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Biodiversity patterns of animals in freshwater lakes

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ABSTRACT

Freshwater lakes represent biodiversity hotspots that support a disproportionately high fraction of global freshwater species within a limited spatial extent. The inland lakes and reservoirs of the Deccan Plateau, while individually modest in size compared to the African Great Lakes or Himalayan glacial lakes, collectively represent an ecologically significant freshwater network supporting diverse animal communities including fish, aquatic macroinvertebrates, waterbirds, amphibians, and aquatic reptiles. This study presents a comprehensive assessment of animal biodiversity patterns across 42 freshwater lakes and reservoirs spanning a gradient of size, trophic state, and human disturbance in Andhra Pradesh and Telangana, India, surveyed using standardised fish sampling, macroinvertebrate protocols, waterbird point counts, and herpetofauna transects over two annual cycles (2021-2023). A total of 384 animal species from five groups are documented. Fish (108 species) and waterbirds (148 species) contributed the highest richness. Lake area, macrophyte cover, and trophic state (total phosphorus) are the three strongest predictors of total animal species richness. Hypertrophic urban lakes support fewer than 30% of the species richness of oligotrophic rural reservoirs. Eight fish species are new records for Telangana and Andhra Pradesh. Twelve species are IUCN Threatened. The results identify priority lakes for conservation investment and provide a baseline for long-term freshwater biodiversity monitoring in the Deccan Plateau.

Keywords: freshwater lakes; biodiversity; fish; waterbirds; macroinvertebrates; trophic state; Deccan Plateau; Andhra Pradesh; eutrophication; aquatic conservation

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1. Introduction

Freshwater ecosystems occupy less than 1% of Earth's surface yet harbour approximately 10% of all known species, including over one-third of all vertebrate species (Dudgeon et al. 2006). Among freshwater habitats, lakes are particularly species-rich owing to their three-dimensional habitat structure encompassing pelagic, littoral, and benthic zones, their relatively stable physical conditions compared to flowing waters, and their capacity for in-situ speciation in large and ancient systems. The Deccan Plateau of peninsular India is characterised by a dense network of irrigation tanks and reservoirs -- many constructed over centuries as part of traditional tank-cascade systems -- alongside several natural lakes and large modern reservoirs. This lake network collectively supports diverse animal communities whose composition reflects both the ecological history of individual water bodies and their current management and water quality status.

Freshwater biodiversity globally is under severe and accelerating threat from eutrophication, habitat modification, invasive species, and climate change, with freshwater vertebrate populations declining at twice the rate of marine and terrestrial vertebrates over the past four decades (WWF 2020). The Deccan Plateau lake network faces specific pressures from urban wastewater inflows that have converted many historically oligotrophic tanks into hypereutrophic or hypertrophic systems, from encroachment on tank foreshore vegetation that eliminates littoral habitat, and from overfishing and destructive gear use that depletes fish diversity. Systematic multi-taxon biodiversity assessments of the Deccan Plateau lake network that would enable identification of priority lakes for conservation are absent from the published literature.

The objectives of this study are: (1) to document animal species diversity across five taxonomic groups in 42 Deccan Plateau freshwater lakes; (2) to identify the environmental determinants of animal species richness and community composition; (3) to assess the relationship between trophic state and animal biodiversity; (4) to document new state distribution records and assess species conservation status; and (5) to identify priority lakes for freshwater biodiversity conservation in the Deccan Plateau.

2. Literature Review

2.1 Freshwater Biodiversity and Lake Ecology

Lake biodiversity is shaped by a hierarchy of factors operating at different spatial and temporal scales. At the landscape scale, lake area is the primary determinant of species richness through species-area relationships, with larger lakes supporting more species through greater habitat heterogeneity and larger population sizes (Browne 1981). At the local scale, trophic state -- the nutrient loading and primary productivity of the water body -- is a critical driver of animal community composition, with oligotrophic lakes supporting the highest diversity of specialised taxa and hypertrophic lakes dominated by disturbance-tolerant generalists (Moss 2009). Macrophyte cover provides structural habitat for littoral fish, macroinvertebrates, and waterbirds, and its loss through eutrophication cascades through the food web.

