least concern	
			<i>Garra lamta</i>	Least concern	
			<i>Garra arupi</i>	Not evaluated	
		Balitoridae	<i>Schistura</i>	<i>Schistura sps</i>	Data deficient
			<i>Aborichthys</i>	<i>Aborichthys sps</i>	Data deficient
Siluriformes	Siluridae	<i>Pterocryptis</i>	<i>Pterocryptis</i>	Endangered	

Order	Family	Genus	Species	IUCN Status
			<i>barakensis</i>	
	Sisoridae	<i>Parachiloganis</i>	<i>Parachiloganis</i> <i>sps</i>	Least concern
		<i>Pseudecheneis</i>	<i>Pseudecheneis</i> <i>sulcata</i>	Least concern

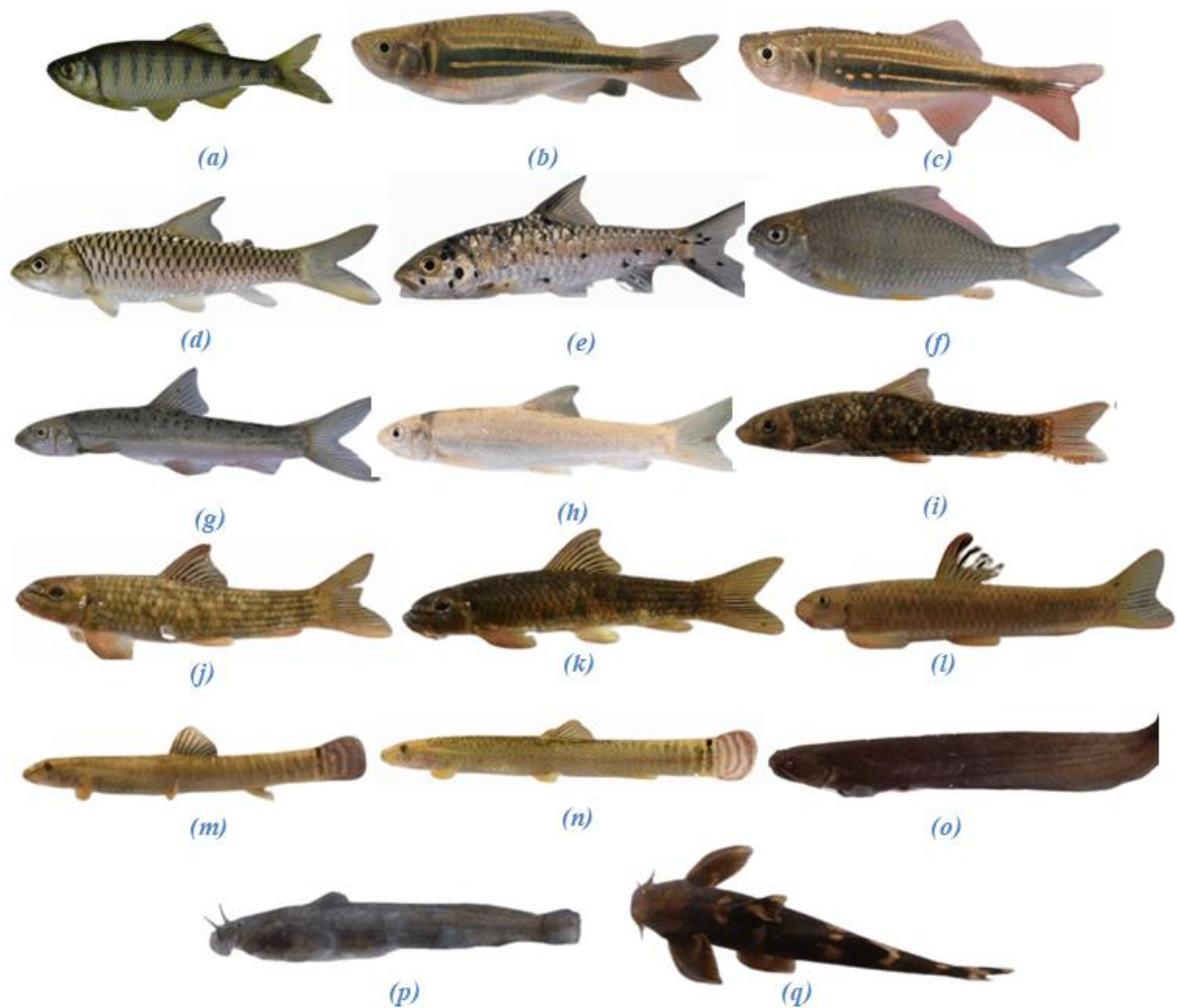


Figure 3: (a) *Barilius barna*; (b) *Devario aequipinnatus*; (c) *Devario assamensis*; (d) *Tor putitora*; (e) *Neolissochilus hexagonolepis*; (f) *Semiplotus semiplotus*; (g) *Ptychobarbus* sps; (h) *Schizothorax* sps; (i) *Garra annandalei*; (j) *Garra gotyla*; (k) *Garra lamta*; (l) *Garra arupi*; (m) *Schistura* sps; (n) *Aborichthys* sps; (o) *Pterocryptis barakensis*; (p) *Parachiloganis* sps; (q) *Pseudecheneis sulcata*

Species richness varied among sites, ranging from 3 species at Katley Khola (S1) to 11 species at the Kali Khola-Sunkosh confluence (S4) (Table 4; Figure 3.1). The spatial variation in species composition

observed in the present study is comparable to post-monsoon community patterns reported from the Nikachhu River (Khanal et al. 2022).

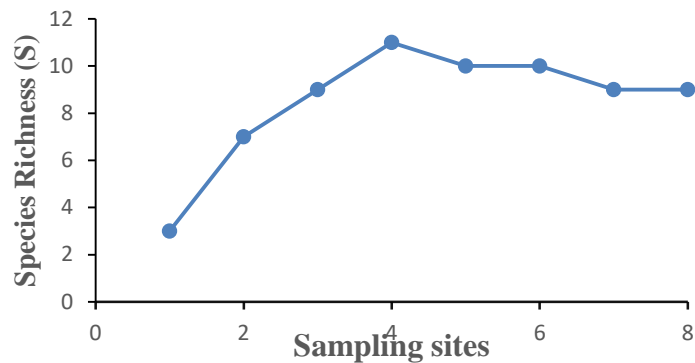


Figure 3.1: Variation in species richness across sampling sites.

Table 4: Site-wise species richness (S) recorded across sampling locations.

