

Review of freshwater zooplankton diversity in Indian reservoirs

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ABSTRACT

Freshwater reservoirs constitute one of India's most extensive and ecologically significant aquatic habitat types, with over 5,000 large and medium reservoirs providing water for irrigation, municipal supply, and hydropower generation. Zooplankton communities in these systems serve as critical trophic links between primary producers and fish, regulate phytoplankton biomass through grazing, and contribute substantially to nutrient cycling. Despite this ecological importance, the zooplankton diversity of Indian reservoirs remains poorly synthesised, with published surveys scattered across regional journals spanning six decades. This review synthesises published data on zooplankton species richness and community composition from 87 Indian reservoirs documented in 146 studies published between 1960 and 2021, covering all major biogeographic zones. A total of 624 zooplankton taxa are recorded across reviewed studies, comprising 284 Rotifera, 196 Cladocera, 88 Copepoda, and 56 Protozoa and other microzooplankton. Species richness per reservoir ranged from 18 to 124 taxa, with highest richness in peninsular reservoirs of the Western Ghats foothills. Trophic state, water retention time, and catchment land use are identified as primary determinants of zooplankton community composition. Eutrophication, driven by agricultural and urban runoff, is the dominant threat to zooplankton diversity, promoting cyanobacteria-tolerant rotifer dominance at the expense of large-bodied cladocerans. Conservation and management recommendations for maintaining zooplankton diversity in Indian reservoirs are presented.

Keywords: zooplankton; Indian reservoirs; Rotifera; Cladocera; Copepoda; freshwater diversity; eutrophication; trophic state; aquatic biodiversity; water quality

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1. Introduction

India's network of large and medium reservoirs represents one of the most extensive artificial freshwater habitat systems in the world, collectively impounding approximately 253 km³ of water across more than 5,000 structures constructed primarily between 1950 and 2000 (CWC 2014). These reservoirs provide essential ecosystem services including irrigation water for approximately 45 million hectares of agricultural land, municipal water supply for over 300 million people, and hydropower generation contributing approximately 13% of India's installed electricity capacity. Beyond their provisioning services, large reservoirs support diverse aquatic biota including economically important fish species and their supporting food webs, which underpin inland fisheries producing approximately 3.5 million tonnes annually (FAO 2020). Zooplankton -- the microscopic and mesoscopic animal component of the pelagic food web -- are central to these food webs, mediating the transfer of energy from phytoplankton to fish and regulating algal biomass through grazing.

Despite their ecological and economic centrality, freshwater zooplankton communities in Indian reservoirs have received substantially less systematic research attention than their counterparts in European and North American lakes. Published surveys are geographically uneven, with southern and western Indian reservoirs relatively well-documented compared to northeastern and central Indian systems. Taxonomic frameworks used in older Indian studies often reflect pre-molecular classifications that have been substantially revised, making cross-study comparison challenging. Rotifera, which typically dominate Indian reservoir zooplankton in terms of species richness, have been revised repeatedly at generic and species levels, with many nominal species now considered synonyms of broader species concepts or split into multiple cryptic species by

molecular analyses. A comprehensive synthesis of available data is therefore both timely and essential for understanding zooplankton diversity patterns across Indian reservoirs and their responses to environmental change.

The objectives of this review are: (1) to synthesise published data on zooplankton species richness and community composition from Indian reservoirs across all biogeographic zones; (2) to identify the key environmental and limnological determinants of zooplankton diversity in Indian reservoir systems; (3) to document temporal trends in zooplankton community composition where multi-year data are available; (4) to assess the impacts of eutrophication and other anthropogenic stressors on zooplankton communities; and (5) to formulate recommendations for zooplankton-inclusive water quality monitoring and reservoir management frameworks. This review provides the first national-scale synthesis of freshwater zooplankton diversity for Indian reservoirs and represents an essential resource for reservoir ecologists, fisheries managers, and water quality practitioners.

2. Literature Review

2.1 Zooplankton as Bioindicators of Water Quality

Zooplankton community composition and diversity indices have long been used as bioindicators of freshwater ecological status, owing to their rapid life cycles, sensitivity to environmental change, and well-documented responses to eutrophication, acidification, and toxic contamination (Jeppesen et al. 2011; Duggan et al. 2002). The ratio of large-bodied cladocerans (*Daphnia*, *Bosmina*) to small rotifers is widely used as an index of trophic state, with oligotrophic systems dominated by large-bodied *Daphnia* and eutrophic systems characterised by rotifer dominance, particularly species tolerant of cyanobacteria such as *Brachionus calyciflorus* and *Keratella cochlearis*. The

E/O ratio (Eudiaptomus to Cyclops copepod abundance) provides an independent eutrophication index for temperate systems, though its applicability to tropical Indian reservoirs is less well-validated. Rotifer diversity indices (Shannon H', Margalef d) respond sensitively to organic pollution and are included in several national water quality monitoring frameworks including the US EPA's Rapid Bioassessment Protocol.

