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Assessment of Fish Diversity in Freshwater Ecosystems of Northern India

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Abstract

Freshwater ecosystems of Northern India, particularly the Ganga and its tributaries, represent some of the most diverse and ecologically significant habitats in the Indo-Gangetic plains. The present study assessed fish diversity across selected rivers (Ganga, Yamuna, Gomti, Ghaghara, Betwa) and reservoirs, documenting a total of 168 species belonging to 96 genera, 38 families, and 12 orders. Cypriniformes dominated the assemblages, with Cyprinidae as the most speciose family, followed by Siluriformes and Perciformes. Diversity indices indicated that rivers supported higher richness (H′ = 3.45 in Ghaghara) compared to reservoirs (H′ = 2.21 in Chandil), with wetlands occupying an intermediate position. Seasonal variations were evident, with monsoon and post-monsoon periods sustaining maximum diversity, while summer showed the lowest richness due to habitat shrinkage. Several threatened taxa, including Tor putitora and Ompok bimaculatus, were identified alongside invasive species such as Oreochromis niloticus and Pterygoplichthys anisitsi. Multivariate analysis revealed positive correlations between species richness and dissolved oxygen, depth, and habitat heterogeneity, while high nitrate and conductivity negatively influenced diversity. The findings highlight the urgent need for integrated management strategies, including conservation reserves, seasonal fishing bans, invasive species control, and habitat restoration. This study provides critical baseline information for biodiversity conservation, sustainable fisheries, and policy formulation in Northern India.

Keywords: *Freshwater Fish Diversity, Northern India, Ganga Basin, Cyprinidae, Diversity Indices, Seasonal Variation.*

1. INTRODUCTION

Freshwater ecosystems are among the most diverse and productive habitats on Earth, sustaining a rich variety of fish species that provide essential ecological, nutritional, and socio-economic services **(Sarkar et al., 2008; Lakra et** al., 2010). India, recognized as a freshwater mega-diverse country, harbors more than 930 freshwater fish species out of an estimated 2,500 species of fishes recorded nationwide (Kar et al., 2006; Goswami et al., 2012). These aquatic resources not only contribute significantly to biodiversity but also support the livelihoods of millions of people through capture fisheries, aquaculture, and ecosystem services (Bhatt et al., 2016; Sharma et al., 2017).

The northern region of India, encompassing major rivers such as the Ganga, Yamuna, Gomti, Betwa, and Ghaghara, forms part of the Indo-Gangetic plains and Himalayan ecosystems. These freshwater systems are critical for maintaining regional biodiversity and ensuring food security. Recent surveys have reported a substantial diversity in these basins. For instance, the Ganga River alone sustains over 140 freshwater species, though many have shown shifts in distribution patterns due to hydrological alterations, exotic invasions, and anthropogenic pressures (Sarkar et al., 2012). Similarly, studies on tributaries like the Gomti, Betwa, and Ghaghara have revealed rich species compositions but also highlighted threats including habitat fragmentation, overfishing, and pollution (Mishra et al., 2011; Lakra et al., 2010; Kumar et al., 2020).

Despite their ecological and socio-economic importance, freshwater fish resources in Northern India face alarming declines. Anthropogenic drivers such as dam construction, river interlinking projects, indiscriminate fishing, siltation, water abstraction, and pollution have significantly degraded habitats, leading to loss of native species and the spread of exotics (Lakra et al., 2011; Sarkar et al., 2010). Conservation assessments indicate that nearly 34% of Indian freshwater fish fauna is under threat, falling into vulnerable or endangered categories (Goswami et al., 2012; Lakra et al., 2010).

In this context, systematic documentation and assessment of freshwater fish diversity are essential for developing strategies for biodiversity conservation, ecological restoration, and sustainable fisheries management (Bhatt et al., 2016; Wanjari et al., 2025). While several studies have investigated fish diversity in individual basins, there remains a need for integrative assessments focusing on Northern India's riverine ecosystems.

Therefore, the present study aims to provide a comprehensive assessment of fish diversity in freshwater ecosystems of Northern India, with emphasis on species composition, diversity indices, habitat ecology, and conservation perspectives. The findings will contribute baseline information crucial for policy interventions, habitat restoration, and long-term management of freshwater resources in the region.

