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Freshwater Fish Diversity in North-East India: Evolutionary History, Endemism, and Biogeographic Significance

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Abstract

Purpose: North-East India is recognized as one of the most species-rich freshwater fish regions in South Asia, characterized by complex topography, a dynamic geological history, and extensive river networks. Positioned at the intersection of the Eastern Himalayan and Indo-Burma biodiversity hotspots, the region harbors high taxonomic diversity and endemism. This review aims to synthesize current knowledge on freshwater fish diversity, spatial patterns of endemicity, evolutionary processes, and biogeographic affinities across major river basins, including the Brahmaputra, Barak, Chindwin–Irrawaddy, and Kaladan systems.

Results: Analysis of published literature indicates that tectonic uplift, river capture events, hydrological isolation, and paleoclimatic fluctuations have collectively driven lineage diversification and adaptive radiation, particularly in hill-stream and basin-restricted taxa. The ichthyofauna exhibits strong biogeographic affinities with both the Indian subcontinent and Southeast Asia, highlighting North-East India as a transitional zone for freshwater biodiversity. Despite its ecological and evolutionary significance, the region's freshwater fishes face mounting threats from habitat degradation, hydropower development, overexploitation, and insufficient taxonomic resolution.

Conclusion: The review identifies critical knowledge gaps and emphasizes the need for integrative taxonomic approaches, basin-scale phylogeographic studies, and habitat-focused management strategies. Implementing these measures is essential for conserving the unique ichthyofaunal assemblages of North-East India and ensuring the long-term preservation of this globally significant freshwater biodiversity hotspot.

Keywords: Freshwater fishes, North-East India, Endemism, Evolutionary history, Biogeography, Eastern Himalaya

Introduction

Freshwater ecosystems in North-East India, though occupying a small fraction of the region's land area, support an extraordinarily rich assemblage of fish species, representing a significant proportion of South Asia's ichthyofaunal diversity. The region's complex topography, varied river systems, and dynamic geological history have facilitated extensive speciation and high levels of endemism. These freshwater habitats are ecologically vital, maintaining nutrient cycling, supporting diverse aquatic communities, and providing critical resources for local livelihoods through fisheries and freshwater biodiversity (Levêque, Oberdorff *et al*. 2008) [8].

Geological instability, including tectonic uplift and landscape shifts, combined with hydrological fragmentation and historical climatic variability, has played a pivotal role in shaping freshwater fish diversity. These factors create isolated habitats and microenvironments that promote allopatric speciation and adaptive radiation, particularly in tropical and subtropical regions where habitat heterogeneity is high. Such dynamic environmental conditions have contributed to the emergence of both widespread and narrowly endemic fish lineages across complex river networks (Albert, Lovejoy *et al*. 2006) [1]. North-East India exemplifies such dynamic environmental conditions, featuring active tectonic processes, pronounced altitudinal gradients, and intricate networks of rivers and tributaries. These geological and hydrological complexities create diverse habitats that facilitate high species richness, endemism, and evolutionary diversification among freshwater fishes (Hora 1951, Kottelat, Baird *et al*. 2012) [5, 7].

The North-Eastern region of India encompasses eight states—Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Tripura, and Sikkim—each characterized by diverse topography and unique freshwater habitats. Geographically, this region serves as a critical biogeographic bridge connecting the Indian subcontinent with Southeast Asia, facilitating faunal exchanges and contributing to the coexistence of distinct ichthyofaunal lineages from both regions (Goswami, Basistha *et al*. 2012) [4].

The freshwater fish assemblage of North-East India comprises taxa of both South Asian and Indo-Burman origin, reflecting the region's unique position at the intersection of two major biogeographic zones. This convergence has fostered exceptional taxonomic richness and phylogenetic diversity, with numerous lineages exhibiting high levels of endemism and evolutionary distinctiveness (Kottelat, Baird *et al*. 2012) [7].

Although recent taxonomic surveys and molecular studies have enhanced our understanding of freshwater fishes in North-East India, knowledge remains fragmented across different basins and habitat types. A comprehensive synthesis that integrates species diversity patterns, levels of endemism, evolutionary histories, and biogeographic affinities is still lacking, limiting effective conservation and management planning (Sarma, Singh *et al*. 2018) [11].

