

Habitat and Distribution Pattern of Threatened Freshwater Fishes found along the Drangmechhu River and its Tributaries in Pemagatshel District, Eastern Bhutan

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Abstract

The distribution of freshwater fishes is primarily determined by physical and chemical water parameters and human activities. However, a complete understanding of how these factors relate to threatened species in the study area is still lacking. This study assessed the habitat association and distribution pattern of three threatened species *Tor putitora* Hamilton, 1822, *Neolissochilus hexagonolepis* McClelland, 1839, and *Schizothorax richardsonii* Gray, 1832, along the Drangmechhu River and its five tributaries in Pemagatshel District, Bhutan. The field data was collected in March 2025 from 33 sampling plots, with each plot covering a 500 m stretch. Fishes were sampled using electrofishing and cast nets. A significant difference in fish abundance was detected across habitat types ($H = 16.64$, $df = 2$, $p = .000$), with riffles supporting the highest abundance (58.4%), followed by pools (30.1%), and runs (11.5%). The species exhibited distinct habitat association with respect to velocity, depth, and substrate composition. These threatened species preferred varying velocities, depths, and substrates. *N. hexagonolepis* favored higher velocities (0.5 m/s), shallower depths (0.44 m), and fine substrates, while *S. richardsonii* preferred lower velocities (0.3 m/s), moderate depths (0.56 m), and coarse substrates. Ecological models revealed highly suitable zones (>0.6) for *N. hexagonolepis* and *S. richardsonii* with strong predictive accuracy (AUC = 0.88–0.996), whereas models for *T. putitora* showed low accuracy (AUC = 0.547–0.569). Conservation implications from the study highlight the importance of habitat-specific management for threatened freshwater fishes along the Drangmechhu River system and its tributaries. Conservation should focus on protecting and restoring riffle habitats.

Keywords: Abundance, conservation, habitat suitability, modelling, threatened species

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Introduction

Bhutan, located in the Eastern Himalayas, represents a part of 36 global biodiversity hotspots, with exceptionally rich freshwater ecosystems (Allen et al., 2010; Nepal, 2022). The country is home to more than 127 fish species belonging to eight orders: Anguilliformes, Beloniformes, Cypriniformes, Perci-

formes, Salmoniformes, Siluriformes, Synbranchiformes, and Tetradontiformes, and 24 families (Gurung & Thoni, 2015; NBC, 2019; Sagar et al., 2023). The new record of *Macrog-nathus aral* Bloch & Schneider, 1801, from the Aiechu-Kalikhola tributary of the Maukhola River in Gelephu, Sarpang District, reported by Sagar et al. (2023), increased the known fish diversity of Bhutan to 128 species.

Despite growing documentation of fish diversity in Bhutan, a significant knowledge gap remains regarding the habitat association and distribution patterns of *Neolissochilus hexagonolepis* McClelland, 1839, *Schizothorax richardsonii* Gray, 1832, and *Tor putitora* Hamilton, 1822. *Tor putitora* is generally associated with pool habitats and large streams; however, its populations are highly fragmented due to habitat alteration and anthropogenic pressures. It is listed as endangered on the IUCN Red List (2019). Similarly, *N. hexagonolepis* is classified as vulnerable (IUCN, 2020) and inhabits well-oxygenated river basins characterised by rocky, boulder-rich stretches and moderate to fast-flowing currents, which provide suitable conditions for feeding and reproduction.

However, *Schizothorax richardsonii* inhabits cold, high-altitude Himalayan streams and fast-flowing rivers characterized by sandy or pebbly substrates. Due to habitat degradation and increasing anthropogenic pressure throughout its range, this species was classified as vulnerable by IUCN in 2010.

Although these species have been recorded from the Drangmechhu River basin (Dorji & Wangchuck, 2014; Wangchuk et al., 2021), detailed information on their habitat association and distribution patterns remains limited. Habi-

tat conditions play a significant ecological role, as they directly influence species survival, feeding behaviour, and reproduction success (Upton & Sutinen, 2005). This understanding is particularly important for threatened fish species, which are highly vulnerable to habitat degradation and fragmentation (Cooke et al., 2012). Therefore, this study investigated the habitat association, environmental associations, and distribution of *T. putitora*, *N. hexagonolepis*, and *S. richardsonii* along the Drangmechhu River and its tributaries in Pemagatshel District. By integrating field-based assessments with statistical analyses and ecological modelling, the study provides essential insights for the effective conservation and management of these species.