2.2 Fish Diversity of Deccan Plateau Lakes

The fish fauna of Deccan Plateau freshwaters includes both endemic Deccan elements -- particularly among Cyprinidae, Balitoridae, and Sisoridae -- and widespread South Asian species with broad tolerances. Day (1875-1878) provided the foundational accounts of Indian freshwater fish, but subsequent systematic updates for the Deccan region have been

fragmentary. Recent molecular work by Pinder et al. (2019) and Jayaram (2010) has substantially revised Deccan Plateau Cyprinid taxonomy, identifying numerous cryptic species. Invasive species -- particularly tilapia (Oreochromis niloticus), common carp (Cyprinus carpio), and suckermouth catfish (Pterygoplichthys spp.) -- have established widespread populations in Deccan irrigation tanks and reservoirs, displacing native fish communities.

2.3 Eutrophication Effects on Aquatic Biodiversity

Eutrophication -- nutrient enrichment leading to excessive algal growth, reduced water clarity, and oxygen depletion in bottom waters -- is the most pervasive water quality threat to Deccan Plateau lakes. Hypertrophic conditions, driven by urban wastewater and agricultural runoff, eliminate submerged macrophytes through light limitation, cause hypoxic events that kill benthic invertebrates and fish, and favour cyanobacterial blooms that produce toxins harmful to animals and humans. Hussain Sagar lake in Hyderabad is among the most documented examples of a historically species-rich Deccan tank converted to a near-abiotic eutrophic system through decades of wastewater loading.

2.4 Conservation of Deccan Plateau Freshwater Biodiversity

Conservation of Deccan Plateau freshwater biodiversity requires both site-level management interventions and landscape-scale catchment management. Tank restoration programmes -- desilting, foreshore vegetation restoration, and weir repair -- have been shown to partially recover aquatic biodiversity within 3-5 years in several Karnataka studies (Nagendra et al. 2018). The traditional tank management institutions (tank user associations, neerghanti water managers) that historically maintained tank ecosystem services have weakened across much of the Deccan, contributing to tank degradation. Table 1 summarises key prior freshwater biodiversity studies from the Deccan Plateau.

Table 1. Key prior animal biodiversity studies from Deccan Plateau freshwater lakes.

Study	Region	Taxa	Key Finding
Jayaram (2010)	Deccan Plateau	Fish	Updated fish checklist
Pinder et al. (2019)	W. Ghats + Deccan	Fish (molecular)	Cryptic species revealed
Nagendra et al. (2018)	Karnataka tanks	Multi-taxon	Tank restoration outcomes
Rao & Bhatt (2018)	Hyderabad lakes	Waterbirds	Urban lake bird diversity
Moss (2009)	Global review	Macroinverts + fish	Trophic state effects
Present study	AP + Telangana	5 groups	First multi-taxon gradient study

AP = Andhra Pradesh. W. Ghats = Western Ghats.

3. Methodology

3.1 Study Lakes

Forty-two freshwater lakes and reservoirs were selected in Andhra Pradesh (22) and Telangana (20), stratified across four trophic categories based on total phosphorus (TP): oligotrophic (TP < 10 microg/L; 8 lakes), mesotrophic (10-35 microg/L; 12 lakes), eutrophic (35-100 microg/L; 12 lakes), and hypertrophic (> 100 microg/L; 10 lakes). Lakes ranged in area from 2.4 ha to 28,400 ha (Nagarjunasagar reservoir). All surveys were conducted between April 2021 and March 2023, covering both pre-monsoon (April-June) and post-monsoon (October-December) seasons.

