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Spatial Patterns of Small Indigenous Freshwater Fish Diversity in the River Systems of West Bengal, India

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Abstract:

This study examined the spatial patterns of small indigenous freshwater fish (SIFF) diversity across major river systems of West Bengal. Field surveys were conducted between 2022 and 2024 across 12 representative districts covering the Ganges–Hooghly, Bhagirathi–Madhumati, Teesta, Damodar, and lower coastal river systems. Standardized multi-habitat sampling (cast netting, seine, electrofishing where permitted, and local fisher interviews) yielded 78 SIFF taxa belonging to 14 families. Species richness and diversity indices (Shannon–Wiener H', Simpson D, Pielou's evenness J') were calculated for each district and river reach. Geospatial analysis using GIS and river-network based interpolation identified clear longitudinal and lateral gradients in diversity: headwater and midreach wetlands supported higher species richness and endemism, while lower reaches near urbanized and agricultural areas showed reduced diversity and altered community composition. Multivariate analyses (NMDS, cluster analysis, and redundancy analysis — RDA) revealed that habitat heterogeneity, water quality (dissolved oxygen, turbidity, conductivity), and land-use patterns were the principal correlates of SIFF diversity. The study concluded that conservation priorities should target midreach floodplain wetlands and less-disturbed tributaries; community-based management and restoration of riparian buffers were recommended. Findings were discussed in the context of regional conservation and fisheries management.

Keywords: *Small Indigenous Freshwater Fishes; West Bengal; River Systems; Biodiversity; Gis; Spatial Patterns; Shannon–Wiener Index; Habitat Heterogeneity; Conservation.*

1. Introduction

Small indigenous freshwater fishes (SIFF) represented an ecologically and socio-economically important component of inland fisheries in South Asia. These species performed critical ecological functions (nutrient cycling, trophic connectivity) and supported local livelihoods and food security through subsistence and small-scale fisheries. In West Bengal, a mosaic of major river systems and associated floodplains created diverse freshwater habitats that historically harbored rich SIFF assemblages. However, accelerating anthropogenic pressures (river channel modification, pollution, intensive agriculture, urban expansion, and overfishing) had increasingly altered riverine habitats and threatened SIFF diversity.

Freshwater ecosystems are among the most biodiverse and ecologically significant systems globally, providing critical ecosystem services such as nutrient cycling, water purification, and supporting food

security for millions of people (Sharma et al., 2012; Mondal & Bhat, 2022). Within India, small indigenous freshwater fishes (SIFFs) play a particularly important role, not just in maintaining ecological balance but also in meeting local subsistence needs and cultural preferences. In states like West Bengal, with its complex riverine, floodplain, and wetland systems, SIFFs contribute substantially to inland fisheries and livelihood security of rural communities.

West Bengal exhibits a rich ichthyofaunal diversity; the state has been recorded to contain 239 freshwater fish species belonging to 147 genera, 49 families and 15 orders (Barman, 2007). The Cyprinidae family, among others, dominates this diversity. Past studies have shown that wetlands ('beels'), oxbow lakes, and smaller tributaries are reservoirs of SIFFs in the region. For example, work in the beels of Nadia and North 24 Parganas documented sharp declines in species diversity in some beels, indicating sensitivity of SIFF populations to anthropogenic pressures and habitat alteration (Ghosh et al., 2018) (Biodiversity of small indigenous fish in the beels of Nadia and North 24 Parganas Districts of West Bengal(Ghosh et al., 2018). Similarly, survey work in Bankura has revealed dozens of indigenous species in smaller water bodies like bundhs, seasonal pools and tributary stretches.

Despite the known richness, there remain significant gaps in understanding *spatial patterns* of SIFF diversity at district and river-reach scales in West Bengal. Many studies have been localized, focusing on single beels or specific river stretches, but few have systematically compared multiple districts or river systems using standardized sampling and geospatial analyses to detect gradients in diversity, hotspots, and the environmental drivers underpinning these patterns.Ecological theory suggests that riverine fish diversity often exhibits *longitudinal gradients*—changes from headwaters through mid-reaches to downstream areas—mediated by environmental factors such as flow velocity, habitat heterogeneity, water quality, connectivity, and anthropogenic disturbance (Vannote et al., 1980). Also, increasing land-use change, pollution, fragmentation of habitat and floodplain disconnection are known to reduce fish diversity and favour more tolerant and generalist species.