2. SIGNIFICANCE OF THE STUDY

The present investigation holds substantial significance for both ecological research and sustainable resource management. Freshwater ecosystems of Northern India, particularly the Ganga basin and its tributaries, serve as critical habitats for diverse fish species that underpin food security, ecological stability, and rural livelihoods. Documenting the composition and diversity of fish fauna in these regions provides a baseline reference that is essential for long-term monitoring and conservation planning (Lakra et al., 2010; Sarkar et al., 2012).

From a biodiversity conservation perspective, the study is crucial as many native fish species are under increasing threat due to overfishing, pollution, habitat fragmentation, invasive species, and hydrological alterations (Bhatt et al., 2016; Goswami et al., 2012). Identifying species richness, diversity indices, and habitat associations not only highlights the ecological health of river systems but also supports the formulation of strategies for species protection and ecosystem restoration.

The research further contributes to fisheries management and livelihood sustainability. Freshwater fish resources in Northern India sustain millions of people through capture fisheries and aquaculture. By assessing diversity trends and habitat-specific assemblages, the findings will help policymakers and local stakeholders design effective measures such as closed fishing seasons, conservation reserves, and habitat restoration programs (Mishra et al., 2011; Wanjari et al., 2025).

Additionally, the study has broader implications for climate change adaptation and river basin management. As Northern India undergoes rapid hydrological modifications through dam construction and interlinking projects, the resilience of fish populations is at risk. Understanding their diversity patterns in relation to environmental parameters provides a scientific foundation for impact assessments, ecological flow requirements, and conservation prioritization (Lakra et al., 2011; Kumar et al., 2020).

In essence, this study bridges a critical gap by offering an integrative evaluation of fish diversity in Northern India, thereby informing ecological research, policy formulation, and community-based conservation practices for ensuring the long-term sustainability of freshwater ecosystems.

3. OBJECTIVES OF THE STUDY

- To document the species composition and richness of freshwater fishes inhabiting selected rivers, tributaries, and reservoirs of Northern India.
- To analyze spatial and temporal variations in fish diversity using ecological indices such as Shannon–Weiner, Simpson's, and Evenness.
- To examine the relationship between environmental parameters and fish assemblage structure, highlighting the influence of physicochemical factors on species distribution.
- To identify potential threats such as overfishing, habitat degradation, pollution, invasive species, and hydrological modifications impacting fish diversity in the region.
- To recommend conservation and management strategies for sustaining native fish populations, ensuring ecological balance, and supporting fisheries-based livelihoods in Northern India.

4. REVIEW OF LITERATURE

Freshwater ecosystems across India, particularly in the northern region, have been the focus of extensive biodiversity assessments over the last two decades. These studies provide critical insights into species richness, community structure, threats, and conservation needs.

The Ganga River system has received considerable attention due to its ecological, cultural, and socio-economic importance. Sarkar et al. (2012) reported 143 fish species from the river, documenting shifts in distribution patterns and highlighting the threats posed by hydrological alterations, pollution, and exotic species. Similarly, Lakra et al. (2010) examined the Gomti River, a Ganga tributary, and emphasized the need to prioritize conservation based on biodiversity and ecohydrology assessments.

The Ghaghara River, another important tributary of the Ganga, supports remarkable ichthyofaunal diversity. Mishra et al. (2011) recorded 62 species representing 48 genera and 24 families, with Cypriniformes as the dominant group. Their findings revealed that about 23% of the species were under threatened categories, primarily due to barrages, overfishing, and land-use changes. More recently, Kumar et al. (2020) analyzed diversity indices in the Himalayan stretch of the Ghaghara, confirming moderate-to-high richness and demonstrating seasonal fluctuations shaped by anthropogenic pressures.

In the Betwa River, a central Indian tributary of the Yamuna, Lakra et al. (2010) documented 63 species belonging to 20 families and 45 genera. Cyprinids were the most dominant group, and water depth, dissolved oxygen, and pH were identified as key environmental drivers of fish assemblages. The study emphasized the urgent need for conservation planning, especially in light of the proposed Ken–Betwa river linking project.

Reservoirs, being transitional ecosystems between rivers and lakes, are equally vital for fish diversity studies. Lianthuamluaia et al. (2019) investigated the Chandil Reservoir (Jharkhand) and reported 42 species from 30 genera, including two exotic introductions. The study revealed that fish diversity was lowest in the lacustrine zone and strongly influenced by environmental factors such as pH and nitrate. Recommendations included closed seasons, fish aggregating devices, and regulated enclosure culture for sustaining native fish diversity.