Materials and Methods

Study Area

The study was carried out in the Drangmechhu River basin and its five tributaries: Kerongchhu, Kurongchhu, Sokporongchhu, Yurichhu, and Demrichhu located in Pemagatshel District (Figure 1), addressing a significant knowledge gap regarding the ichthyofauna of the region (Wangchuk et al., 2021). The elevation of the sampling sites ranges from 200 m a.s.l. from the lowest point to over 1600 m a.s.l. at the highest. The riverine landscape of the study area ranges from subtropical forests in the lower valleys, through warm broadleaved and chirpine forests in the mid-elevation, to cool broadleaved forests at higher elevations (NLC, 2020). The region experiences an average annual temperature of 16°C, ranging from 7°C to 25°C, and receives an annual precipitation of 1500–3000 mm. (FAO, 1995; Tshewang & Wangchuk, 2019). The

study area is characterised by highly dissected mountain ranges, steep slopes, and narrow valleys, where majority of the local people depend on agriculture as their primary livelihood. The region is covered by approximately 91.18% forest, while agricultural land constitutes 4.50% of the total area. These variations create diverse microclimatic conditions, enabling threatened fish species to occupy and adapt to various habitats based on their ecological association (Fisher, 2012).

Sampling design

The river was stratified into the main river and its tributaries using ArcGIS Pro version 11.3.0. Thirty-three sampling plots, each covering a 500-m stretch, were assessed to include different habitat types, such as run, riffle, and pool (Sagar et al., 2023; Wangchuk et al., 2021). Sampling points were established at a distance of 1.5 km between sampling plots

(Dorji & Sagar, 2025). A total of 11 sampling plots were located along the main river and 33 plots in its five tributaries. This sampling design was intended to gather comprehensive information on the threatened species (DoFPS, 2020).

Data collection and identification

Data were collected in March 2025 using mild electric shockers and cast nets (Dorji & Sagar, 2025; Wangchuk et al., 2021). The electric shocker was used to temporarily stun the fish, facilitating closer examination and measurement (Alonso, 2001). For identification of fishes, we followed *Fishes of Bhutan: A preliminary checklist* (Gurung & Thoni, 2015), *Freshwater Fishes of the Indian Region* (Jayaram, 2010), and National Research Centre for Riverine and Lake Fisheries (NRDCR & LF, 2020) of Haa, Bhutan.

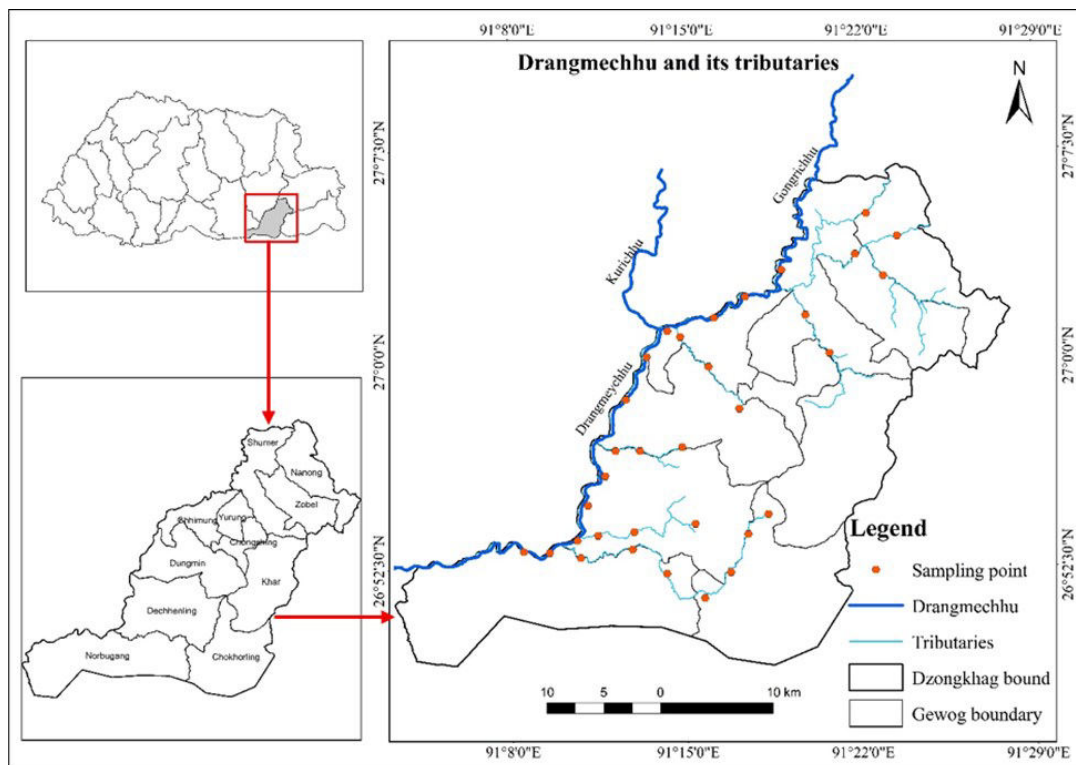


Figure 1: Study area showing the location of sampling plots along the Drangmechhu River and its tributaries