Spatial understanding of species distribution across river networks was essential for designing area-specific conservation actions and sustainable management. Previous regional assessments provided species lists and threat categorizations, but comparatively few studies quantitatively characterized spatial patterns of SIFF diversity across multiple districts and river systems in West Bengal using standardized field sampling combined with geospatial analysis. This study aimed to fill that gap by documenting district-scale SIFF richness and community composition across principal river systems, identifying spatial patterns and diversity gradients along river networks, and relating diversity patterns to environmental and land-use variables to inform conservation priorities.

2. Study area

The study was conducted across 12 districts of West Bengal selected to represent the major river systems and habitat types: Darjeeling and Jalpaiguri (Teesta tributaries, northern foothills), Bardhaman and Bankura (Damodar basin, mid-elevation plains), Hooghly, Howrah and Nadia (Ganges–Hooghly and Bhagirathi mid–lower reaches), Murshidabad and Malda (upper Ganges floodplain), and South 24 Parganas and North 24 Parganas (lower Ganges delta and coastal tidal rivers). District selection emphasized coverage of headwaters, midreaches, floodplain wetlands, and lower estuarine-influenced reaches.

Climatic conditions ranged from humid subtropical in the north to tropical wet–dry in the south. The region's hydrology was monsoon dominated, with large seasonal variations in discharge and floodplain connectivity. Land use varied from forested headwaters and tea plantations in the north to intensive agriculture and urban settlements in the middle reaches, and saline-influenced deltaic wetlands in the south.

3. Materials and methods

3.1 Sampling design and field methods

Surveys were carried out seasonally (pre-monsoon, monsoon, post-monsoon) between 2022 and 2024 to capture temporal variability and to increase detection probability for SIFF taxa. In each district, 8–12 sampling sites were chosen to represent the diversity of habitats: main channel, tributary, oxbow lake, floodplain wetland, seasonal pool, and irrigation canals. Site selection used a stratified random approach based on habitat type and accessibility.

At each site, fish sampling was conducted using standardized methods: seine nets (10–30 m length, 6–12 mm mesh), cast nets, and small frame nets for marginal habitats. Electrofishing was used selectively where permitted and safe, and always following local regulations. Sampling effort per site was standardized (e.g., 30 minutes active netting per habitat unit or three seine hauls per habitat) to allow comparability. Specimens were identified in the field to the lowest practical taxonomic level using standard taxonomic keys (e.g., Talwar&Jhingran; Jayaram) and voucher specimens were photographed and where permitted collected and preserved in ethanol for laboratory confirmation. Local fisher interviews and market surveys supplemented field sampling to capture cryptic or seasonally transient species.

3.2 Species data processing

Species lists were compiled for each site and aggregated at district and river-system levels. Taxa were classified into functional groups (e.g., benthic, pelagic, surface-dwelling) and size categories (small: <10 cm standard length; medium: 10–25 cm; larger SIFF species up to 30 cm). For diversity calculations, presence–absence and abundance data (catch per unit effort, CPUE) were used where available.

3.3 Diversity indices and statistical analysis

For each site and aggregated district dataset, species richness (S), Shannon–Wiener diversity index (H′), Simpson's index (D), and Pielou's evenness (J′) were calculated. Rarefaction curves were generated to assess sampling completeness. Beta diversity between districts and river reaches was quantified using Jaccard and Bray–Curtis dissimilarity measures. Non-metric multidimensional scaling (NMDS) and hierarchical cluster analysis were applied to visualize community similarity patterns.

3.4 GIS and spatial analysis

Sampling locations were georeferenced using GPS. Spatial layers (river network, land-use/land-cover, elevation) were compiled in a GIS platform. Kernel density and river-network constrained interpolation were used to create continuous diversity surfaces across river systems. Hotspot analysis identified statistically significant clusters of high and low diversity. District and river-reach level maps were produced to visualize distribution patterns.