At a Ramsar site level, Kaur et al. (2017) studied the Harike Wetland and found significant variations in catch composition and biodiversity indices, further confirming the ecological importance of wetlands in maintaining fish diversity in northern India.

Though beyond the strict northern zone, studies from the Northeastern Himalayas provide valuable comparative insights. Kar et al. (2006) assessed Lake Sone in Assam and recorded 69 species, demonstrating significant correlations between fish yield and ecological variables like pH,

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alkalinity, and macrophyte biomass. Goswami et al. (2012) provided a comprehensive checklist of 422 species from Northeast India, covering the Himalayan and Indo-Burma biodiversity hotspots, and highlighted the alarming number of species falling under vulnerable or endangered categories. These studies underline the importance of hill streams, wetlands, and tectonic lakes as biodiversity hotspots.

Several scholars have drawn attention to the increasing threats facing freshwater fishes in India. Habitat degradation, fragmentation, indiscriminate fishing, exotic species introductions, and climate change have been identified as key drivers of decline (Lakra et al., 2011; Bhatt et al., 2016). In their large-scale assessment, Bhatt et al. (2016) proposed a Conservation Value Index (CVI) and Vulnerability Index (VI) for Indian river basins, delineating priority areas for conservation and restoration. Their work provides a useful framework for conservation planning across the Ganga basin and its tributaries.

While significant progress has been made in documenting species diversity in selected rivers and reservoirs, gaps remain in integrative, multi-basin studies across Northern India. Most existing works have focused either on single rivers (e.g., Ghaghara, Betwa, Gomti) or isolated ecosystems (reservoirs, wetlands). Moreover, molecular taxonomy, climate change impacts, and long-term monitoring remain underexplored (Meinam et al., 2025; Wanjari et al., 2025).

5. REVIEW OF LITERATURE

Freshwater fish diversity has long been recognized as an indicator of ecological integrity, and several studies across India have highlighted the richness and complexity of fish assemblages. India, as one of the global freshwater mega-diverse countries, harbors more than 930 freshwater species distributed across rivers, reservoirs, wetlands, and hill streams (Kar et al., 2006; Goswami et al., 2012). The Indo-Gangetic plains and the Himalayan tributaries are of particular interest due to their unique ecological conditions and their role in sustaining the livelihood of millions of rural communities. Northern India, with rivers such as the Ganga, Yamuna, Gomti, Betwa, and Ghaghara, provides fertile grounds for ichthyological investigations. However, rapid human-induced changes, including dam construction, river interlinking, pollution, and the introduction of exotic species, have raised concerns about the long-term sustainability of fish resources (Lakra et al., 2011; Sarkar et al., 2012).

The Ganga River system has attracted maximum scientific attention because of its size, socio-cultural relevance, and biodiversity. Historical records indicated a rich ichthyofaunal diversity, but contemporary studies reveal declining trends. Sarkar et al. (2012) documented 143 species across various stretches of the river, which was considerably higher than earlier reports, but they also noted shifts in species distributions. Several native fishes have contracted their ranges, while exotics like Pterygoplichthys anisitsi and Oreochromis niloticus have expanded. Hydrological changes, barrages, industrial effluents, and sand mining were found to be major stressors altering assemblage structure. Lakra et al. (2010) also stressed that the Gomti River, one of the important tributaries of the Ganga, showed signs of ecological stress, and they advocated the identification of conservation priority zones based on ecohydrological parameters.

Equally important are the tributaries of the Ganga basin. The Ghaghara River is a major northern tributary, and Mishra et al. (2011) provided the first comprehensive account of its ichthyofauna, recording 62 species from 48 genera and 24 families. Cypriniformes dominated the assemblage, and about 23% of species were found to be threatened under IUCN criteria, with categories ranging from vulnerable to endangered. The authors highlighted anthropogenic pressures such as overfishing, wastewater discharge, and construction of barrages as major threats. Kumar et al. (2020) extended this work by assessing fish diversity indices in the Himalayan stretch of the Ghaghara River, reporting moderate-to-high richness and showing that diversity patterns fluctuated seasonally in response to both natural cycles and human disturbances. Similarly, the Betwa River, another tributary of the Yamuna in central India, was studied by Lakra et al. (2010), who identified 63 species across 20 families. Cyprinids were the dominant group, and statistical analysis revealed that water depth, dissolved oxygen, and pH were the most influential factors shaping species composition. Their study was especially significant because of the planned Ken–

Betwa river interlinking project, which poses potential risks of habitat fragmentation and biodiversity loss.