2. Hydrographic and Physiographic Framework

The freshwater fish diversity of North-East India is largely organized around four major river systems: the Brahmaputra, Barak, Chindwin–Irrawaddy, and Kaladan basins, each exhibiting distinct hydrological characteristics and habitat heterogeneity. These river networks provide a variety of ecological niches, shaping species distribution patterns and facilitating both widespread and basin-restricted endemism. These river basins differ markedly in their geological origin, flow patterns, drainage orientation, and hydrological regimes, as well as in their historical connectivity with adjacent river systems. Such variations play a crucial role in shaping fish dispersal, promoting habitat specialization, and driving evolutionary diversification, particularly among endemic and range-restricted species (Albert, Lovejoy *et al*. 2006) [1].

The Brahmaputra River basin, the largest and most topographically diverse in North-East India, originates in the eastern Himalayas and encompasses a broad spectrum of freshwater habitats, ranging from expansive lowland floodplains to fast-flowing, high-gradient hill streams. This environmental heterogeneity provides diverse ecological niches, supporting high species richness, complex community structures, and numerous endemic fish taxa (Talwar and Jhingran 1991, Sarma, Singh *et al*. 2018) [12, 11].

The Barak River basin, flowing through southern Assam and adjoining states, ultimately joins the Meghna River system in Bangladesh and harbors a unique ichthyofaunal assemblage. It supports a mixture of Gangetic species typical of the Indian subcontinent and Indo-Burman elements characteristic of Southeast Asia, reflecting historical biogeographic connectivity and ecological overlap between these regions (Goswami, Basistha *et al*. 2012) [4].

The Chindwin–Irrawaddy basin, spanning parts of Manipur and adjoining areas, displays pronounced faunal similarities with the freshwater ichthyofauna of Myanmar. These affinities reflect historical hydrological connectivity and past river linkages with Southeast Asia, which have facilitated species dispersal, lineage exchange, and the establishment of shared evolutionary lineages across the region (Kottelat, Baird *et al*. 2012) [7].

Although relatively smaller in size, the Kaladan River basin harbors several unique freshwater fish taxa and serves a critical biogeographic function by connecting the ichthyofaunal assemblages of North-East India with those of western Myanmar. Its position and historical hydrological linkages have facilitated species exchange and contributed to the region's high levels of diversity and endemism (Kottelat, Baird *et al*. 2012) [7].

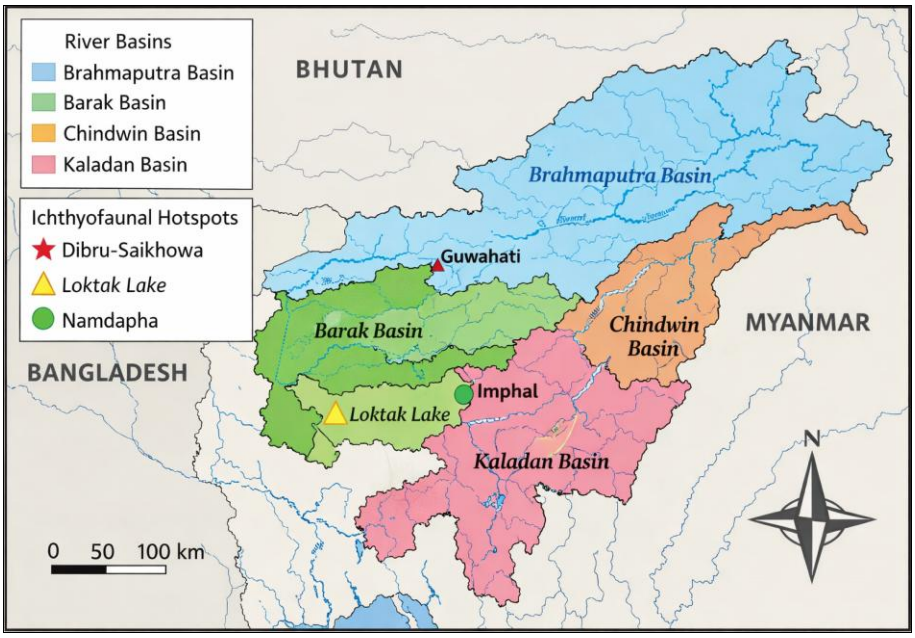

Fig 1: Freshwater ichthyofaunal hotspots of North-East India (*image source: Google image*)