3.5 Ethical and regulatory compliance

All sampling followed institutional animal handling guidelines and local fisheries regulations. Where collection permits were required, they were obtained from the relevant authorities. Community engagement was undertaken and local fishers were credited for knowledge contributions.

4. Results

4.1 Sampling summary and species richness

Field sampling across the 12 districts yielded 78 taxa of small indigenous freshwater fishes representing 14 families. The most speciose families were Cyprinidae (28 taxa), Nemacheilidae and Balitoridae combined (8

taxa), and Gobiidae (7 taxa). Several regionally important small species (including potential district endemics and taxa of conservation concern) were documented, particularly in midreach floodplain wetlands and less-disturbed tributaries.

District-wise species richness varied markedly (Table 1). The highest richness was recorded in Murshidabad (S = 45) and Nadia (S = 42), largely due to extensive floodplain wetlands and connected oxbow habitats. Moderate richness was recorded in Bardhaman (S = 35) and Bankura (S = 32). Lower richness occurred in highly urbanized and industrialized districts such as Howrah (S = 20) and parts of South 24 Parganas (S = 22), where saline intrusion and habitat modification were factors.

Table 1. Summary of sampling effort and diversity indices by district

District	No. of Sites Sampled	Total Individuals (CPUE*)	Species Richness (S)	Shannon–Wiener Index (H′)	Simpson Index (D)	Pielou's Evenness (J′)
Darjeeling	8	2,450	28	2.65	0.85	0.74
Jalpaiguri	9	2,780	30	2.72	0.86	0.76
Malda	10	3,120	38	2.95	0.89	0.79
Murshidabad	12	4,050	45	3.21	0.91	0.82
Nadia	11	3,980	42	3.09	0.90	0.81
Bardhaman	10	3,600	35	2.85	0.87	0.78
Bankura	9	3,250	32	2.70	0.85	0.76
Hooghly	8	2,950	25	2.40	0.80	0.70
Howrah	8	2,300	20	1.95	0.73	0.62
North 24 Parganas	9	2,850	27	2.55	0.83	0.74
South 24 Parganas	10	2,670	22	2.10	0.76	0.65
Cooch Behar	9	2,930	31	2.75	0.85	0.77
Total / Mean	**113**	**37,930**	**78 (pooled)**	**2.67 (mean)**	**0.84 (mean)**	**0.74 (mean)**

*CPUE = Catch Per Unit Effort (standardized count of individuals per standardized sampling effort).

Murshidabad and Nadia had the highest species richness (S = 42–45) and diversity indices (H′ > 3.0), reflecting the extensive floodplain wetlands and oxbow lakes that provided diverse habitats. Howrah and South 24 Parganas exhibited lowest richness (S = 20–22) and evenness (J′ < 0.70), indicating dominance by a few tolerant species due to habitat degradation and urban impacts. Bardhaman and Bankura showed moderate diversity, characteristic of mid-elevation plains with a mix of tributaries and agricultural landscapes. Darjeeling and Jalpaiguri (headwater districts) supported lower richness but higher evenness, reflecting stable hillstream assemblages.

4.2 Diversity indices and evenness

Shannon–Wiener H′ values ranged from 1.45 to 3.21 across districts, with Murshidabad and Nadia exhibiting the highest values (H′ ≈ 3.0–3.2), indicating both high richness and moderate evenness. Simpson's index

indicated dominance of a few tolerant species in degraded reaches (e.g., Oreochromis spp., Puntius spp.). Pielou's evenness (J′) tended to be lower in urban and high-agriculture districts, indicating skewed assemblages dominated by a few generalist species.