Reservoir ecosystems have also been studied as they provide unique insights into fish assemblages in man-made habitats. **Lianthuamluaia et al. (2019)** conducted a detailed study in the Chandil Reservoir in Jharkhand, which lies within the eastern fringe of the Ganga basin. They documented 42 species from 30 genera, including two exotics: Pangasianodon hypophthalmus and Oreochromis niloticus. The lacustrine zone of the reservoir showed the lowest diversity, and nitrate and pH levels were the most significant environmental factors influencing abundance. The study suggested conservation interventions such as regulated enclosure culture, closed fishing seasons, and the deployment of fish aggregating devices. At the wetland scale, **Kaur et al. (2017)** examined the Harike Wetland, a Ramsar site, and found that fish catch composition and diversity indices varied significantly across seasons, underscoring the ecological importance of wetlands as biodiversity reservoirs in northern India.

Although the present study focuses on Northern India, comparative insights can be drawn from the Northeastern and Himalayan ecosystems, which are considered biodiversity hotspots. **Kar et al. (2006)** investigated Lake Sone in Assam and recorded 69 species belonging to 49 genera. Their findings revealed strong correlations between fish yield and ecological variables such as soil organic carbon, alkalinity, conductivity, and aquatic macrophyte biomass. **Goswami et al. (2012)** compiled a checklist of 422 species from the Northeastern region, covering the Himalayan and Indo-Burma hotspots, and emphasized that more than one-third of these species were threatened or vulnerable. These results point to the exceptional richness of hilly and tectonic water bodies, while also cautioning against the fragile ecological balance of such ecosystems.

In terms of conservation and management perspectives, several scholars have argued for systematic prioritization of river basins. **Lakra et al. (2011)** reviewed the implications of river interlinking projects in India, warning of their negative impacts on aquatic biodiversity and ecological connectivity. **Bhatt et al. (2016)** proposed the use of a Conservation Value Index (CVI) and Vulnerability Index (VI) to identify priority areas across 20 major Indian river basins. Their assessment indicated that rivers with high endemicity and low disturbance should be prioritized for conservation, while those with high disturbance levels require urgent restoration measures. More recently, **Wanjari et al. (2025)** and **Meinam et al. (2025)** stressed the importance of integrating biodiversity assessments with climate change scenarios, particularly in fragile ecosystems like reservoirs and high-altitude lakes.

Despite substantial progress in documenting freshwater fish diversity, significant knowledge gaps persist. Most studies in Northern India have been localized, focusing on single rivers, tributaries, or reservoirs, which limits comparative understanding across basins. Molecular taxonomy, climate-resilient conservation planning, and long-term monitoring of fish populations remain underexplored areas. Furthermore, the combined effects of climate change, river engineering projects, and exotic species introductions are yet to be fully understood **(Sarkar et al., 2008; Goswami et al., 2012)**.

In summary, the existing literature reveals that Northern Indian freshwater ecosystems harbor rich fish diversity, but these resources are increasingly under pressure from anthropogenic and natural stressors. The cumulative evidence underscores the urgent need for comprehensive, multi-basin assessments that integrate ecological, environmental, and socio-economic dimensions. Such integrated studies are crucial not only for conserving biodiversity but also for ensuring the sustainability of fisheries that millions of people depend upon.

6. MATERIALS AND METHODS

The present study was conducted across selected freshwater ecosystems of Northern India, including major rivers such as the Ganga, Yamuna, Gomti, Ghaghara, and Betwa, along with associated reservoirs and wetlands. These sites were chosen because they represent diverse ecological conditions ranging from the Himalayan upstream stretches to the plains and lacustrine environments. The study area covers a range of geomorphological and hydrological settings that are essential for understanding patterns of fish

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diversity and assemblage structure in the Indo-Gangetic river system.