3. Species Richness and Taxonomic Composition

3.1 Overall Diversity

North-East India harbors over 300 species of freshwater fishes, encompassing more than 30 families and 10 orders, which together represent a significant fraction of the country's overall freshwater ichthyofaunal diversity. This remarkable

richness reflects the region's diverse habitats, complex river networks, and historical biogeographic connections, making it one of the most important centers of freshwater biodiversity in South Asia (Talwar and Jhingran 1991, Sarma, Singh *et al*. 2018) [12, 11].

Within the freshwater fish assemblage of North-East India, the order Cypriniformes is the most speciose, reflecting its widespread dominance in Asian freshwater ecosystems, followed by Siluriformes, which are particularly abundant in hill streams and floodplain habitats. This taxonomic composition aligns with general patterns observed across South and Southeast Asia, highlighting both ecological specialization and evolutionary diversification within the region (Levêque, Oberdorff *et al*. 2008) [8].

The family Cyprinidae represents the most species-rich group in North-East India's freshwater ecosystems, reflecting its remarkable ecological adaptability and extensive evolutionary diversification across a variety of riverine habitats. Its dominance is attributed to the ability of cyprinids to exploit diverse ecological niches, from fast-flowing hill streams to lowland floodplains, facilitating both widespread distribution and speciation (Hora 1951, Kottelat, Baird *et al*. 2012) [5, 7].

Other notable freshwater fish families in North-East India include Nemacheilidae, Sisoridae, Bagridae, Cobitidae, and Channidae, which are especially abundant in fast-flowing hill streams and upland river systems. These families contribute significantly to the region's high levels of species richness and endemism, reflecting adaptations to specialized habitats and hydrological conditions (Goswami, Basistha *et al*. 2012, Sarma, Singh *et al*. 2018) [4, 11].

3.2. Basin-wise Distribution

The Brahmaputra basin exhibits the greatest species richness in North-East India, with over 220 freshwater fish species documented, a pattern attributable to the basin's extensive area and diverse range of aquatic habitats (Sarma, Singh *et al*. 2018) [11].

Although the Barak and Chindwin basins support a comparatively lower total number of species, they exhibit a higher representation of endemic fishes and taxa with Southeast Asian affinities, particularly among species adapted to fast-flowing hill-stream habitats (Kottelat, Baird *et al*. 2012) [7].

Table 1: Freshwater fish diversity of North-East India across major river basins

River Basin	Approx. Species	Dominant Families
Brahmaputra	>220	Cyprinidae, Nemacheilidae
Barak	~120	Cyprinidae, Siluridae
Chindwin	~100	Cyprinidae, Sisoridae
Kaladan	~30	Cyprinidae, Channidae

4. Patterns of Endemism

High levels of endemism are a distinctive feature of North-East India's freshwater fish assemblages (Sarma, Singh *et al*. 2018) [11]. Around 130 to 140 freshwater fish species are endemic to North-East India, with a significant proportion confined to individual river basins or even isolated tributaries, highlighting their highly restricted distributions (Goswami, Basistha *et al*. 2012, Sarma, Singh *et al*. 2018) [4].

4.1. Taxonomic Distribution of Endemics

High levels of species endemism are especially evident in hill-stream specialist families such as Nemacheilidae and Sisoridae, which have evolved morphological and behavioral adaptations to cope with fast-flowing, turbulent waters. Their restricted dispersal and strong reliance on specialized microhabitats contribute to the concentration of endemic taxa in ecologically isolated streams. Genera including *Schistura*, *Aborichthys*, *Glyptothorax*, and *Exostoma* demonstrate pronounced local endemism, largely due to their restricted dispersal capacities and specialized adaptations to specific hill-stream habitats, emphasizing the influence of ecological isolation on species diversification (Kottelat, Baird *et al*. 2012) [7].