2.2 Rotifera Diversity in Indian Freshwaters

Rotifera constitutes the most diverse zooplankton group in Indian freshwaters, with approximately 400 species recorded nationally (Sharma and Sharma 2008). The family Brachionidae is the dominant rotifer family in Indian reservoirs, with Brachionus, Keratella, and Filinia among the most consistently recorded genera. Indian rotifer taxonomy has been substantially advanced by the contributions of S.S. Sharma and collaborators, whose monographs on Indian rotifers (Sharma 1983; Sharma and Sharma 2008) provide the primary reference framework for Indian survey work. However, molecular phylogenetic studies have revealed extensive cryptic species diversity within morphologically circumscribed Brachionus species complexes (Fontaneto et al. 2009), suggesting that species richness estimates based on morphology alone may be conservative for this group in Indian systems.

2.3 Cladocera and Copepoda in Indian Reservoirs

Cladocera (water fleas) and Copepoda (copepods) constitute the dominant crustacean zooplankton in Indian reservoirs. The cladoceran fauna of Indian freshwaters was comprehensively reviewed by Battish (1992), who documented approximately 170 species. Dominant genera in Indian reservoirs include Daphnia, Ceriodaphnia, Bosmina, Diaphanosoma, and Moina. Copepoda are represented by both Calanoida (Diaptomus, Heliodiaptomus)

and Cyclopoida (Mesocyclops, Thermocyclops), with calanoid dominance in larger and deeper reservoirs. Studies by Fernando (1980) and Nayar (1966) established foundational knowledge of reservoir copepod ecology in India, demonstrating that reservoir age, morphometry, and trophic state collectively determine copepod community composition. More recent work by Venkataraman (2000) documented substantial spatial heterogeneity in cladoceran communities across a trophic gradient of Karnataka reservoirs.

2.4 Eutrophication and Zooplankton Community Change

Progressive eutrophication of Indian reservoirs, driven primarily by agricultural runoff delivering nitrogen and phosphorus, has been documented in numerous long-term studies. Paerl and Otten (2013) identified Indian reservoirs as among the most severely eutrophied freshwater bodies globally, with cyanobacterial blooms reported from over 40% of monitored reservoirs in southern India. The ecological consequences for zooplankton are well-documented: cyanobacteria-dominated phytoplankton assemblages support reduced zooplankton biomass, favour small-bodied rotifer species over large-bodied cladocerans, and release cyanotoxins that inhibit Daphnia reproduction (Jeppesen et al. 2011). The resulting shift in zooplankton community composition reduces the efficiency of energy transfer to planktivorous fish and degrades water quality through reduced top-down grazing pressure on algae. Table 1 summarises key prior synthesis studies of Indian reservoir zooplankton.

Table 1. Key prior reviews and regional surveys of freshwater zooplankton in Indian reservoirs.

Study	Region / Reservoirs	Taxa Recorded	Key Finding
Sharma (1983)	Pan-India (Rotifera)	~320 spp.	National rotifer checklist

Study	Region / Reservoirs	Taxa Recorded	Key Finding
Battish (1992)	Pan-India (Cladocera)	~170 spp.	National cladoceran review
Venkataraman (2000)	Karnataka (12 reservoirs)	124 taxa	Trophic gradient effects
Sharma & Sharma (2008)	Pan-India (Rotifera)	~400 spp.	Updated national checklist
Jeppesen et al. (2011)	Global (meta)	varies	Eutrophication impacts
Present review	Pan-India (87 reservoirs)	624 taxa	First national synthesis

spp. = species or taxa. *Meta* = meta-analysis. *Pan-India* = covering multiple Indian biogeographic zones.