The number of individuals captured was recorded based on the sampling effort per hour in each sampling stretch (DoFPS, 2020). To standardise the sampling effort, in each sampling stretch, one hour of electrofishing was conducted with 10 cast net throws. The number of species encountered was live photographed using a high-resolution Canon EOS 80D camera to maintain a clear picture and colours (Sagar et al., 2023). Length and weight of the fish caught were measured and recorded using a scale on the spot, and the fish were released back alive into the river (Gurung et al., 2013; Sagar et al., 2023; Wangchuk et al., 2021). Coordinates and water quality parameters at fish encounter sites were recorded using a SW map to facilitate analysis of relationships between environmental variables and fish distribution (Dorji & Sagar, 2025; Radinger et al., 2019).

Habitat and water parameters

Geocoordinates and altitudes of the sampling points were recorded using a Garmin eTREX 20 (Behivoke et al., 2021). Water quality parameters such as Temperature (°C), pH, Dissolved Oxygen (DO), total dissolved solids (TDS), and electric conductivity (EC) were measured using the PCS testr35 (Odo et al., 2024). Area Flow Velocity Meter (Gore & Banning, 2017) was used to measure velocity (m/s), depth (cm), and width (cm) of the stream for each sampling point. Additionally, canopy cover (%), substrate type, hardness, depth, and habitat types (run, riffle, and pool) were recorded using the Spherical Crown Densiometer and the Flow Velocity Meter (Dorji & Sagar, 2025).

Data processing and statistical analysis

The data were analysed using both Microsoft Excel 2019 and R Studio software version 4.4.1 (R Core Team, 2024). Descriptive statistics were calculated to compare results from different microhabitats. Statistical analyses were conducted to evaluate the significance of habitat association by the threatened species. As the data were not normally distributed, the Kruskal-Wallis H Test was used to assess fish distribution across different habitat types, water velocities, and river depth (Dorji & Sagar, 2025). Pairwise post-hoc tests were performed to compare differences identified by the Kruskal-Wallis H Test (Pohlert, 2014). Additionally, a chi-square test was also performed for categorical variables, primarily to examine how substrate type influenced the distribution of fish species (Mogaka, 2024).

Further, Principal Component Analysis (PCA) was performed in R version 4.4.1 (R Core Team, 2024) using the FactoMineR and factoextra packages to evaluate the influence of environmental variables on the fish species (Dorji & Sagar, 2025; Kassambara & Mundt, 2017; Lê et al., 2008). Environmental factors such as temperature, salinity, TDS, EC, pH, DO, and total hardness were included in the analysis.

Ecological modelling was performed in R using the randomForest, FactoMineR, and factoextra packages to predict the potential distribution of the threatened species in the study area (Ekundayo & Okoh, 2019). Further, to predict the habitat suitability, environmental predictors such as DEM, slope, temperature, precipitation, settlement, Normalized Difference Vegetation Index (NDVI), human disturbance, topography, and road were used in

Table 1: Relative abundance of fishes across different habitat types

Habitat type	Median	IQR	Sum count	RA %	<i>P</i>
Pool	1	1.00	63	30.1	
Riffle	5	4.75	122	58.4	< .001
Run	2.5	2.00	24	11.5	

the analysis. An ensemble model, combining Generalised Linear Models (GLM) and Random Forest (RF), was applied to capture linear and nonlinear relationships between species and environmental variables (Mi et al., 2017). The models were validated using True Skill Statistics (TSS) and Area Under the Curve (AUC) for cross-validation to ensure reliable prediction, and habitat suitability was analysed using the MaxKappa threshold (Huang & Frimpong, 2015).

Results and Discussion

Fish Relative Abundance Across Habitat Types

The Relative Abundance (RA) of threatened fish species (*Neolissochilus hexagonolepis*, *Schizothorax richardsonii* and *Tor putitora*) in different habitats was highest in the riffle habitat (58.4%) and lowest in the run habitat (11.5%) (Table 1). The Kruskal-Wallis H Test showed significant differences in the relative abundance of fish distribution between the habitat types ($H = 16.64$, $df = 2$, $p < .001$). Pairwise post-hoc comparison was done using Dunn's test. The relative abundance between

the pool and riffle was significant ($Z = -4.05$, $p < .001$). However, there was no significant difference in relative abundance between riffle and run ($Z = 1.057$, $p = 0.145$) and pool and run ($Z = -1.599$, $p = 0.109$).