Zone (River)	Sampling site	Site ID	No of Species Diversity (S)	Species
Katley Khola	Tsakaling Katley	S1	3	<i>Garra annandalei</i> , <i>Ptychobarbus sp</i> , <i>Parachiloganis sp</i>
Kali Khola		S2	7	<i>Devario assamensis</i> , <i>Devario aequipinnatus</i> , <i>Ptychobarbus sp</i> , <i>Neolissochilus hexagonolepis</i> , <i>Aborichthys sp</i> , <i>Garra annandalei</i> , <i>Garra gotyla</i>
	Malbasey Mid	S3	9	<i>Devario assamensis</i> , <i>Devario aequipinnatus</i> , <i>Ptychobarbus sp</i> , <i>Neolissochilus hexagonolepis</i> , <i>Aborichthys sp</i> , <i>Garra annandalei</i> , <i>Garra gotyla</i> , <i>Garra arupi</i> , <i>Barilius barna</i>
	Kali Khola-Sunkosh Confluence	S4	11	<i>Tor putitora</i> , <i>Devario assamensis</i> , <i>Devario aequipinnatus</i> , <i>Garra annandalei</i> , <i>Garra lamta</i> , <i>Garra gotyla</i> , <i>Barilius barna</i> , <i>Neolissochilus hexagonolepis</i> , <i>Aborichthys sp</i> , <i>Semiplotus semiplotus</i> , <i>Pterocryptis barakensis</i>
	Lower end	S5	10	<i>Devario assamensis</i> , <i>Devario aequipinnatus</i> , <i>Neolissochilus hexagonolepis</i> , <i>Schizothorax sps</i> , <i>Ptychobarbus sp</i> , <i>Aborichthys sp</i> , <i>Garra lamta</i> , <i>Garra gotyla</i> , <i>Garra arupi</i> , <i>Parachiloganis sps</i>
Upper Dhanasey	Upper end	S6	10	<i>Devario assamensis</i> , <i>Devario aequipinnatus</i> , <i>Neolissochilus hexagonolepis</i> , <i>Schizothorax sps</i> , <i>Ptychobarbus sp</i> , <i>Aborichthys sp</i> , <i>Garra lamta</i> , <i>Garra gotyla</i> , <i>Garra arupi</i> , <i>Parachiloganis sps</i>