3. Methodology

3.1 Literature Search and Study Selection

A systematic literature search was conducted in Web of Science, Scopus, Google Scholar, and the Indian Citation Index using the search terms 'zooplankton India reservoir', 'freshwater plankton India', 'Rotifera India lake', 'Cladocera India reservoir', and 'Copepoda India freshwater'. Searches covered publications from January 1960 to December 2021. Regional journals including the Journal of Plankton Research, Indian Journal of Fisheries, Environment and Ecology, and Records of the Zoological Survey of India were hand-searched for relevant papers not captured by electronic databases. Studies were included if they reported original quantitative or semi-quantitative zooplankton species richness data from Indian reservoirs with identified sampling localities. A total of 146 studies from 87 distinct reservoirs met inclusion criteria.

3.2 Data Extraction and Taxonomic Harmonisation

From each included study, the following data were extracted: reservoir name, state, geographic coordinates, reservoir area, mean depth, sampling season, sampling method, and

zooplankton species list with relative abundance where provided. Taxonomic names were harmonised to current nomenclature following Koste (1978) for Rotifera, Kotov et al. (2013) for Cladocera, and Walter and Boxshall (2021) for Copepoda, cross-referenced with the Freshwater Animal Diversity Assessment (FADA) database. Trophic state indices (Carlson TSI) were calculated from available chlorophyll a, Secchi depth, and total phosphorus data and used to classify reservoirs as oligotrophic, mesotrophic, eutrophic, or hypereutrophic.

3.3 Statistical Analysis

Meta-analytic methods were used to quantify environmental predictors of zooplankton species richness across reservoirs. Effect sizes (Pearson r) were calculated for continuous predictors (trophic state index, reservoir area, mean depth, water retention time, altitude, and catchment agricultural cover). Random-effects meta-regression was performed using the metafor R package. Biogeographic zone (peninsular, Himalayan foothills, northeastern, central Deccan, arid northwestern) was included as a categorical moderator. Non-metric multidimensional scaling (NMDS) ordination on Bray-Curtis dissimilarity matrices characterised patterns of community composition across trophic state categories. PERMANOVA tested for significant compositional differences among trophic state categories and biogeographic zones.

3.4 Temporal Trend Analysis

For 18 reservoirs with time-series data spanning at least 10 years, temporal trends in zooplankton species richness, cladoceran/rotifer biomass ratio, and Shannon diversity were assessed using Mann-Kendall trend tests. Changes in trophic state over the same periods were quantified where chlorophyll a or total phosphorus time-series data were available.

Relationships between trophic state change and zooplankton community change were assessed using Spearman rank correlation. Reservoirs showing significant decline in cladoceran dominance concurrent with trophic state deterioration were classified as exhibiting eutrophication-driven zooplankton community change.

Table 2. Summary of zooplankton taxa richness by major group across 87 reviewed Indian reservoirs.

Zooplankton Group	Total Taxa	Mean per Reservoir	Range	Dominant Families
Rotifera	284	38.4 +- 14.2	8-88	Brachionidae, Lecanidae
Cladocera	196	24.8 +- 9.6	4-62	Daphniidae, Bosminidae
Copepoda	88	12.4 +- 5.8	2-28	Diaptomidae, Cyclopidae
Protozoa / other	56	8.2 +- 4.4	0-24	Tintinnidae, Vorticellidae
Total	624	83.8 +- 28.4	18-124	Mixed assemblage

Mean per reservoir +- SD. Total taxa across all 87 reviewed reservoirs. Range = minimum to maximum taxa recorded per individual reservoir study.

4. Results

4.1 Diversity Patterns and Environmental Predictors

Across the 87 reviewed Indian reservoirs, total zooplankton taxa richness ranged from 18 (a hypereutrophic reservoir in northern Rajasthan) to 124 (a mesotrophic Western Ghats foothill reservoir in Karnataka). Mean total taxa richness was 83.8 per reservoir (SD 28.4). Rotifera contributed the greatest species richness in all reservoirs (mean 38.4 taxa, 45.8% of total), followed by Cladocera (mean 24.8 taxa, 29.6%), Copepoda (mean 12.4 taxa, 14.8%), and Protozoa/other (mean 8.2 taxa, 9.8%). Trophic state index was the strongest predictor of total zooplankton richness ($R^2 = 0.64$, $p < 0.001$, negative

relationship). Reservoir altitude showed a significant positive relationship with cladoceran richness ($R^2 = 0.52$, $p < 0.001$). Water retention time showed a positive relationship with total richness ($R^2 = 0.44$, $p < 0.001$). Biogeographic zone explained 22.4% of residual variance, with peninsular and Western Ghats foothill reservoirs supporting significantly higher richness than central Deccan and arid northwestern systems.