Majority of the fishes (90%) observed during the field survey were juveniles and were primarily concentrated in the riffle habitat. Similar observations have been reported in Himachal Pradesh, India (Hauer et al., 2011; Schlosser, 1987; Sharma & Banyal, 2024). This distribution is mainly due to juveniles of cyprinids and small-bodied fishes being displaced from pools by the presence of predators, particularly large piscivorous fish (Hauer et al., 2011; Mahato et al., 2023; Schlosser, 1987). The higher abundance in riffles reflects greater oxygen levels and higher availability of macroinvertebrate prey for juvenile fishes (Sharma & Banyal, 2024). However, this taxon of adults with larger maximum sizes, including cyprinids, is often found in run and pool habitats (Kar et al., 2010; Schlosser, 1987; Wangchuk et al., 2021).

Table 2: Results of Kruskal-Wallis and Dunn's Post-Hoc Tests of fish against water velocity association

Species	Comparison	Median Velocity (m/s)	Statistic	<i>P</i> -value
<i>N. hexagonolepis</i>	vs. <i>S. richardsonii</i>	0.50	$Z = 2.277$.011*
<i>S. richardsonii</i>	vs. <i>T. putitora</i>	0.30	$Z = 5.876$	< .001*
<i>T. putitora</i>	vs. <i>N. hexagonolepis</i>	0.14	$Z = 6.413$	< .001*

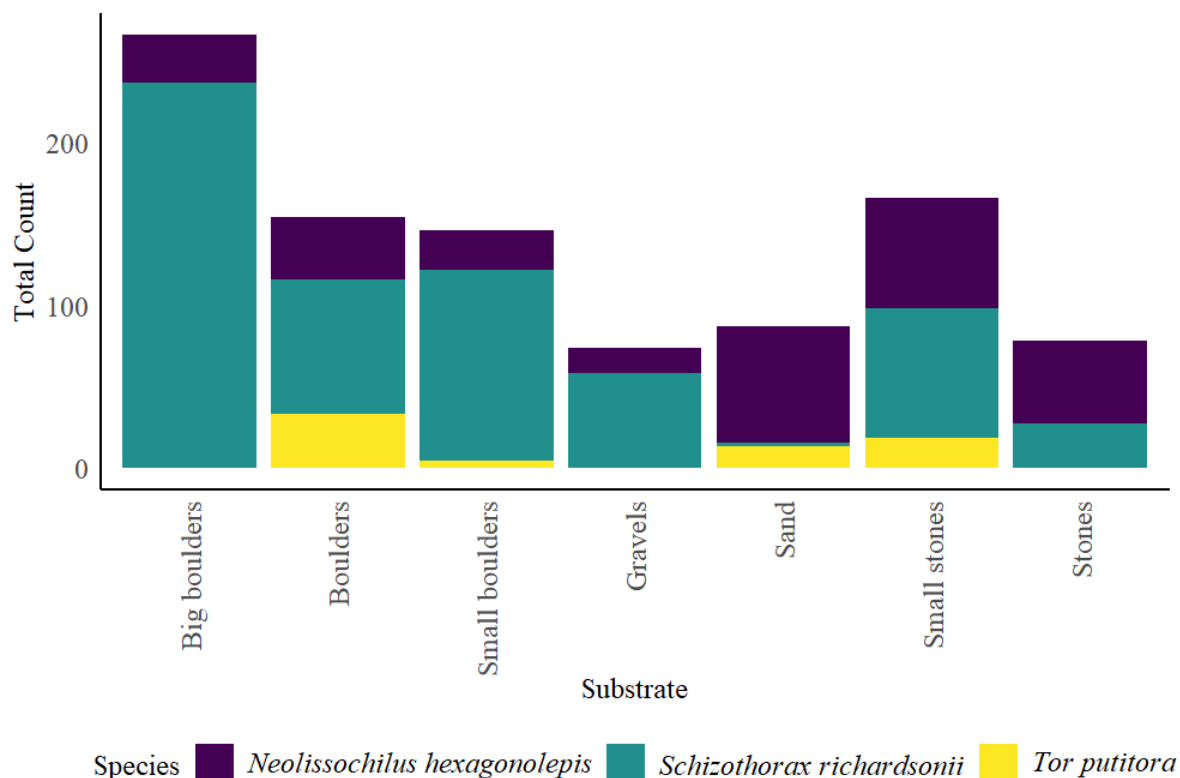


Figure 2: Fish distribution and habitat association across various substrates

Velocity Association among Fish Species

The water velocity preference of *N. hexagonolepis*, *S. richardsonii*, and *T. putitora* are summarised in Table 2. The Kruskal-Wallis H Test revealed significant differences amongs species ($H = 41.28$, $df = 2$, $p < .001$), with *N. hexagonolepis* associated with higher water velocity habitats ($Mdn = 0.5$ m/s), *S. richardsonii* with lower water velocities ($Mdn = 0.3$ m/s), and *T. putitora* showing the lowest median association ($Mdn = 0.14$ m/s). Post-hoc comparison using Dunn’s test (Table 2) revealed a significant difference in water velocity association between *N. hexagonolepis* and *S. richardsonii* ($Z = 2.277$, $p = .011$), between *N. hexagonolepis* and *T. putitora* ($Z = 6.413$, $p < .0001$), and between *S. richardsonii* and *T. putitora* ($Z = 5.876$, $p < .0001$).