Zone (River)	Sampling site	Site ID	No of Species Diversity (S)	Species
	Lower end	S7	9	<i>Ptychobarbus sp</i> , <i>Neolissochilus hexagonolepis</i> , <i>Aborichthys sp</i> , <i>Garra gotyla</i> , <i>Garra arupi</i> , <i>Pseudecheneis sulcata</i> , <i>Schistura sps</i> , <i>Parachiloganis sps</i> , <i>Devario assamensis</i>
Lower Dhanasey	Upper end	S8	9	<i>Ptychobarbus sp</i> , <i>Neolissochilus hexagonolepis</i> , <i>Aborichthys sp</i> , <i>Garra gotyla</i> , <i>Garra arupi</i> , <i>Pseudecheneis sulcata</i> , <i>Schistura sps</i> , <i>Parachiloganis sps</i> , <i>Devario assamensis</i>

Species under the genus *Garra* were recorded at most sampling sites, indicating wide distribution across the river systems. Species of the genus *Devario* were recorded from Kali Khola and the upper reaches of Dhanasey Chhu but were not detected at Katley Khola and lower Dhanasey sites.

Three species; *Tor putitora*, *Semiplotus semiplotus*, and *Pterocryptis barakensis* were recorded exclusively from the Kali Khola-Sunkosh confluence, contributing to the higher species richness observed at this site.

The Kali Khola-Sunkosh confluence constitutes a critical conservation zone due to its high habitat heterogeneity and associated fish species richness, as Bhutan's river systems at lower elevations support relatively higher fish diversity and require prioritized aquatic biodiversity conservation efforts (Wangchuk and Tshering 2022). The exclusive occurrence of conservation-priority and migratory species such as *Tor putitora*, *Semiplotus semiplotus*, and *Pterocryptis barakensis* underscores its role as a key ecological refuge and movement corridor. Species composition further reflects favorable water quality and minimal habitat

degradation. Targeted protection of this confluence is therefore essential for maintaining fish biodiversity and ecological integrity within the Sunkosh river system.

Further, diversity analysis using the Shannon-Wiener and Simpson indices (Table 4) revealed moderate to high fish diversity across the study sites. Shannon index values ranged from 0.76 at S1 to 2.23 at S5, indicating increasing diversity in downstream sections and river confluence areas. The highest diversity was recorded at S5 and S4, which correspond to areas with greater habitat heterogeneity and higher species richness. Simpson index values ranged from 0.44 to 0.89, suggesting relatively low species dominance and well-balanced fish communities at most sampling sites. The lowest diversity observed at S1 may reflect the smaller stream size and limited habitat complexity of Katley Khola.

Spatial variation in fish distribution across sampling sites is likely influenced by ecological factors such as flow velocity, substrate composition, and riparian canopy cover, which are key determinants of fish assemblage structure in Himalayan rivers. Hydromorphological heterogeneity

strongly structured fish assemblages across the study area, with high-velocity reaches characterized by coarse substrates (boulders, cobbles, and gravels) supporting rheophilic and benthic taxa such as *Garra* spp., *Pseudecheneis sulcata*, *Schistura* spp., and *Parachiloganis* spp., while lower-velocity runs and pool habitats favored more mobile, water-column-oriented cyprinids including *Devario aequipinnatus*, *Devario assamensis*, and *Neolissochilus hexagonolepis* (Allan and Castillo 2007; Jayaram 2010; Gurung and Thoni 2015). Additionally, riparian vegetation and heterogeneous habitats such as riffle-run-pool sequences and river confluences enhance habitat complexity, thereby supporting higher species diversity and influencing fish assemblage composition across the study area (Dorji, 2021; Wangda et al. 2023; Wangmo et al. 2023; Jamtsho and Sridith 2017). Similar habitat-driven patterns of fish distribution have been reported in Bhutanese river systems, highlighting the role of local habitat conditions in structuring freshwater fish diversity (Wangchuk and Wangmo 2022; Gurung and Thoni 2015; Tshering and Wangchuk 2018).

3.3 Abundance patterns

Among all species recorded, *Neolissochilus hexagonolepis* was the

most abundant, with 88 individuals ($\approx 34\%$ of the total catch), followed by *Ptychobarbus* spp. (37 individuals, $\approx 14\%$) and *Aborichthys* spp. (29 individuals, $\approx 11\%$) (Table 6). Site-wise abundance varied considerably, with Site S6 recording the highest total number of individuals (67, $\approx 26\%$ of total catch), while Site S1 recorded the lowest (14, $\approx 5\%$).