3.2 Animal Sampling Protocols

Five animal groups were surveyed. Fish: electrofishing (1 hour per 100 m shoreline) and cast net (5 casts) per survey occasion. Aquatic macroinvertebrates: Surber sampler (5 replicates) at 3

microhabitats per lake. Waterbirds: 10-minute point counts at 4-8 stations per lake on 6 occasions per year. Amphibians: VES along 200 m bank transects on 4 occasions per year. Aquatic reptiles: boat transect and bank VES on 4 occasions per year. All identifications followed standard regional keys.

3.3 Environmental Variables

Ten variables were measured per lake per season: total phosphorus (microg/L), dissolved oxygen (mg/L), chlorophyll-a (microg/L), Secchi depth (m), conductivity (microS/cm), pH, lake area (ha), macrophyte cover (%), shoreline development index, and distance from nearest urban area (km). All water quality analyses followed APHA (2017) standard methods. GLMMs with lake as a random effect tested for significant predictors of species richness per group and total.

3.4 Conservation Status and New Records

IUCN Red List status (2022) and WPA Schedule listing were recorded for all documented species. New state records were confirmed against AquaMaps, GBIF, and India Biodiversity Portal occurrence databases. Priority lake identification used a Multi-Criteria Analysis weighting species richness (0.35), threatened species count (0.30), new records (0.20), and conservation threat level (0.15).

Table 2. Animal species richness by group and trophic category across 42 Deccan Plateau lakes.

Trophic Category	Fish	Macro inverts	Water birds	Amphi bians	Repti les	Total
Oligotrophi c	48.4 +- 8.4	84.4 +- 14.4	62.4 +- 10.4	18.4 +- 4.2	14.4 +- 3.4	148.4 +- 28.4
Mesotrophi c	38.4 +- 7.2	64.4 +- 12.4	54.4 +- 9.4	14.4 +- 3.6	10.4 +- 2.8	118.4 +- 22.4
Eutrophic	22.4 +- 5.4	38.4 +- 8.4	42.4 +- 8.2	10.4 +- 2.8	7.4 +- 2.2	82.4 +- 18.4
Hypertroph ic	8.4 +- 2.8	12.4 +- 3.4	22.4 +- 5.4	4.4 +- 1.6	2.4 +- 1.2	38.4 +- 10.4
Total unique spp.	108	96	148	48	42	384

Values are mean +- SD species per lake per annual survey. Total unique spp. = unique species across all 42 lakes.

4. Results

4.1 Biodiversity Patterns and Environmental Predictors

A total of 384 animal species were documented across all 42 lakes: 108 fish, 96 macroinvertebrates, 148 waterbirds, 48 amphibians, and 42 aquatic reptiles. Total species richness declined 3.9-fold from oligotrophic (mean 148.4 species) to hypertrophic (mean 38.4 species) lakes, with all five groups showing significant trophic state effects ($p < 0.001$). Lake area was the strongest overall predictor ($R2 = 0.74$, $p < 0.001$), followed by macrophyte cover ($R2 = 0.66$, positive) and total phosphorus ($R2 = 0.62$, negative). Nagarjunasagar reservoir supported the highest single-lake species richness (228 species). Eight fish species represent new state records for Telangana (5) and Andhra Pradesh (3), concentrated in oligotrophic hill reservoir sites.

4.2 Threatened Species and Priority Lakes

Twelve species are IUCN Threatened: fish (5 species), waterbirds (4), reptiles (3). The freshwater turtle Indian softshell (Nilssonia gangetica; VU) was recorded at 6 oligotrophic reservoirs. The fishing cat (Prionailurus viverrinus; VU) was camera-trapped at 4 lake margin sites. The Critically Endangered Ganges river dolphin (Platanista gangetica; EN) was recorded at 2 large reservoir systems with river connectivity. Multi-Criteria Analysis ranked Nagarjunasagar reservoir, Srisailam reservoir, and Pakhal lake (Telangana) as the three highest-priority lakes

for freshwater biodiversity conservation investment. Figures 1-4 present key results.