4.2. Geographic Hotspots of Endemism

The highest levels of freshwater fish endemism in North-East India are observed in the upper tributaries of the Brahmaputra River in Arunachal Pradesh, the Chindwin basin of Manipur, and the plateau streams of Meghalaya. These regions, characterized by long-term hydrological stability and relative isolation, provide unique ecological conditions that have facilitated speciation and the persistence of narrowly distributed endemic species.

These areas exhibit prolonged hydrological stability and geographic isolation, creating environmental conditions that promote allopatric speciation. Such isolation limits gene flow between populations, allowing evolutionary divergence and the emergence of regionally restricted endemic fish species (Albert, Lovejoy *et al*. 2006) [1]. Families such as Nemacheilidae (stone loaches) and Sisoridae (hill-stream catfishes) show exceptional adaptive radiation in fast-flowing montane habitats.

Table 2: Major endemic fish groups of North-East India

Family	Representative Endemic Genera
Nemacheilidae	*Schistura, Aborichthys*
Sisoridae	*Glyptothorax, Exostoma*
Cyprinidae	*Garra, Danio*

5. Evolutionary History and Drivers of Diversification

5.1. Geological Influences

The convergence of the Indian and Eurasian plates during the early Cenozoic initiated extensive tectonic deformation, culminating in the uplift of the Himalayan orogen. This major geodynamic event fundamentally reshaped the regional topography, triggering large-scale reorganization of river courses, watershed boundaries, and sediment dispersal systems across North-East India, with long-lasting implications for its hydrology and landscape evolution (Molnar and Tapponnier 1975) [9].

Tectonically driven processes such as river capture, drainage rearrangement, and progressive basin fragmentation disrupted formerly continuous river networks, creating isolated aquatic habitats. These geomorphological changes restricted gene flow among freshwater fish populations, fostering long-term population isolation. Over evolutionary timescales, such isolation facilitated genetic differentiation, local adaptation, and the emergence of distinct evolutionary lineages within freshwater fish assemblages.

5.2. Paleoclimatic Effects

During the Pleistocene, pronounced climatic fluctuations led to cyclical changes in temperature and precipitation regimes, resulting in recurrent expansion and contraction of riverine and floodplain habitats. Periods of increased connectivity during wetter phases facilitated dispersal and gene flow

among aquatic populations, whereas habitat fragmentation during drier or cooler intervals promoted population isolation. These alternating phases of connectivity and isolation played a crucial role in shaping population structure, driving genetic differentiation and influencing the evolutionary trajectories of aquatic organisms (Hewitt 2000) [6]. These geological and climatic mechanisms are widely regarded as key forces underlying the evolutionary diversification and species richness observed in tropical freshwater fish lineages (Albert, Lovejoy *et al*. 2006) [1].

5.3. Adaptive Evolution

Hill-stream fishes of North-East India exhibit a suite of convergent morphological and functional adaptations that enhance survival in high-velocity flow regimes. These include dorsoventrally flattened bodies that reduce drag, enlarged and well-developed paired fins that improve station-holding and maneuverability, and specialized adhesive or suctorial structures that facilitate attachment to rocky substrates. The repeated evolution of these traits across unrelated taxa highlights the intense and consistent selective pressures exerted by torrential, structurally complex hill-stream environments (Hora 1951, Goswami, Basistha *et al*. 2012) [5].

6. Biogeographic Affinities

The freshwater fish assemblages of North-East India display a complex biogeographic composition, reflecting faunal links with both South Asian and Southeast Asian regions. This mixture arises from the region's geographical position at the junction of major biotic realms, coupled with a dynamic geological history that facilitated episodic dispersal, isolation, and faunal exchange. As a result, the ichthyofauna comprises elements characteristic of the Indian subcontinent alongside lineages more closely allied to Indo-Burman and Southeast Asian freshwater systems, underscoring North-East India as a transitional and evolutionarily significant biogeographic zone.