Several species, including *Barilius barna* and *Pseudecheneis sulcata*, were represented by low numbers during the survey ($<3\%$ each). Their low abundance may reflect a combination of sampling bias associated with electrofishing efficiency, seasonal variation in habitat uses or movement patterns, and the naturally low population densities typical of specialized hill-stream fishes in Himalayan River systems, where many species exhibit patchy distributions linked to microhabitat availability (Dorji 2021; Wangmo et al. 2022; Ngor et al. 2018; Jyrwa et al. 2019). Species such as *Tor putitora*, *Semiplotus semiplotus*, and *Pterocryptis barakensis* were restricted to the Kali Khola-Sunkosh confluence, where overall species richness and total abundance were comparatively high (Table 5).

Table 5: Showing Shannon-Wiener and Simpson diversity indices interpretation at 8 different sampling sites.

Sites	Total Individuals (N)	Species Richness (S)	Shannon Index (H')	Simpson Index (D)	Diversity Interpretation
S1	14	3	0.76	0.44	Very low diversity
S2	27	7	1.64	0.74	Moderate diversity
S3	43	9	1.52	0.67	Moderate diversity
S4	30	11	2.13	0.86	High diversity
S5	40	10	2.23	0.89	Highest diversity
S6	67	10	2.01	0.83	High diversity
S7	21	9	2.11	0.87	High diversity
S8	32	9	1.82	0.78	Moderate-high diversity

Table 6: Species-wise abundance of fish recorded during the survey.

Species	Code	Abundance (nos)								Total
		S1	S2	S3	S4	S5	S6	S7	S8	
<i>Barilius barna</i>	Bar_bar	0	0	1	1	0	0	0	0	2
<i>Devario aequipinnatus</i>	Dev_aeq	0	1	2	2	3	7	0	0	15
<i>Devario assamensis</i>	Dev_ass	0	2	2	2	4	6	2	3	21
<i>Tor putitora</i>	Tor_put	0	0	0	4	0	0	0	0	4
<i>Neolissochilus hexagonolepis</i>	Neo_hex	0	12	23	8	7	20	5	13	88
<i>Semiplotus semiplotus</i>	Sem_sem	0	0	0	3	0	0	0	0	3
<i>Ptychobarbus sps</i>	Pty_sps	10	2	1	0	6	15	2	1	37
<i>Schizothorax sps</i>	Sch_sps	0	0	0	0	5	4	0	0	9
<i>Garra annandalei</i>	Gar_ann	1	4	3	3	0	0	0	0	11
<i>Garra gotyla</i>	Gar_got	0	3	2	0	2	4	2	3	16
<i>Garra lamta</i>	Gar_lam	0	0	0	3	4	3	0	0	10
<i>Garra arupi</i>	Gar_aru	0	0	1	0	3	2	2	1	9
<i>Schistura sps</i>	Sch_sps	0	0	0	0	0	0	1	2	3
<i>Aborichthys sps</i>	Abo_sps	0	3	8	3	4	3	3	5	29
<i>Pterocryptis barakensis</i>	Pte_bar	0	0	0	1	0	0	0	0	1
<i>Parachilognanias sps</i>	Par_sps	3	0	0	0	2	3	2	3	13
<i>Pseudecheneis sulcata</i>	Pse_sul	0	0	0	0	0	0	2	1	3
TOTAL		14	27	43	30	40	67	21	32	274

The widespread occurrence of *Garra* spp. across sites ($\approx 12\%$ of total catch) likely reflects their ecological adaptability to heterogeneous riverine habitats. Members of this genus are benthic and rheophilic, possessing a specialized adhesive disc that enables attachment to substrates in fast-flowing waters, allowing them to thrive in riffle- and run-dominated habitats (Jayaram 2010). Their grazing behavior on periphyton further supports persistence across varying productivity gradients.

In contrast, the limited occurrence of *Devario* spp. ($\approx 4\%$ of total catch) may be attributed to both habitat specificity and gear selectivity. *Devario* species are typically mid-water, schooling cyprinids that prefer moderate-flow and open-water microhabitats, which may have been spatially restricted at some sites. Moreover, electrofishing is generally more efficient for benthic and substrate-associated fishes, whereas highly mobile, pelagic species may

evade capture, potentially leading to underrepresentation (Bonar et al. 2009).