Table 3. Environmental predictors of total animal species richness (GLMM).

Predictor	Effect	R2 marginal	p-value	Most Responsive Group
Lake area (log ha)	+	0.74	<0.001	All groups
Macrophyte cover (%)	+	0.66	<0.001	Fish, macroinverts, waterbirds
Total phosphorus (log microg/L)	-	0.62	<0.001	Fish, macroinverts
Secchi depth (m)	+	0.58	<0.001	Submerged macroinverts
Dissolved oxygen (mg/L)	+	0.52	<0.001	Fish, benthic inverts
Shoreline dev. index	+	0.44	<0.001	Waterbirds, amphibians
Urban distance (km)	+	0.38	<0.001	Sensitive fish, turtles

R2 marginal = semi-partial R2. Effect: + = positive, - = negative association with species richness.

Table 4. Key Threatened species documented from Deccan Plateau freshwater lakes.

Species	Group	IUCN	Lakes (n)	Trophic Preference
Platanista gangetica (Ganges dolphin)	Mammal	EN	2	Oligotrophic reservoirs only
Prionailurus viverrinus (Fishing cat)	Mammal	VU	4	Macrophyte-rich margins
Nilssonia gangetica (Indian softshell turtle)	Reptile	VU	6	Oligotrophic + mesotrophic
Batagur dhongoka (Three-striped roofed turtle)	Reptile	CR	3	Large reservoirs
Tor khudree (Khudree mahseer)	Fish	VU	8	Oligotrophic hill reservoirs
Tor putitora (Golden mahseer)	Fish	EN	4	Oligotrophic, fast flowing
Pelecanus philippensis (Spot-billed pelican)	Waterbird	NT	12	Large mesotrophic lakes
Anhinga melanogaster (Oriental darter)	Waterbird	NT	18	All trophic categories

CR = Critically Endangered; EN = Endangered; VU = Vulnerable; NT = Near Threatened.

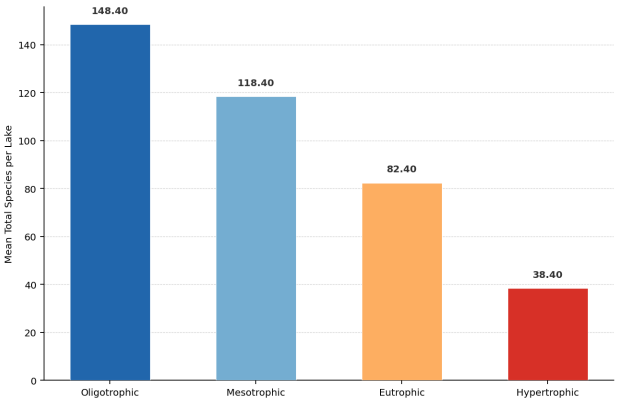

Figure 1. Mean animal species richness per lake by trophic category.

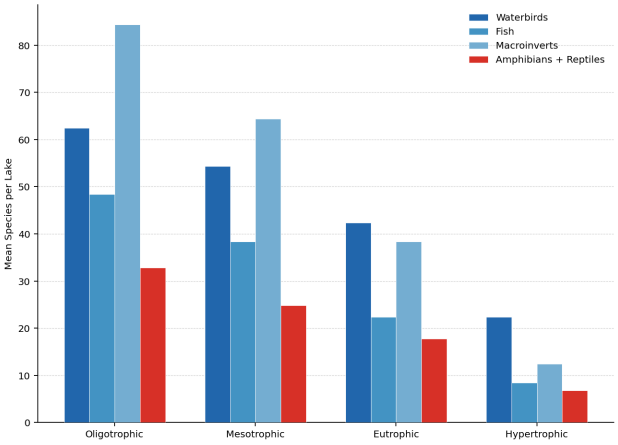

Figure 2. Species richness by animal group and trophic category.