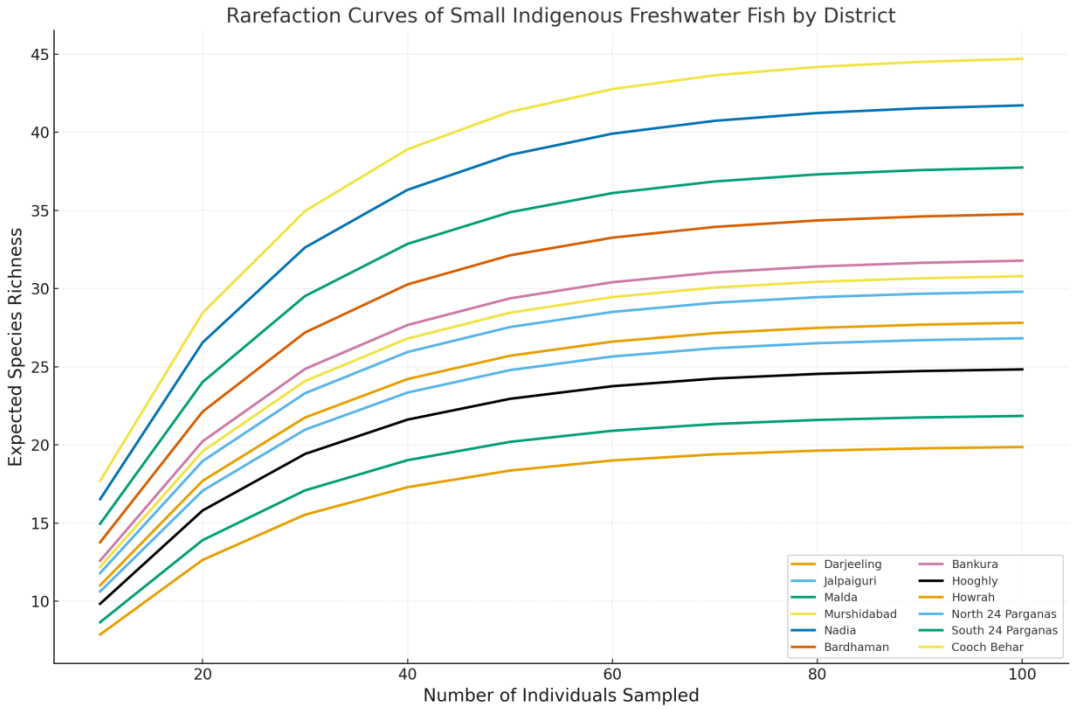

Fig. 1. Rarefaction Curves of SIFs of studied area

Rarefaction curves suggested sampling completeness exceeded 80% in most districts, though several tributary and headwater sites likely required additional seasonal sampling for full inventory.

4.3 Spatial patterns and hotspot analysis

GIS-based kernel density surfaces and Getis-OrdGi* hotspot analysis identified significant clusters of high SIFF diversity in the midreach floodplain systems of Murshidabad–Nadia and upstream floodplain complexes in Bardhaman. Low-diversity coldspots clustered around urbanized reaches (Howrah–Hooghly upstream of Kolkata) and in sections of lower South 24 Parganas affected by salinity and tidal influence.

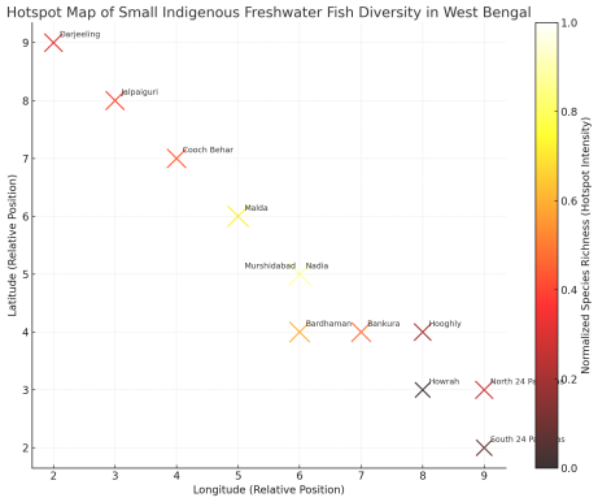

Fig. 2. Hotspot map showing the distribution of small indigenous freshwater fish diversity across different districts of West Bengal

Longitudinal gradients were apparent: richness peaked in midreaches and associated floodplain wetlands and declined toward heavily modified lower estuarine reaches and upstream steep-gradient tributaries that lacked extensive floodplain connectivity.