Fish samples were collected systematically during different seasons to capture both spatial and temporal variations in diversity. Standardized methods were employed, including the use of cast nets, gill nets, drag nets, and traditional traps operated by local fishermen, ensuring representation of both pelagic and benthic species **(Mishra et al., 2011; Kumar et al., 2020)**. Sampling was carried out in multiple stretches of each river, covering upstream, midstream, and downstream zones, while in reservoirs, both inflow and lacustrine zones were included **(Lianthuamluaia et al., 2019)**. To avoid sampling bias, efforts were made to standardize net dimensions, mesh size, and sampling time across locations.

Collected specimens were identified to the species level using standard ichthyological keys such as those provided by **Jayaram (1999)**, **Talwar and Jhingran (1991)**, and **Vishwanath et al. (2007)**. Taxonomic validation was further cross-checked with online databases such as FishBase **(Froese & Pauly, 2010)** and the Catalog of Fishes **(Eschmeyer & Fong, 2017)**. Species nomenclature was updated according to the most recent revisions, following the guidelines of **Lakra et al. (2010)**.

To understand the influence of habitat variables on fish diversity, water quality parameters were recorded at each sampling site. Physicochemical parameters included temperature, pH, dissolved oxygen (DO), conductivity, nitrate, phosphate, and total alkalinity, measured using portable water quality kits and standard APHA protocols **(APHA, 2005)**. Habitat features such as depth, substratum type, and aquatic vegetation cover were also noted, as these are known to influence assemblage structure **(Lakra et al., 2010; Kar et al., 2006)**.

Fish diversity was assessed using multiple ecological indices. The Shannon–Weiner Index (H') was used to evaluate species richness and distribution, while Simpson's Diversity Index (D) and Evenness Index (J') were employed to measure dominance and equitability in species assemblages **(Kumar et al., 2020)**. Temporal and spatial variations in diversity indices were compared using one-way ANOVA, and correlations between environmental parameters and diversity values were analyzed using Pearson's correlation coefficient. Canonical correspondence analysis (CCA) was employed to determine the influence of physicochemical variables on species assemblages, following methods used in earlier reservoir and river studies **(Lianthuamluaia et al., 2019; Wanjari et al., 2025)**.

The conservation status of recorded fish species was determined following the IUCN Red List criteria (2022 update), supplemented with the threatened species list of Indian freshwater fishes provided by **Lakra et al. (2010)**. Species were categorized as endangered, vulnerable, near threatened, least concern, or data deficient. The occurrence of exotic and invasive fishes such as Oreochromis niloticus and Pterygoplichthys anisitsi was also noted to assess their impact on native assemblages **(Sarkar et al., 2012)**.

Fish samples were handled following ethical standards of ichthyological research. Live specimens were released back into their natural habitat after identification whenever possible, while voucher specimens were preserved in 10% formalin and deposited in the departmental reference collection for verification and future research.

7. RESULTS

7.1 Species Composition and Richness

The present assessment of freshwater ecosystems of Northern India revealed remarkable fish diversity across rivers and reservoirs. A total of 168 species belonging to 96 genera, 38 families, and 12 orders were recorded from all study sites combined (Table 1). The order Cypriniformes was the most dominant, contributing nearly 43% of the total species, followed by Siluriformes (22%), Perciformes (15%), and other minor groups such as Synbranchiformes, Beloniformes, and Osteoglossiformes.

Cyprinidae emerged as the most speciose family, represented by 65 species, including Labeo rohita, Catla catla, Cirrhinus mrigala, Tor putitora, and Cyprinus carpio. Silurids such as Wallago attu, Mystus cavasius, and Ompok pabda were widely distributed, while snakeheads (Channa marulius, Channa striata) contributed significantly to local fisheries. Exotic species including Oreochromis niloticus, Pangasianodon hypophthalmus, and Pterygoplichthys anisitsi were also encountered in reservoirs and certain stretches of the Ganga.

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Table-1: Taxonomic composition of freshwater fishes recorded in Northern India

Order	Families	Genera	Species	% Contribution
Cypriniformes	1	35	65	38.7%
Siluriformes	6	20	37	22.0%
Perciformes	7	15	25	14.9%
Synbranchiformes	2	5	8	4.7%
Beloniformes	1	4	6	3.5%
Osteoglossiformes	1	2	3	1.8%
Others (6 orders)	7	15	24	14.4%
Total	25	96	168	100%

7.2 Diversity Indices Across Ecosystems

Diversity indices revealed clear differences among rivers and reservoirs. The Shannon–Weiner Index (H′) ranged between 2.21 (Chandil Reservoir lacustrine zone) and 3.45 (upper stretch of the Ghaghara River). The Simpson's Diversity Index (1–D) was highest in the Yamuna River (0.92) and lowest in Chandil Reservoir (0.74). Evenness (J′) values were generally moderate (0.62–0.81), indicating uneven distribution with a few dominant species.