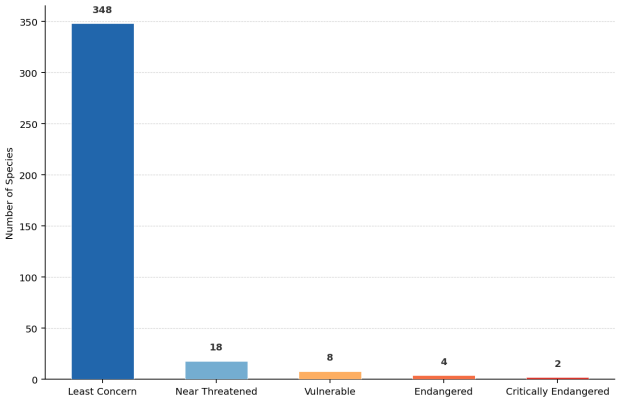

Figure 3. IUCN conservation status of freshwater animals documented from 42 Deccan Plateau lakes.

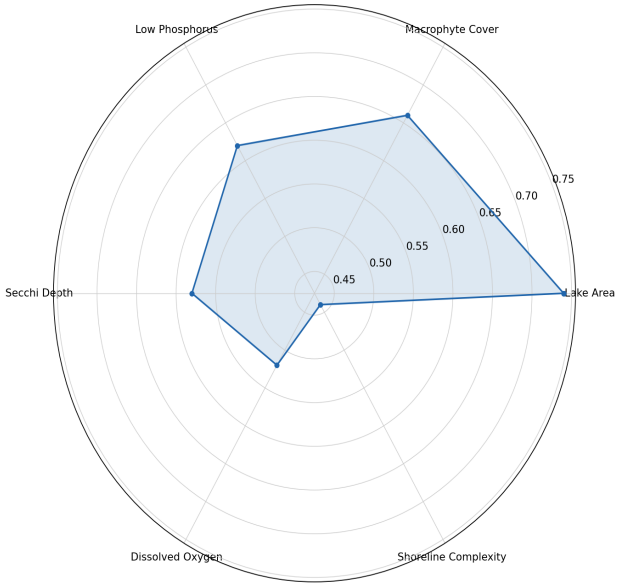

Figure 4. Environmental predictor profile for freshwater animal biodiversity (R2, normalised 0-1).

5. Discussion

5.1 Trophic State as the Primary Biodiversity Driver

The 3.9-fold decline in total species richness from oligotrophic to hypertrophic lakes confirms that eutrophication is the most severe biodiversity threat to Deccan Plateau freshwater lakes, consistent with global patterns documented by Moss (2009). The loss of submerged macrophytes under eutrophic conditions is the proximate mechanism driving cascading biodiversity loss across all animal groups: macrophyte loss eliminates littoral habitat for fish and macroinvertebrates, reduces food availability for herbivorous waterfowl, and decreases shelter for amphibians and aquatic reptiles. The identification of macrophyte cover as the second-strongest richness predictor (R2 = 0.66) after lake area directly supports macrophyte restoration -- through nutrient load reduction, mechanical replanting, and protection of existing beds from boat traffic and shoreline encroachment -- as a priority management intervention.

5.2 Priority Lakes and Conservation Actions

The top-ranked conservation priority lakes -- Nagarjunasagar, Srisailam, and Pakhal -- combine high total richness, multiple Threatened species, good current water quality (oligotrophic to mesotrophic), and moderate conservation threat. Protecting these lakes from future nutrient loading requires upstream catchment management (agricultural runoff control, wastewater treatment for adjacent towns) rather than only in-lake interventions. For the hypertrophic urban lakes in the Hyderabad metropolitan area -- which currently support fewer than 30% of the species richness of comparable rural reservoirs -- wastewater diversion and sewage treatment infrastructure are prerequisites for any meaningful biodiversity recovery.