3.4 Catch per Unit Effort (CPUE)

Catch per unit effort (CPUE) varied substantially among sampling sites and between fishing gears (Table 7). Electrofishing CPUE ranged from 48.4 g hr^{-1} at Site S1 to 723.0 g hr^{-1} at Site S7 (Figure 4). Similarly, cast net CPUE ranged from 0.4 g min^{-1} at Site S1 to 8.2 g min^{-1} at Site S7⁴(Figure 5).

Comparable approaches have been used in Indian pelagic fisheries, where CPUE served as a key indicator of stock status (Banerji 1973). Sites S5, S6, S7, and S8 consistently recorded higher CPUE values for both gear

⁴ CPUE was calculated separately for each gear type using gear-specific effort units; electrofishing was standardized per hour of active sampling (g hr^{-1}), whereas cast netting was standardized per minute of deployment (g min^{-1}) to reflect differences in sampling duration and operational mechanics.

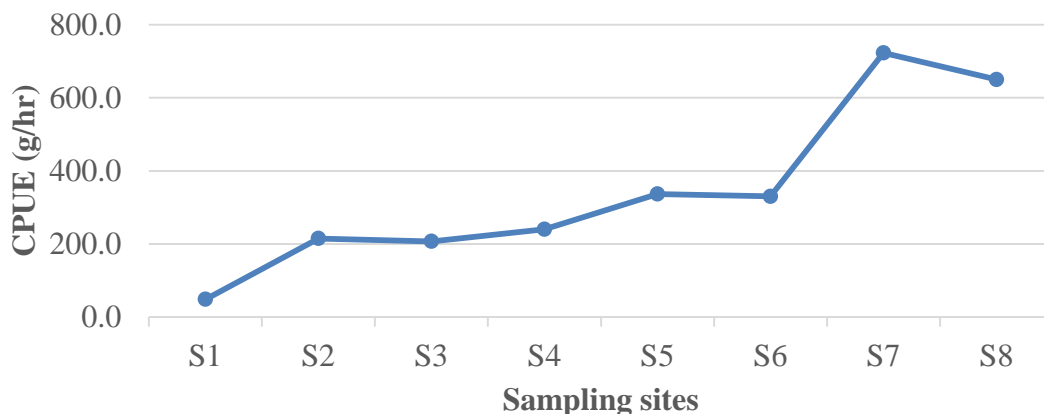


Figure 4: Electrofishing catch per unit effort (CPUE) recorded across sampling sites.

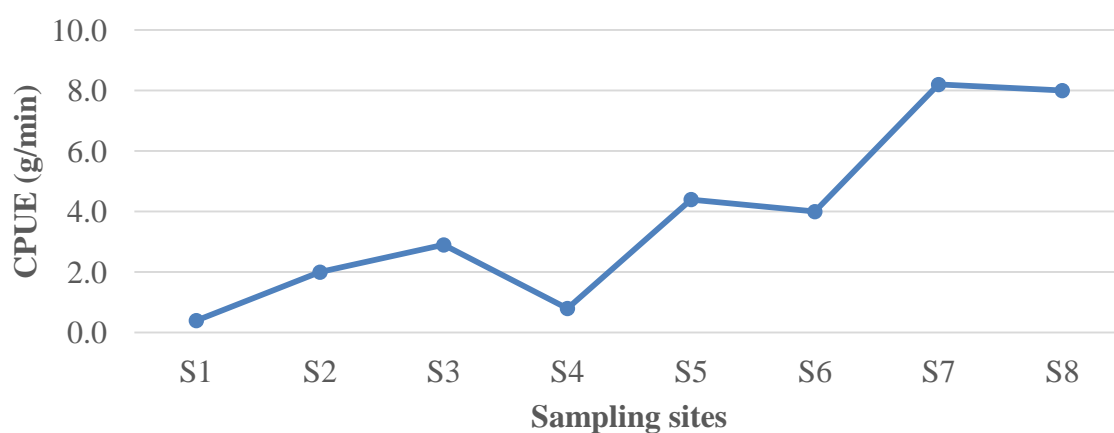


Figure 5: Cast net catch per unit effort (CPUE) recorded across sampling sites.

Table 7. Catch per unit effort (CPUE) recorded using electrofishing and cast net across sampling sites.

Zone (River)	Sampling site	Site ID	Catch per unit effort (CPUE)	
			Electrofisher (g/hr)	Cast net (g/min)
Katley Khola	Tsakaling Katley	S1	48.4	0.4
	Malbasey Proper	S2	215	2
Kali Khola	Malbasey Mid	S3	207.1	2.9
	Kali Khola-Sunkosh Confluence	S4	240	0.8
Upper Dhanasey	Lower end	S5	336.6	4.4
	Upper end	S6	330	4
Lower Dhanasey	Lower end	S7	723	8.2
	Upper end	S8	650	8

Table 8. Results of one-way ANOVA testing differences in CPUE among sampling sites.