Floodplain river systems of North-East India are primarily characterized by fish taxa typical of the Indian subcontinent, including genera such as *Labeo* and *Catla*, which are well adapted to lowland, slow-flowing, and seasonally inundated habitats. In contrast, upland and hill-stream environments are dominated by assemblages showing close biogeographic links to the Indo-Burman region, reflecting adaptations to high-gradient, fast-flowing conditions. This spatial segregation of taxonomic affinities highlights the influence of physiography and historical connectivity in shaping the composition and distribution of freshwater fish communities across the region (Albert, Lovejoy *et al*. 2006, Goswami, Basistha *et al*. 2012) [1, 4].

The simultaneous presence of Indian subcontinental and Indo-Burman ichthyofaunal elements underscores the significance of North-East India as a major biogeographic transition zone. This region has historically functioned as a corridor for dispersal as well as a zone of overlap where lineages from adjacent biotic realms have interacted. Such faunal mixing, combined with periodic isolation driven by geological and climatic processes, has promoted both species exchange and in situ diversification, contributing to the exceptional richness and evolutionary complexity of the freshwater fish fauna in this part of Asia (Myers, Mittermeier *et al*. 2000) [10].

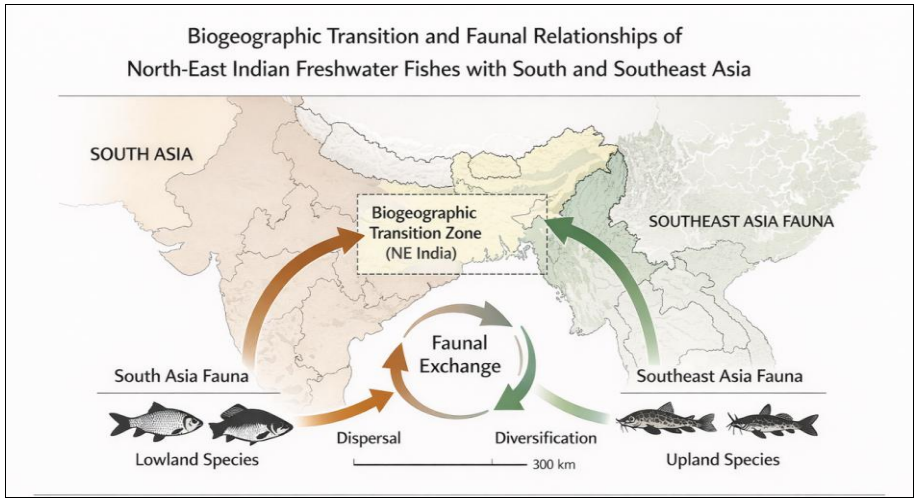

Fig 2: Biogeographic transition of freshwater fishes

7. Conservation Status and Threats

Freshwater fish species in North-East India are increasingly exposed to multiple anthropogenic pressures that threaten their survival and ecosystem integrity. Habitat degradation, including deforestation, siltation, and wetland reclamation, has led to the loss and fragmentation of critical aquatic environments. River regulation through dams, diversions, and irrigation infrastructure disrupts natural flow regimes, alters sediment transport, and impedes migratory routes. In addition, overexploitation from artisanal and commercial fishing reduces population abundance, while pollution from agricultural runoff, industrial effluents, and domestic waste further compromises water quality. Collectively, these stressors pose significant risks to the diversity, population structure, and long-term sustainability of freshwater ichthyofauna in the region (Dudgeon, Arthington *et al*. 2006, Goswami, Basistha *et al*. 2012) [3, 4].

A considerable number of freshwater fish species endemic to North-East India are currently classified as Data Deficient on the IUCN Red List. This designation reflects the paucity of reliable information regarding their geographic distribution, population size, and trends, as well as ecological requirements. The limited availability of field surveys, taxonomic studies, and long-term monitoring hampers accurate assessment of their conservation status, leaving many species potentially at risk without formal recognition. Consequently, these knowledge gaps impede the development of targeted conservation strategies and management plans

necessary to safeguard the region's unique ichthyofaunal diversity.