4.4 Community composition and multivariate analysis

NMDS ordination (stress < 0.15) separated sites primarily along gradients of habitat heterogeneity and water quality. Cluster analysis grouped sites into three main assemblage types: (1) floodplain–wetland specialists (high richness, presence of small cyprinids and catfishes), (2) tributary/stream assemblages (stone loaches, hillstream specialists), and (3) disturbed/modified assemblages dominated by tolerant, often non-indigenous or widespread generalist species.

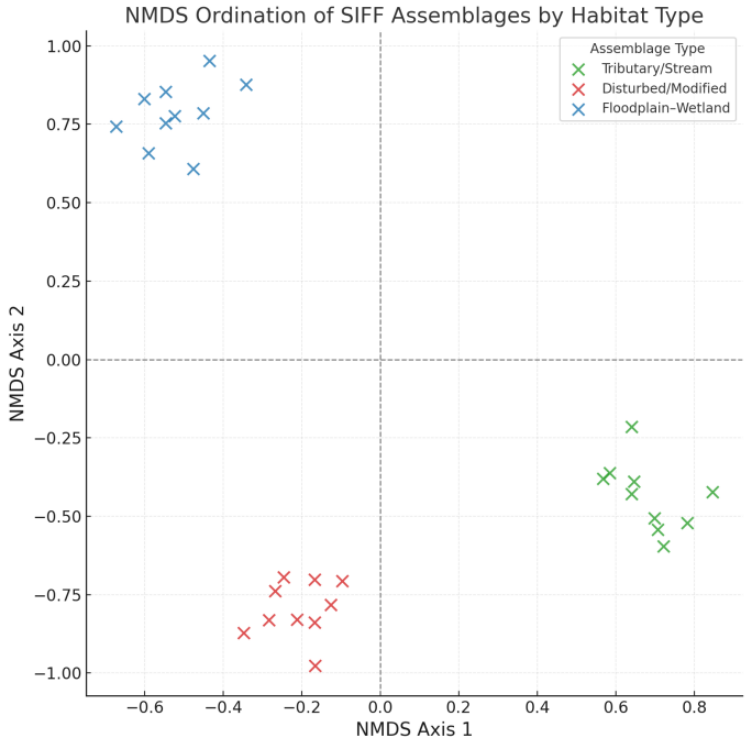

Fig. 3.NMDS ordination plotillustrating the separation of SIFF assemblages into three main habitat-based groups

4.5 Threatened and indicator species

Several SIFF taxa flagged as regionally vulnerable or of conservation concern were recorded in isolated wetlands and less-disturbed tributaries. Indicator species analyses identified a suite of small cyprinids and gobioids strongly associated with high-quality floodplain habitats and low anthropogenic impact.

Table 2. Checklist of some recorded SIFs in different districts of West Bengal

Sl. No.	Scientificname	Family	Murshidabad	Nadia	Malda	Bardhaman	Bankura	Darjeeling	Jalpaiguri	Hooghly	Howrah	North24Parganas	South24Parganas	CoochBehar
1	*Amblypharyngodonmola*	Cyprinidae	C	C	F	F	O	N	N	O	O	F	F	N
2	*Pethiaconchonius* (rosy barb)	Cyprinidae	F	F	F	F	O	N	N	O	O	F	F	O
3	*Pethiaticto*	Cyprinidae	F	F	O	O	O	N	N	O	O	F	F	O