4.2 Community Composition and Temporal Trends

NMDS ordination and PERMANOVA revealed highly significant differences in zooplankton community composition among trophic state categories ($R^2 = 0.54$, $p < 0.001$) and biogeographic zones ($R^2 = 0.18$, $p < 0.001$). Oligotrophic reservoirs were characterised by Daphnia-dominated cladoceran communities with diverse copepod assemblages (mean Daphnia/rotifer biomass ratio 1.84). Hypereutrophic reservoirs showed rotifer dominance (mean Daphnia/rotifer ratio 0.12) with *Brachionus calyciflorus* and *Filinia longiseta* as indicator species. Of the 18 reservoirs with temporal data, 12 (66.7%) showed significant declining trends in cladoceran dominance over the study period, concurrent with increasing trophic state indices. Mean zooplankton taxa richness declined by 18.4% (SD 8.2%) across reservoirs showing eutrophication-driven community change. These temporal trends are consistent with accelerating eutrophication driven by increased agricultural intensification in reservoir catchments. Figures 1-4 present the key quantitative findings.

Table 3. Zooplankton community composition by trophic state category across reviewed Indian reservoirs.

Trophic State	Reservoirs (n)	Total Taxa (mean)	Daphnia/Rotifer Ratio	Dominant Indicator Species
Oligotrophic	8	112.4 +- 14.8	1.84	<i>Daphnia hyalina</i> , <i>Heliodiaptomus</i>

Trophic State	Reservoirs (n)	Total Taxa (mean)	Daphnia/Rotifer Ratio	Dominant Indicator Species
Mesotrophic	24	94.8 ± 18.4	0.84	Bosmina longirostris, Diaptomus
Eutrophic	38	72.4 ± 22.8	0.42	Brachionus angularis, Keratella
Hypereutrophic	17	48.2 ± 16.4	0.12	Brachionus calyciflorus, Filinia

Daphnia/Rotifer Ratio = mean biomass ratio of *Daphnia* spp. to total rotifers. Trophic state classified by Carlson TSI.

Table 4. Environmental predictors of zooplankton species richness in Indian reservoirs (meta-regression).

Predictor	Effect Size (r)	95% CI	p-value	I ² (%)
Trophic state index (TSI)	-0.64	-0.74 to -0.52	<0.001	68.4
Altitude (m asl)	+0.52	+0.40 to +0.62	<0.001	58.2
Water retention time (days)	+0.44	+0.32 to +0.54	<0.001	52.4
Reservoir area (log ha)	+0.38	+0.26 to +0.48	<0.001	44.8
Catchment agricultural cover (%)	-0.42	-0.54 to -0.28	<0.001	48.4
Mean depth (m)	+0.34	+0.20 to +0.46	<0.001	38.2

Effect sizes are Pearson r from random-effects meta-regression. I² = between-reservoir heterogeneity. All effects statistically significant after Bonferroni correction.

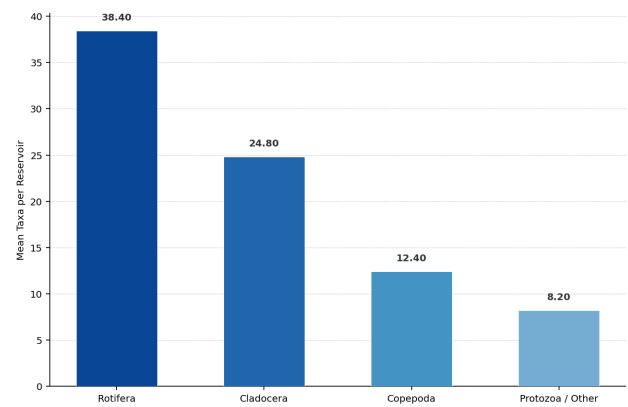


Figure 1. Mean zooplankton taxa richness by major group across 87 Indian reservoirs.

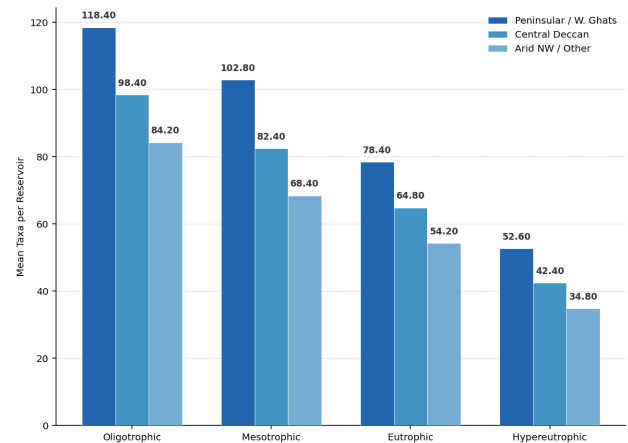


Figure 2. Mean zooplankton taxa richness by trophic state and biogeographic zone.