Water velocity association vary among different stages of fish species, and having a range of water velocities generally enhances

fish habitat quality (Gebrekios, 2016; Hou et al., 2019). In this study, *N. hexagonolepis* juveniles were observed to associate with high velocity rivers (>1 m/s), and adults mostly occurred in the mid-stream areas with high velocity, primarily to feed on filamentous green algae (Gebrekios, 2016; Morrow Jr & Fischenich, 2000). These comparisons indicate that juveniles of *N. hexagonolepis* were associated with high water velocity habitats, whereas *S. richardsonii* and *T. putitora* were associated with lower water velocities, consistent with the findings of Wangchuk et al. (2021).

Substrate Association among Fish Species

The distribution of fish across various substrates differed significantly (Figure 2). *Neolissochilus hexagonolepis* mostly associated with finer substrates, such as sand, stones, and small stones. In contrast, *S. richardsonii* fa-

Table 3: Dunn's Post-Hoc Test of comparisons for depth distribution

Species	Comparison	Median Depth (m)	Z-value	P-value
<i>S. richardsonii</i>	vs. <i>N. hexagonolepis</i>	0.58	-10.437	< .001*
<i>N. hexagonolepis</i>	vs. <i>T. putitora</i>	0.45	-2.908	.002*
<i>T. putitora</i>	vs. <i>S. richardsonii</i>	0.44	2.08	.018*

voured coarser substrates, particularly large boulders (> 512 mm), followed by smaller boulders (256–384 mm). However, *T. putitora* preferred intermediate substrates, such as medium-sized boulders (384–512 mm), and less frequently large boulders and finer gravel (2–8 mm) habitats. These differences in habitat association were statistically significant ($\chi^2 = 359.38$, $df = 12$, $p < .001$).

The distribution of fish varied significantly across substrate types among the threatened species surveyed (Figure 2). *N. hexagonolepis* was found predominantly on finer substrates, which, according to Morrow Jr. and Fischenich (2000), support their sifting behaviour while feeding on benthic macroinvertebrates. In contrast, *S. richardsonii* was more abundant on coarse substrates, particularly medium to large boulders. This association is closely linked to their feeding habits, as such habitats offer both foraging opportunities and refuge from strong currents and predators (Bai et al., 2022).

T. putitora preferred intermediate substrates such as stones and boulders, which provide suitable feeding and essential for spawning ground, allowing proper egg attachment and development (Dhawan et al., 2023). These patterns are consistent with findings of Sarma and Mohan (2024), who noted that substrate

selection is strongly governed by species-specific biological and ecological requirements, including feeding efficiency, shelter needs, and reproductive success. Overall, the variation in substrate association reflects ecological adaptations that enhance survival and optimize resource use within the dynamic riverine environment.

The distribution of the three threatened species, *N. hexagonolepis*, *S. richardsonii* and *T. putitora* differed significantly across different water depths. *N. hexagonolepis* occurred predominantly in shallow water ($Mdn = 0.44$ m), whereas *S. richardsonii* was primarily found in shallow to intermediate depths, with peak presence around $Mdn = 0.45$ m. In contrast, *T. putitora* occupied a broader range of depths and was more frequently found in deeper waters ($Mdn = 0.58$ m) than the other two species. There was a significant difference in species distribution (Table 3) across various depths ($H = 111.23$, $df = 2$, $p < 2.2 \times 10^{-16}$).