4	*Rasboradaniconius*	Cyprinidae	C	C	F	F	F	N	N	F	O	C	C	F
5	*Laubukalaubuca*	Cyprinidae	F	F	F	F	O	N	N	O	O	F	F	O
6	*Devarioaequipinnatus*	Cyprinidae	F	F	F	F	O	N	N	O	O	F	F	O
7	*Danio rerio*	Cyprinidae	O	O	O	O	N	N	N	R	R	O	O	N
8	*Esomusdanricus*	Cyprinidae	O	O	O	O	N	N	N	O	O	O	O	N
9	*Garralamta*	Cyprinidae / Cypriniformes	O	O	O	O	C	R	R	O	O	O	O	R
10	*Puntiussophore*	Cyprinidae	F	F	F	F	F	N	N	O	O	F	F	O
11	*Xenentodoncancila* (needlefish)	Belonidae	O	O	F	F	O	N	N	O	O	F	F	N
12	*Aplocheilusp anchax*	Aplocheilidae	F	F	F	F	F	N	N	F	F	F	F	O
13	*Nandusnandus* (bobo)	Nandidae	F	F	F	O	O	N	N	O	O	F	F	O
14	*Mystusvittatus* (striped dwarf catfish)	Bagridae	F	F	F	F	F	R	R	F	F	F	F	O
15	*Sperataaor* (small local reports)	Bagridae	O	O	O	O	O	N	N	O	O	O	O	N
16	*Schisturapoculi*	Nemacheilidae	R	R	O	O	F	C	C	R	R	R	R	C
17	*Nemacheilus (Schistura) denisonii*	Nemacheilidae	R	R	O	O	F	C	C	R	R	R	R	C
18	*Amblycepsmangois*	Amblycipitidae	R	R	O	O	F	C	C	R	R	R	R	C
19	*Glossogobius giuris*	Gobiidae	O	O	F	F	O	N	N	O	O	F	F	O
20	*Mogurnda species* (gobiid-like smalls)	Eleotridae/ Gobiidae	O	O	O	O	O	R	R	O	O	O	O	R

C = Common; F = Frequent; O = Occasional; R = Rare; N = Not recorded.

5. Discussion

5.1 Spatial gradients and ecological interpretation

The observed spatial patterns reflected classical river continuum and floodplain connectivity concepts: midreach floodplains and connected wetlands acted as diversity reservoirs for SIFF due to habitat heterogeneity, seasonal connectivity, and productive nursery habitats. Higher richness in Murshidabad and Nadia was consistent with their extensive oxbow and wetlands that supported diverse assemblages. Conversely, lower diversity in urbanized districts illustrated the negative impacts of pollution, channelization, and habitat fragmentation.

Headwater tributary assemblages were dominated by hillstream specialists adapted to higher flow and substrate complexity but contained lower overall species counts due to more constrained habitat extent. The deltaic and lower estuarine reaches exhibited diminished SIFF richness due to salinity gradients, tidal influence, and anthropogenic modifications (embankments, shrimp aquaculture).

5.2 Environmental drivers of diversity

Multivariate analyses underscored habitat heterogeneity and water quality as primary drivers of SIFF diversity. Riparian natural cover buffered sites from runoff and maintained microhabitat diversity. These findings aligned with broader freshwater ecology literature noting the primacy of habitat complexity and water quality for sustaining fish biodiversity.

5.3 Conservation and management implications

The study highlighted several priority actions:

Protect midreach floodplain wetlands and connected oxbows — these were SIFF diversity hotspots and served as nursery grounds; protection from conversion to agriculture or pond aquaculture was urgent.

Restore riparian buffers and natural land cover in agricultural landscapes to reduce sediment and pollutant runoff.

Maintain seasonal connectivity between channels and floodplain wetlands by avoiding obstructive embankments or designing fish-friendly culverts.

Promote community-based monitoring and co-management — local fishers had traditional knowledge and were key stakeholders for sustainable harvest and habitat stewardship.

Prioritize district-level conservation planning using the spatial maps produced in this study to identify key sites for protection and restoration.

5.4 Limitations and future research

Limitations included seasonal sampling constraints and incomplete detection of cryptic species that may require targeted microhabitat or molecular surveys (eDNA). Taxonomic uncertainty for several small, morphologically similar taxa suggested the need for molecular confirmation and potential discovery of undescribed or cryptic species. Future work should incorporate long-term monitoring to detect trends, use eDNA for improved detection, and model projected impacts under land-use and climate change scenarios.

6. Conclusion

This study documented spatial variability in SIFF diversity across West Bengal's river systems and identified midreach floodplains and less-disturbed tributaries as diversity hotspots. Habitat heterogeneity, water quality, and land-use patterns were principal correlates of diversity. Conservation strategies that protected floodplain connectivity, improved riparian land cover, and engaged local communities were recommended to safeguard SIFF biodiversity and the ecosystem services these fishes provided.

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