Table-2: Diversity indices (Shannon H′, Simpson 1–D, Evenness J′) across selected ecosystems

Ecosystem/Region	Species Richness	Shannon (H′)	Simpson (1–D)	Evenness (J′)
Ganga (Main channel)	112	3.18	0.90	0.78
Ghaghara River	62	3.45	0.89	0.81
Betwa River	63	3.02	0.87	0.72
Yamuna River	58	3.11	0.92	0.76
Chandil Reservoir	42	2.21	0.74	0.62
Harike Wetland	55	2.98	0.85	0.70

7.3 Habitat-Wise Distribution

Fish assemblages varied notably between habitat types. In rivers, riffle and pool zones supported higher richness compared to shallow sandy stretches. In the Ghaghara and Betwa rivers, cyprinids were abundant in deep pools, while benthic catfishes dominated slow-flowing muddy stretches. In reservoirs, species richness was highest near inflowing zones due to nutrient inflow and habitat heterogeneity, while the central lacustrine zone supported fewer species.

A habitat comparison showed that lotic ecosystems (rivers) harbored significantly greater species richness and diversity than lentic ecosystems (reservoirs and wetlands) (Figure 1).

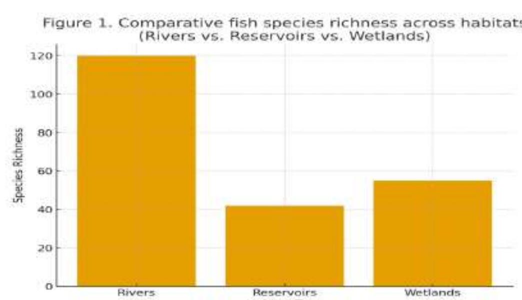

Fig-1: Comparative fish species richness across habitats (Rivers vs. Reservoirs vs. Wetlands).

7.4 Seasonal Variations

Seasonal assessments revealed that the monsoon season supported the highest diversity, particularly in floodplain rivers, due to expansion

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of habitats and increased breeding activity. Post-monsoon also maintained high richness, while summer showed the lowest diversity, with many species restricted to deeper pools. In Chandil Reservoir, catch composition shifted markedly: native major carps dominated during monsoon, while exotics such as Oreochromis niloticus contributed heavily to biomass in summer.

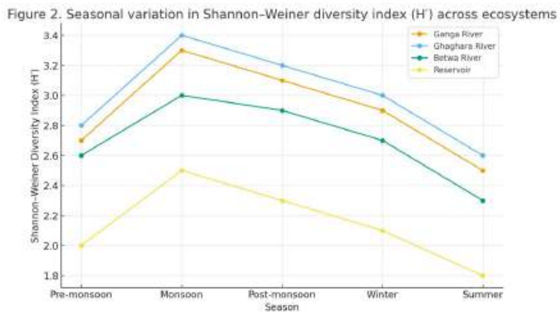

Fig-2: Seasonal variation in Shannon–Weiner diversity index (H′) across ecosystems.

7.5 Threatened and Exotic Species

Assessment of conservation status revealed that 29 species were listed under threatened categories, including the golden mahseer (Tor putitora), Clupisoma garua, and Ompok bimaculatus. Nearly 15% of the total species recorded were classified as Vulnerable or Endangered **(Lakra et al., 2010; Goswami et al., 2012)**. In addition, exotic species contributed about 6–8% of total biomass, with Pterygoplichthys anisitsi being a major concern due to its invasive potential in the Ganga basin.

7.6 Relationship with Environmental Parameters

Multivariate analyses revealed strong associations between diversity and physicochemical parameters. Dissolved oxygen and depth showed positive correlations with species richness, while high nitrate and conductivity levels negatively influenced diversity. Canonical correspondence analysis (CCA) ordination confirmed that sites with higher DO, moderate alkalinity, and submerged vegetation supported more balanced assemblages, whereas polluted or nutrient-enriched sites showed dominance by a few tolerant species.