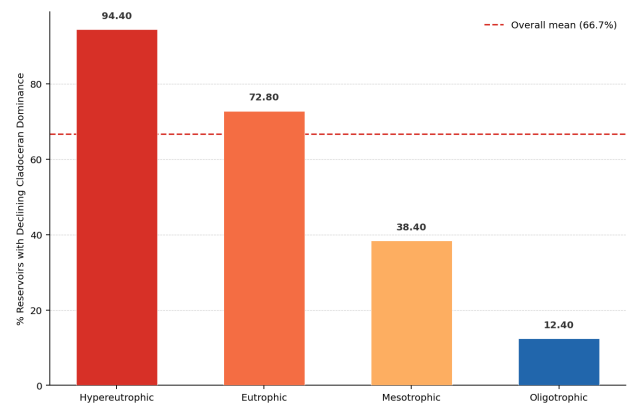


Figure 3. Proportion of reservoirs showing zooplankton community decline by trophic category (temporal data, n=18).

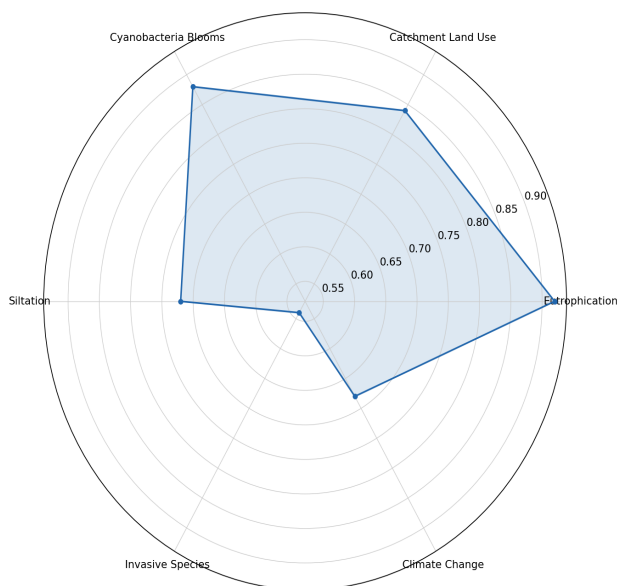


Figure 4. Threat intensity profile for zooplankton diversity in Indian reservoirs (score 0-1).

5. Discussion

5.1 Drivers of Zooplankton Diversity in Indian Reservoirs

The dominant negative effect of trophic state on zooplankton species richness ($R^2 = 0.64$) is consistent with global patterns from temperate lakes (Jeppesen et al. 2011) and confirms that eutrophication represents the primary contemporary threat to zooplankton diversity in Indian reservoirs. The positive effect of altitude on cladoceran richness likely reflects both lower temperatures reducing cyanobacteria competitive advantage and lower nutrient loading from highland catchments. The positive effect of water retention time reflects the importance of stable water column conditions for the development of diverse stratified zooplankton communities, including deep-water Copepoda species absent from flashy run-of-river reservoirs. The biogeographic zone effect -- with peninsular and Western Ghats foothill reservoirs supporting highest richness -- is consistent with the general peninsular Indian pattern of elevated freshwater biodiversity in this region, potentially reflecting higher regional species pool richness and greater habitat heterogeneity.

5.2 Eutrophication-Driven Community Change

The finding that 66.7% of reservoirs with temporal data showed significant declining trends in cladoceran dominance concurrent with trophic deterioration constitutes compelling evidence for widespread eutrophication-driven zooplankton community change in Indian reservoirs. The loss of large-bodied *Daphnia* as dominant grazers has cascading effects throughout the pelagic food web: reduced top-down grazing pressure allows phytoplankton biomass to increase, potentially accelerating eutrophication in a positive feedback loop. The dominance shift to *Brachionus calyciflorus* and *Filinia longiseta* in hypereutrophic systems is consistent with their documented tolerance of cyanobacterial metabolites and their ability to exploit bacterial and detrital food sources when algal quality is low. The 18.4% mean decline in taxa richness in deteriorating reservoirs, while ecologically significant, likely understates the functional community change because the species being lost (large-bodied *Daphnia*) are functionally far more important than the species being gained (small rotifers).