To better understand variation in species occupancy across depths, a Dunn's post hoc test was performed. The results showed a highly significant difference between *N. hexagonolepis* and *S. richardsonii* ($Z = -10.437$, $p < .001$), as well as between *N. hexagonolepis* and *T. putitora* ($Z = -2.908$, $p = .002$) and *S. richardsonii* and *T. putitora* ($Z = 2.080$, p

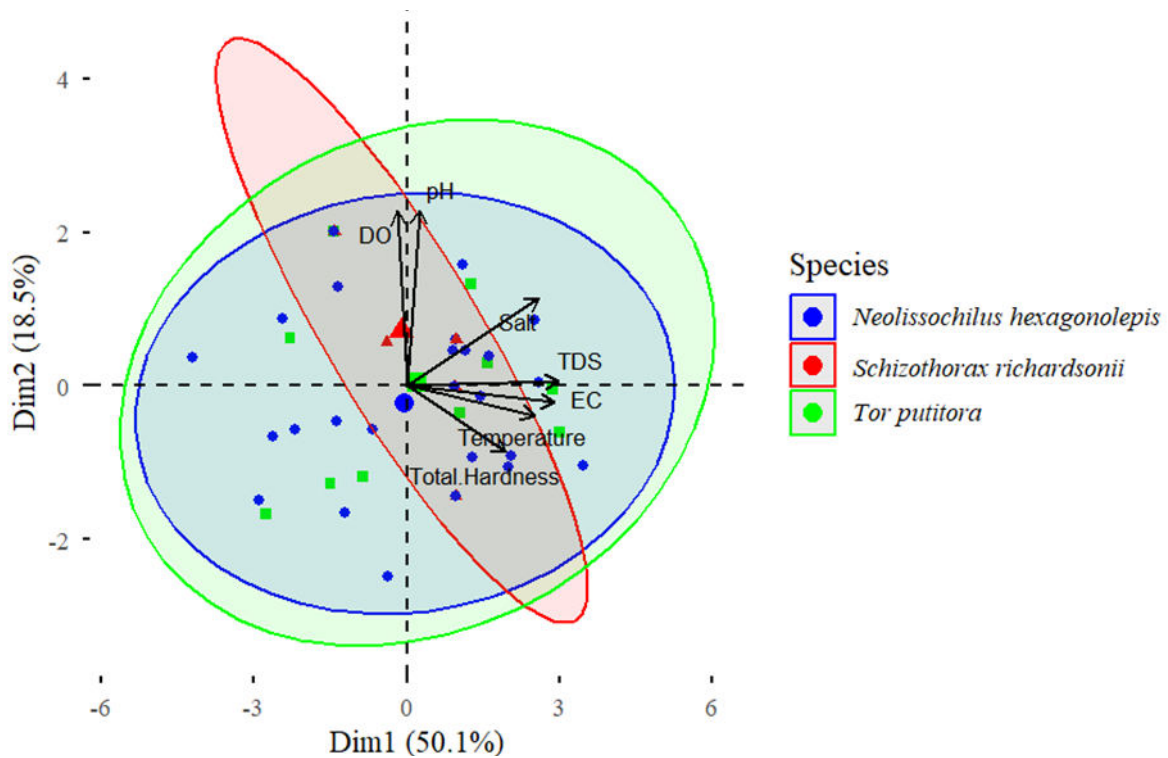


Figure 3: PCA biplot showing the relationship between fish species groups and environmental variables.

Variable	PC1 Loading	PC2 Loading
Temperature	0.803988	-0.12541
Salt	0.832184	0.365594
TDS	0.954592	0.019088
EC	0.92725	-0.06854
pH	0.078846	0.730779
DO	-0.06004	0.72842
Total Hardness	0.621789	-0.27657

Table 4: PCA loading plot of PC1 and PC2 for correlation between fish species and environmental variables

= .018). Therefore, the results show that species occur at different depths, suggesting habitat partitioning among the three taxa.

Environmental variables such as water depth influence fish community composition and affect species distribution and abundance (Gebrekiros, 2016). In addition, depth, along with elevation and stream size, has been identified as a key determinant of habitat association and a major driver of density and distribution of freshwater fish

species.

The distribution of *T. putitora* in Himalayan rivers is strongly influenced by elevation and flow length, although the species can tolerate a broad depth gradient (Mahato et al., 2023). Likewise, *S. richardsonii* is known to inhabit higher elevations across a variety of water bodies, commonly associated with runs and pools (Bhatt & Manish, 2023; Wangchuk et al., 2021). However, studies from other river systems found that no specific depth distri-

bution is exhibited by fish species, with some associating shallow water and others occupying a broader range of depths (Miranda & Killgore, 2014). Additionally, morphological differences among species are often associated with their contrasting habitats, with juveniles and adults occupying distinct ecological niches (Chakona & Swartz, 2012).

3.5 Habitat Parameter Analysis for Threatened Species using PCA

The Principal Component Analysis (PCA) revealed distinct patterns in the association between fish species and environmental variables (Figure 3). The first two principal components (Dim1 and Dim2) together explained 68.6% of the total variance, with Dim1 contributing 50.1% and Dim2 accounting for 18.5%. This indicates that these two components capture the most influential environ-

mental gradients affecting the fish assemblage. PC1 showed strong positive loading for TDS (0.95), EC (0.92), salinity (0.83), temperature (0.80) and total hardness (0.62), and PC2 revealed higher loading for pH (0.73) and DO (0.72). The contribution of these variables suggest that the species examined were associated with habitats characterised by higher ionic concentration and thermal conditions.