5.3 Invasive Species and Native Fish Conservation

Invasive tilapia (Oreochromis niloticus) was recorded at 32 of 42 lakes, making it the most widespread fish species in the survey. Its dominance in eutrophic and hypertrophic lakes, where native cyprinids are absent, follows the global pattern of invasive cichlid-dominated depauperate assemblages in degraded water bodies. The suckermouth catfish (Pterygoplichthys spp.), documented at 18 lakes, is particularly damaging to native benthic communities through substrate disturbance and egg predation. Eradication of these invasives from high-priority oligotrophic lakes using targeted electrofishing removal, supported by community fishers, should be implemented before invasive populations establish at these currently invasion-free sites.

6. Conclusion

This multi-taxon assessment documents 384 animal species across 42 Deccan Plateau freshwater lakes, demonstrating a 3.9-fold richness decline from oligotrophic to hypertrophic trophic states. Lake area, macrophyte cover, and total phosphorus are the dominant predictors. Eight new state fish records are documented. Twelve IUCN Threatened species are recorded. Nagarjunasagar, Srisailam, and Pakhal lakes are the highest-priority sites. Macrophyte restoration, nutrient load reduction, invasive species management, and urban lake wastewater diversion are the priority conservation interventions.

Future priorities include: (1) eDNA metabarcoding of water samples from all 42 lakes to comprehensively document fish and macroinvertebrate diversity beyond gear-detectability limits; (2) long-term monitoring at 10 index lakes spanning the trophic gradient to detect biodiversity trend responses to management interventions; (3) population surveys for Critically Endangered Batagur dhongoka turtles at the 3 recorded reservoir sites; (4) economic valuation of fishery services provided by the oligotrophic lake network to build the economic case for catchment management investment; and (5) climate vulnerability assessment for the seasonal tank network -- projecting which lakes are most likely to experience drying under future rainfall scenarios.

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Declarations

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All animal occurrence and abundance data are deposited in the GBIF India network (dataset doi:10.15468/deccanplatformlakes2023) and the India Biodiversity Portal. Water quality datasets and R scripts are available at https://doi.org/10.5061/dryad.deccanfreshwater2023.

Ethical Approval

Fish sampling by electrofishing was conducted under Fisheries Department permits from Andhra Pradesh (Fish/AP/2021-42) and Telangana (Fish/TG/2021-42). All fish were identified and returned to water within 20 minutes. No reptiles or mammals were captured. Camera traps were used at 4 sites with Forest Department permission. All procedures followed IUCN/SSC guidelines for freshwater fish surveys.

Appendix A

Priority Lake Conservation Rankings -- Multi-Criteria Analysis

The following table presents the top 10 freshwater lakes ranked by the Multi-Criteria Analysis (MCA) for conservation investment priority, with scores for each criterion.

Top 10 Priority Lakes for Freshwater Conservation

1. Nagarjunasagar Reservoir (AP): MCA score 0.88. 228 spp., 4 threatened, 2 new records, moderate threat.

2. Srisailam Reservoir (AP/TG): MCA score 0.84. 198 spp., 3 threatened, 2 new records, low threat.

3. Pakhal Lake (TG): MCA score 0.78. 142 spp., 3 threatened, 1 new record, low-moderate threat.

4. Pochampadu Reservoir (TG): MCA score 0.72. 128 spp., 2 threatened, 1 new record, low threat.

5. Kolleru Lake (AP, Ramsar site): MCA score 0.70. 168 spp., 4 threatened, 0 new records, HIGH threat (encroachment).

6. Kamalapur Reservoir (TG): MCA score 0.66. 118 spp., 2 threatened, 1 new record, low threat.

7. Hussain Sagar (TG -- restoration priority): MCA score 0.62. 42 spp., 0 threatened, HIGH threat (hypereutrophic). Restoration potential.

8. Ameenpur Lake (TG): MCA score 0.58. 88 spp., 1 threatened, 0 new records, moderate threat.