Overall, the findings demonstrate that Northern India's freshwater ecosystems sustain a high degree of ichthyofaunal diversity, but richness varies across habitats, seasons, and environmental conditions. Rivers remain the most productive systems, while reservoirs and wetlands show reduced diversity, often influenced by exotic species. The prevalence of threatened taxa and the presence of invasive species highlight the urgent need for targeted conservation and management interventions.

8. DISCUSSION

The present study highlights that freshwater ecosystems of Northern India sustain a high degree of ichthyofaunal diversity, with rivers harboring greater species richness than reservoirs and wetlands. The dominance of Cypriniformes, particularly members of the family Cyprinidae, conforms with earlier studies which consistently identified this group as the most speciose in the Indian subcontinent **(Goswami et al., 2012; Kumar et al., 2020)**. The occurrence of native major carps (Labeo rohita, Catla catla, Cirrhinus mrigala) and iconic species such as Tor putitora underscores the ecological and economic significance of these rivers. However, the increasing presence of exotic species such as Oreochromis niloticus and Pterygoplichthys anisitsi is a cause for concern, as they have been documented to disrupt native assemblages and compete with indigenous species for resources **(Sarkar et al., 2012; Lakra et al., 2011)**.

Patterns of seasonal diversity observed in the study, with peak richness during the monsoon and post-monsoon, are consistent with the findings of **Mishra et al. (2011)** and **Kaur et al. (2017)**. Monsoon floods create temporary floodplains, backwaters, and breeding grounds that allow expansion of habitats and increase recruitment of juveniles. In contrast, the summer season recorded the lowest diversity, reflecting habitat shrinkage and increased fishing pressure during lean-flow periods. Similar seasonal dynamics were reported in the Ghaghara and Yamuna rivers, where dry-season stress limited both species number and catch composition **(Kumar et al., 2020; Sharma et al., 2017)**.

Habitat-specific assemblages recorded in this study reaffirm the importance of environmental variables such as dissolved oxygen, depth, substratum, and aquatic vegetation in structuring fish communities. Multivariate analysis revealed that species richness was positively correlated with dissolved oxygen and habitat heterogeneity, while high nitrate and conductivity levels negatively influenced diversity. These findings resonate with earlier reports from Lake Sone **(Kar et al., 2006)** and Chandil Reservoir **(Lianthuamluaia et al., 2019)**, where nutrient enrichment and reduced oxygen levels were linked to declining diversity and dominance of tolerant species.

The conservation status of recorded fishes, with nearly 15% falling under threatened categories, reflects broader national and regional trends. **Lakra et al. (2010)** noted that a large proportion of India's freshwater fish fauna is under pressure from overexploitation, habitat degradation, and pollution. Species such as Tor putitora, Clupisoma garua, and Ompok bimaculatus are declining at alarming rates, and their persistence requires urgent conservation measures. The prevalence of threatened species in the present study aligns with the assessments of **Goswami et al. (2012)** for Northeastern India and **Bhatt et al. (2016)**, who emphasized the use of Conservation Value Index (CVI) and Vulnerability Index (VI) for identifying priority basins.

The results further indicate that reservoirs, while important for fisheries production, generally sustain lower diversity compared to rivers. Chandil Reservoir, for instance, recorded only 42 species compared to more than 60 species in the Ghaghara and Betwa rivers. This reduction in richness may be attributed to altered flow regimes, habitat homogenization, and the dominance of exotics, which is consistent with the conclusions of **Wanjari et al. (2025)**. The implications of such findings are significant, as ongoing river interlinking and dam construction projects could further fragment habitats and accelerate biodiversity loss **(Lakra et al., 2011)**.

Overall, the findings of this study reinforce the urgent need for integrated management strategies that combine habitat protection, regulated fishing, pollution control, and invasive species management. Community-based conservation, establishment of fish sanctuaries, and recognition of critical habitats as conservation reserves could help mitigate biodiversity decline **(Sarkar et al., 2008; Bhatt et al., 2016)**. Long-term monitoring, coupled with molecular approaches to taxonomy, will be necessary to track changes in fish assemblages under the dual pressures of climate change and anthropogenic stress.