Previous studies have similarly emphasised that physicochemical analyses demonstrated that water chemistry parameters, particularly total dissolved solids (TDS) and electrical conductivity (EC), play a significant role in shaping aquatic species distributions (Tsai et al., 2007).

The biplot shows that *N. hexagonolepis* clusters near the centre, overlapping with both *T. putitora* and *S. richardsonii*, indicating that it tolerates a broad range of environmental

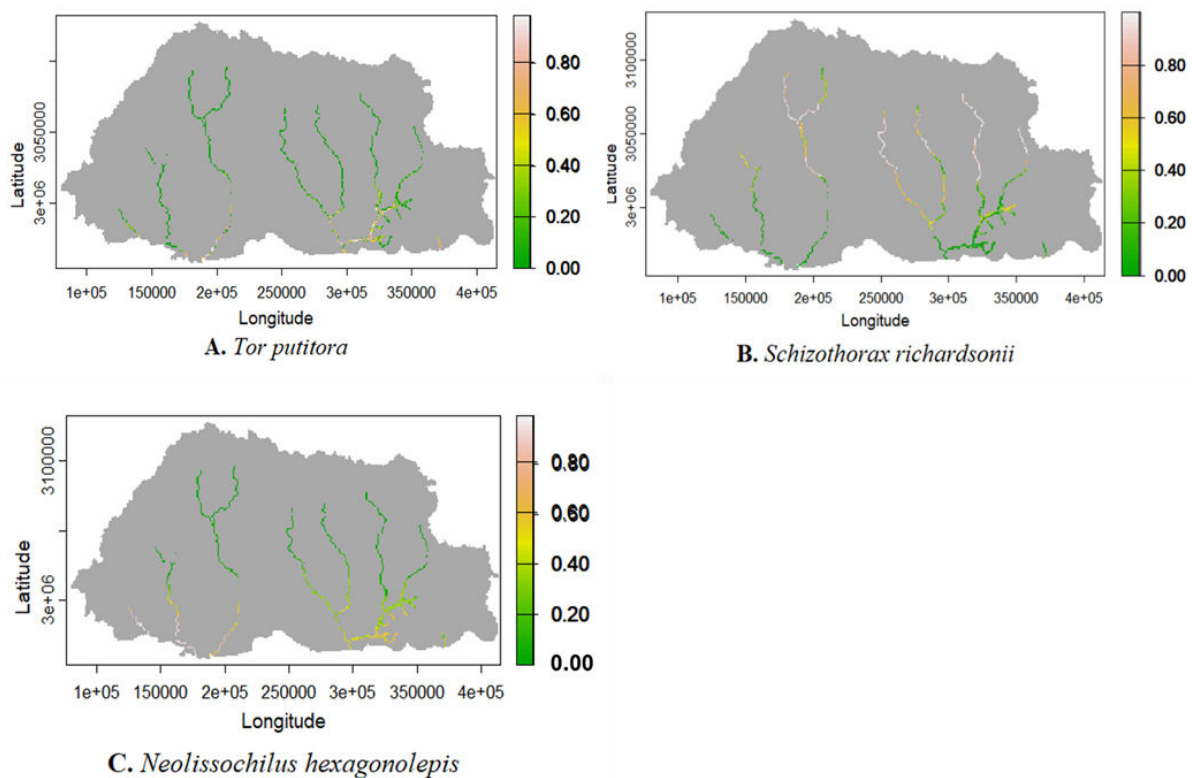


Figure 4: Ensemble model-predicted habitat suitability for (A). *Tor putitora*, (B). *Schizothorax richardsonii* and (C) *Neolissochilus hexagonolepis* across five major river systems of Bhutan

conditions (Figure 3).). This pattern aligns with the findings of Nath et al. (2016), who documented its wide altitudinal distribution in Meghalaya, India. In contrast, *T. putitora* (green group) appears on the right side of the biplot, reflecting a strong association with higher TDS, EC, and salinity levels. This distribution pattern suggests that the species favours warmer and mineral-rich habitats typically found at lower altitudes. Such environments are generally more productive and support greater food availability, consistent with observations of other cyprinids in ion-rich Himalayan rivers (Olson & Hawkins, 2017; Zhu et al., 2019). In contrast, *S. richardsonii* (red group) clusters toward the upper portion of Dim2, showing a stronger relationship with dissolved oxygen (DO) and pH. Pokharel et al. (2018) reported that *S. richardsonii* is typically found alongside other upstream species that depend on highly oxygenated waters, and its occurrence shows strong correlations with dissolved oxygen, pH, conductivity, and other water quality variables in the Seti Gandaki River Basin, Nepal. Overall, PCA has proven to be an effective tool for clarifying fish-species-environment relationships across diverse aquatic systems.