The destruction and alteration of hill-stream ecosystems represent a critical threat to freshwater fishes that are narrowly endemic and highly specialized. These species often exhibit restricted geographic ranges and possess limited dispersal abilities, making them especially vulnerable to habitat loss caused by deforestation, dam construction, water abstraction, and sedimentation. The fragmentation of their natural habitats not only reduces available refugia but also isolates populations, limiting gene flow and increasing the risk of local extinctions. Consequently, the preservation of intact hill-stream environments is essential for maintaining the survival and evolutionary potential of these ecologically sensitive and range-restricted taxa.

8. Future Research Directions

Addressing the high levels of cryptic diversity among freshwater fishes in North-East India requires integrative taxonomic approaches that combine traditional morphological analyses with molecular techniques such as DNA barcoding, phylogenetics, and genomic studies. Morphological examination alone may overlook subtle phenotypic differences or misidentify closely related species, whereas molecular data provide independent evidence of genetic divergence and evolutionary relationships. By integrating both lines of evidence, researchers can more accurately delimit species, uncover hidden diversity, clarify taxonomic ambiguities, and generate robust frameworks for biodiversity assessment and conservation planning in this ecologically complex region.

Comprehensive basin-wide phylogeographic investigations are crucial for elucidating the historical patterns of connectivity, dispersal, and diversification among freshwater fish populations in North-East India. Such studies, which integrate genetic analyses across multiple populations and river systems, can reveal how past geological events, climatic fluctuations, and hydrological changes shaped population structure and lineage divergence. Understanding these historical processes provides insights into the mechanisms driving speciation, endemism, and genetic diversity, and forms a critical foundation for developing informed conservation strategies aimed at preserving the evolutionary potential and resilience of freshwater ichthyofauna in the region (Albert, Lovejoy *et al*. 2006) [1].

Community-based conservation approaches play a pivotal role in ensuring the sustainable management of freshwater ecosystems in North-East India. By actively involving local communities in the stewardship of rivers, streams, and wetlands, these strategies integrate traditional ecological knowledge with scientific management practices. Such participation fosters awareness, promotes responsible resource use, and encourages the protection of critical habitats and endemic species. Moreover, community engagement helps mitigate overfishing, pollution, and habitat degradation by empowering stakeholders to monitor and regulate activities within their watersheds. Overall, these participatory frameworks are essential for balancing biodiversity conservation with the socio-economic needs of local populations, ensuring long-term sustainability of freshwater resources in the region (Dudgeon, Arthington *et al*. 2006) [3].

9. Conclusions

The freshwater fish diversity of North-East India represents the cumulative outcome of a dynamic and multifaceted evolutionary history shaped by geological, hydrological, and biogeographic processes. The collision of the Indian and Eurasian plates, Himalayan uplift, and subsequent river rearrangements created isolated habitats that facilitated speciation and endemism. Climatic fluctuations during the Pleistocene further influenced habitat connectivity, driving population expansions, contractions, and genetic structuring. Additionally, the region's position at the intersection of South and Southeast Asian biotic realms has fostered faunal exchange, resulting in a unique assemblage of lowland and upland species. Together, these factors have produced an exceptionally rich and heterogeneous ichthyofauna, highlighting North-East India as a critical zone for evolutionary research, biodiversity conservation, and the sustainable management of freshwater ecosystems. The exceptional endemism and unique evolutionary lineages of freshwater fishes in North-East India emphasize its status as a global biodiversity hotspot. These characteristics not only reflect the region's complex evolutionary history but also highlight its irreplaceable ecological value, underscoring the urgent need for targeted conservation and sustainable management to safeguard its distinct ichthyofaunal heritage. Incorporating evolutionary history and biogeographic patterns into conservation strategies is crucial for effectively protecting North-East India's freshwater fishes. Such an approach enables the identification of evolutionarily significant units, prioritization of critical habitats, and maintenance of genetic diversity, thereby ensuring the long-term persistence and resilience of the region's unique ichthyofaunal communities.

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