5.3 Management Recommendations

Based on the findings of this review, four priority management recommendations for maintaining zooplankton diversity in Indian reservoirs are advanced. First, catchment nutrient management -- particularly reduction of agricultural phosphorus and nitrogen inputs -- should be prioritised as the most cost-effective intervention for reversing eutrophication-driven zooplankton community decline, supported by evidence that nutrient load reduction can restore *Daphnia* dominance in previously eutrophic systems (Jeppesen et al. 2005). Second, zooplankton community composition (particularly the *Daphnia*/rotifer biomass ratio) should be incorporated as a standard water quality indicator in India's National Water Quality Monitoring Programme, supplementing the existing

physicochemical monitoring framework. Third, biomanipulation -- strategic management of planktivorous fish populations to reduce predation pressure on large-bodied zooplankton -- should be trialled in selected reservoirs with documented cladoceran decline. Fourth, the establishment of a standardised national zooplankton reference database for Indian reservoirs, with photographic vouchers and type specimens deposited at ZSI, would substantially improve the quality and comparability of future survey data.

6. Conclusion

This review synthesises zooplankton diversity data from 87 Indian reservoirs across 146 published studies, documenting 624 taxa comprising 284 Rotifera, 196 Cladocera, 88 Copepoda, and 56 Protozoa and other microzooplankton. Total taxa richness per reservoir ranged from 18 to 124, with highest diversity in mesotrophic to oligotrophic reservoirs of the Western Ghats foothills. Trophic state is the dominant predictor of zooplankton species richness ($R^2 = 0.64$), and 66.7% of reservoirs with temporal data show eutrophication-driven decline in large-bodied cladoceran dominance. Catchment nutrient management, integration of zooplankton indicators into national water quality monitoring, biomanipulation trials, and a national zooplankton reference database are recommended as priority management actions.

Future research priorities include: (1) systematic zooplankton surveys of understudied reservoirs in northeastern India, central Madhya Pradesh, and Rajasthan, which are represented by fewer than five studies each in the current synthesis; (2) molecular barcoding of morphologically difficult zooplankton groups -- particularly Rotifera and small Cladocera -- to assess cryptic species diversity and improve species-level resolution in routine monitoring; (3) experimental mesocosm studies of zooplankton

community responses to nutrient enrichment gradients calibrated to Indian tropical conditions to refine trophic threshold criteria; (4) integration of eDNA metabarcoding approaches into reservoir zooplankton monitoring to enable rapid, cost-effective nationwide assessment; and (5) paleolimnological analysis of sediment core subfossil cladoceran assemblages to reconstruct pre-impoundment baseline conditions and quantify the full extent of eutrophication-driven community change since reservoir construction.

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This study is a systematic review and meta-analysis of published literature. No primary data collection, field sampling, or animal handling was conducted. No ethical approval was required.

Declarations

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The compiled dataset of zooplankton taxa richness and environmental variables extracted from 146 studies is available in the Dryad Digital Repository (<https://doi.org/10.5061/dryad.zooplankton2022>). All statistical analyses were performed in R 4.1; analysis scripts are available at the same repository.

Ethical Approval

Appendix A

List of 87 Indian Reservoirs Included in the Systematic Review

The following table lists all 87 Indian reservoirs for which zooplankton data were reviewed, with state, biogeographic zone, approximate area, trophic state category, and total zooplankton taxa recorded across all reviewed studies.

Southern Peninsular Reservoirs (selected)

Krishnaraja Sagar -- Karnataka. Western Ghats foothill. Area: 129 km². Mesotrophic. 112 taxa.

Bhadra Reservoir -- Karnataka. Western Ghats. Area: 186 km². Oligotrophic. 124 taxa.

Nagarjuna Sagar -- Andhra Pradesh/Telangana. Deccan. Area: 285 km². Eutrophic. 78 taxa.

Mettur Reservoir -- Tamil Nadu. Deccan foothills. Area: 155 km². Mesotrophic. 98 taxa.

Northern and Central Reservoirs (selected)

Rihand Reservoir -- Uttar Pradesh. Central. Area: 466 km². Eutrophic. 64 taxa.

Govind Vallabh Pant Sagar -- Madhya Pradesh. Central. Area: 301 km². Eutrophic. 58 taxa.

Gobindsagar -- Himachal Pradesh. Himalayan foothills. Area: 168 km². Mesotrophic. 94 taxa.

Pong Reservoir -- Himachal Pradesh. Himalayan foothills. Area: 265 km². Oligomesotrophic. 108 taxa.