Ecological modelling for the distribution of three threatened fish species

The potential distribution of *T. putitora*, *S. richardsonii*, and *N. hexagonolepis* was studied using ecological modelling. Weighted ensemble methods were used to combine predictions across the riverine habitats of Bhutan, with a particular focus on the Drangmechhu River basin and its tributaries in Pemagatshel District (Figure 4).

The final model prediction revealed that the highest habitat suitability for *T. putitora* was in the southern and eastern regions of Bhutan (Probability ≥ 0.80), particularly within the major river systems. The larger basins also exhibited a suitability score (> 0.6), suggesting specific favourable conditions for this species. Similarly, *N. hexagonolepis* showed high habitat suitability in the southern and eastern parts of the river system.

The habitat suitability score (0.6) in southeastern river basins shows association for fast-flowing warm water with rocky bottoms. . In contrast, the habitat suitability for *S. richardsonii* was found specifically in the northern regions, followed by the central river systems in Bhutan. The patches of high suitability (scores > 0.6) for this species present a different microhabitat association compared to the other two species.

Predictive accuracy for each species was assessed using True Skill Statistics (TSS) and Area Under the Curve (AUC). All three species exhibited strong model performance. *N. hexagonolepis*, the best-performing model, showed excellent predictive performance, with AUC values ranging from 0.88 to 0.92 and a TSS of 0.78, indicating excellent predictive capability. Similarly, *S. richardsonii* showed very high accuracy, with Random Forest model yielding an AUC of 0.99 and the GLM an AUC of 0.98, alongside TSS values of 0.96 and 0.89, respectively. . *T. putitora* also demonstrated strong predictive performance, with GLM models yielding AUC values between 0.93 and 0.99 and Random Forest models ranging from 0.94 to 0.96. Overall, these results confirm that the selected environmental predictors, precipitation, elevation, and topog-

raphy, were highly effective in explaining species distribution patterns across the river network.

Ecological modelling is widely recognised as an essential tool for understanding fish habitat suitability and supporting conservation planning in freshwater ecosystems. The model applied to the endangered *T. putitora* demonstrated strong predictive performance, identifying upstream elevation and flow length as the most influential environmental variables (Mahato et al., 2023). Further supporting the effectiveness of the modelling approaches, Rose et al. (2016) compared three modelling strategies for fish assemblages and found that ensemble models were the most robust, demonstrating high sensitivity and low bias across datasets.

According to Grenouillet et al. (2011) ensemble modelling, particularly for specialist species, enhances predictive accuracy and produces more consistent and reliable predictions. Moreover, ensemble modelling revealed the importance of capturing model uncertainty in habitat suitability assessment and effectively providing habitat suitability projections for stream fish species (Lin et al., 2015).

4. Conclusions

This study on the assessment of threatened fish species in the Drangmechu and its tributaries provides valuable baseline information on their habitat and ecological relationships in eastern Bhutan. The results show that all three threatened species were most abundant in riffle habitats, followed by pools and runs, highlighting the importance of maintaining diverse microhabitats that support healthy

fish populations. Differences in habitat use were further evident in their preference for water velocity, depth, and substrate types. *N. hexagonolepis* exhibited broad ecological tolerance, favouring shallow waters with finer substrates and relatively higher flow velocities. *S. richardsonii* showed stronger associations with coarse substrates, such as large and small boulders and occupied a wider depth range. In contrast, *T. putitora* preferred less coarse substrates, variable depths, and showed a stronger affinity for physicochemical factors, including TDS, EC, and salinity.

The PCA further highlighted the adaptability of *N. hexagonolepis*, which showed substantial overlap with the habitats of *S. richardsonii* and *T. putitora*, suggesting its resilience across environmental gradients. In contrast, the distinct clustering of *T. putitora* indicates a greater vulnerability to environmental changes linked to water parameters. Ecological modelling revealed that both *T. putitora* and *N. hexagonolepis* were mostly distributed in the southern part of the study area, whereas *S. richardsonii* was sparsely distributed in the northern part of the study area.

Overall, this study highlights critical ecological requirements of threatened fish species in the Drangmechu basin and emphasizes the importance of habitat-specific conservation strategies. Protecting riffle and pool habitat, maintaining the natural flow regime, and monitoring water quality parameters will be essential for sustaining these species. The findings provide a valuable baseline for future ecological research and conservation planning in freshwater ecosystems, particularly in eastern Bhutan.

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