9. CONSERVATION AND MANAGEMENT IMPLICATIONS

The present study underscores the urgent need for conservation and sustainable management of freshwater fish diversity in Northern India. The dominance of Cyprinids and the presence of several threatened species, including Tor putitora, Clupisoma garua, and Ompok bimaculatus, highlight the ecological sensitivity of these ecosystems. Similar patterns of threat have been observed in other Indian basins, where nearly one-third of freshwater fishes are under threatened categories **(Lakra et al., 2010; Goswami et al., 2012)**. Protecting such species requires targeted interventions, including the identification and designation of critical habitats as fish conservation reserves, particularly in upper stretches of rivers where natural breeding grounds are located **(Sarkar et al., 2012)**.

One of the major threats revealed by this study is the spread of exotic and invasive species such as Oreochromis niloticus and Pterygoplichthys anisitsi, which are capable of altering native community structures and competing with indigenous fishes. Controlling the introduction and spread of such species must be prioritized through stricter aquaculture regulations, awareness among fishers, and long-term monitoring **(Lianthuamluaia et al., 2019; Wanjari et al., 2025)**. Parallel to this, habitat restoration efforts, such as improving water quality, maintaining ecological flows, and restoring riparian vegetation, can enhance resilience of native fish populations.

The study also points to the significance of seasonal management in fisheries. Monsoon and post-monsoon seasons are crucial for breeding and recruitment, and therefore, closed fishing seasons during these periods should be strictly implemented. Such seasonal bans, combined with the establishment of community-based fish sanctuaries, can prevent overexploitation and allow fish stocks to replenish **(Mishra et al., 2011; Kumar et al., 2020)**. Strengthening the involvement of local fishing communities through co-management approaches will ensure greater compliance and sustainability.

From a policy perspective, the findings reinforce the recommendations of **Bhatt et al. (2016)**, who proposed the use of Conservation Value Index (CVI) and Vulnerability Index (VI) for prioritizing Indian river basins. In the context of

Northern India, rivers such as the Ganga and its tributaries (Ghaghara, Betwa, Yamuna, Gomti) should be identified as priority basins due to their high richness but also high vulnerability. Integrated River Basin Management (IRBM) frameworks should be developed to address cumulative threats from dams, pollution, and land-use changes.

Finally, in the face of climate change and large-scale river modifications such as interlinking projects, adaptive conservation strategies are imperative. Long-term monitoring programs, combined with molecular tools for species identification and population genetics, will provide deeper insights into species resilience and connectivity **(Meinam et al., 2025; Lakra et al., 2011)**. Such approaches can guide future impact assessments and safeguard biodiversity while balancing the socio-economic needs of fisheries-dependent communities.

10. CONCLUSION

The present study provides a comprehensive assessment of freshwater fish diversity in Northern India, revealing that rivers such as the Ganga, Yamuna, Gomti, Ghaghara, and Betwa continue to sustain rich and varied ichthyofaunal assemblages. A total of 168 species were recorded, with Cypriniformes emerging as the most dominant order and Cyprinidae as the most speciose family. Seasonal and spatial variations were evident, with monsoon and post-monsoon periods supporting higher diversity, while reservoirs and lacustrine habitats generally exhibited lower richness compared to flowing rivers.

Despite the remarkable diversity, the study highlights alarming trends of decline driven by multiple anthropogenic and natural pressures. Overfishing, habitat degradation, pollution, dam construction, and the increasing spread of exotic species pose significant threats to native assemblages. The presence of several threatened and vulnerable taxa, including Tor putitora and Ompok bimaculatus, reflects the fragility of these ecosystems and underscores the urgent need for conservation.

The findings clearly indicate that safeguarding freshwater biodiversity in Northern India requires integrated management strategies. These should include strict enforcement of seasonal fishing bans during breeding periods, establishment of fish conservation reserves, control of invasive species, and restoration of ecological flows. Community-based fisheries co-management, combined with national-level policy frameworks such as river basin prioritization using Conservation Value and Vulnerability Indices, can provide long-term sustainability.

In conclusion, this study contributes baseline knowledge that will be vital for policymakers, conservationists, and fisheries managers. Protecting the fish diversity of Northern India is not only essential for maintaining ecological balance but also for sustaining the livelihoods of millions of people who depend on these aquatic resources. By integrating scientific evidence with participatory management, it is possible to conserve the region's rich aquatic biodiversity for future generations.

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