Source of Variation	df	Sum of Squares	Mean Square	F-value	p-value
Among Sites	7	384520	54931	5.82	<0.01
Within Sites	16	151060	9441		
Total	23	535580			

types compared to upstream locations (Figures 4 and 5). The lowest CPUE values were observed at Katley Khola (S1) across both sampling methods.

One-way ANOVA revealed significant spatial variation in CPUE among sampling sites for electrofishing ($F_{7,16} = 5.82$, $p < 0.01$) and cast net sampling ($F_{7,16} = 4.37$, $p < 0.05$), indicating that fish abundance differed significantly across the study sites as shown in the Table 8.

4. CONCLUSION, AND RECOMMENDATIONS

The study assessed fish species composition, relative abundance, and catch per unit effort (CPUE) across selected riverine sites using electrofishing and cast netting. Results indicated clear spatial variation in species distribution and abundance, reflecting habitat heterogeneity, flow regimes, and localized environmental conditions. The observed differences in species richness across sites may be attributed to variations in habitat heterogeneity, such as substrate composition and canopy cover, as well as the degree of anthropogenic influence, including fishing pressure and land-use activities.

The study recorded 274 fish specimens representing 17 species, with the Kali Khola-Sunkosh confluence exhibiting the highest species richness and Katley Khola the lowest. *Neolissochilus hexagonolepis* dominated overall abundance, while *Tor putitora*, *Semiplotus semiplotus*, and *Pterocryptis barakensis* were restricted to the confluence, underscoring its ecological significance. The river harbors fish species of high conservation value, including several

that are threatened or migratory, emphasizing the urgency for targeted protection. Conserving these populations is critical for maintaining biodiversity, ecosystem balance, and local fisheries sustainability.

Widespread *Garra* spp. demonstrated adaptability to typical Bhutanese hill-stream environments, whereas limited occurrence of *Devario* spp. may reflect habitat specificity or sampling constraints. Differences in CPUE between gear types further underscore the influence of methodological factors on abundance estimates.

The findings highlight the importance of maintaining habitat integrity in river systems to support fish diversity. Conservation efforts could be strengthened through riparian buffer zone protection, regulation of destructive fishing practices, and seasonal fishing restrictions during spawning periods, which would help maintain habitat quality and sustain fish populations in the study area.

The study recommends prioritizing future research that standardizes sampling protocols, including gear type, effort, and duration, and conducts multi-seasonal surveys to capture temporal variability in fish distribution and habitat conditions. Integrating physicochemical and habitat parameters, focusing monitoring on restricted species, and incorporating complementary methods such as environmental DNA (eDNA) and additional netting techniques will improve species detection, reduce gear bias, and support evidence-based fisheries management and

freshwater biodiversity conservation in Bhutan.

The study was limited by short-term sampling and reliance on two gear types, which may have introduced selectivity bias, while the absence of detailed seasonal and environmental data restricted comprehensive ecological interpretation. Thus, the observed distribution patterns likely reflect a combination of habitat variability and methodological sampling limitations. Nevertheless, despite these logistical constraints, the study provides critical baseline data for environmental impact assessment and conservation planning; accordingly, priority conservation of the confluence zone, long-term biodiversity monitoring, improved field logistics, and adequate resourcing are recommended to support sustainable riverine management in Bhutan. To achieve this, specific actions are recommended, including establishing protected areas or habitat refuges, implementing seasonal or gear-specific fishing restrictions, enhancing community awareness programs, and integrating monitoring results into national fisheries and biodiversity policy frameworks.

Future research should adopt long-term monitoring frameworks, expand spatial coverage, and apply multivariate statistical analyses to better understand species-habitat relationships and strengthen evidence-based fisheries management and biodiversity conservation.

Acknowledgement

The authors acknowledge the National Biodiversity Centre, Serbithang, Thimphu, for organizing and funding this study. Gratitude is extended to our Centre Management (National Research Development Centre for Riverine & Lake Fisheries), for technical guidance and field support, and to supervisors, colleagues, and field assistants for their invaluable contributions, including logistical coordination, data management, and behind-

the-scenes support. Appreciation is also extended to the local government and communities under Tsirang District for their assistance with logistics and transportation during fieldwork.

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