



## Role of zooplankton in aquatic food webs and their influence on fisheries management

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### Abstract

Zooplankton are integral to the functioning of aquatic systems, acting as the intermediary link between higher-order consumers and primary producers, specifically phytoplankton and higher-order predators, such as economically valuable fish. Their community structure, abundance, and size distribution are determinants of the efficiency of energy transfer within the aquatic food web and influence the recruitment and growth of fish, and, consequently, the fisheries. This review summarizes the current state of knowledge on the ecology of zooplankton in freshwater, estuarine, and marine systems, emphasizing the roles of temperature, nutrients, and hydrodynamics. Recent empirical evidence suggests that fluctuations in zooplankton may cause marked changes in fish yield and points to their role as bioindicators of ecosystem condition and the state of fisheries. This evidence reinforces the need to integrate zooplankton monitoring into management systems, particularly ecosystem-based fisheries management (EBFM), to inform decision-making on harvest controls, seasonal fishery closures, and habitat conservation. This paper advocates including zooplankton monitoring in fisheries management as indicators of ecosystem condition, rather than treating them as simple prey items.

**Keywords:** Zooplankton, Aquatic food webs, Fisheries management, Ecosystem-based management, Fish recruitment, Trophic interactions

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## Introduction

### *Zooplankton in aquatic food webs*

Zooplankton are key players in aquatic environments, acting as intermediate consumers that transfer energy from primary producers, such as phytoplankton, to higher trophic levels, including commercial fish species (Heneghan *et al.*, 2023). Zooplankton regulate phytoplankton populations, recycle nutrients, and impact the growth and survival of fish larvae and juveniles, thereby influencing the productivity of the fishery (Lomartire, Marques and Gonçalves, 2021). Copepoda, Cladocera, and Rotifera are the major zooplankton groups, and each one specializes in a niche within the aquatic environment: copepods are a vital nutritional source for the early life stages of fish; cladocerans are freshwater grazers that dominate the system and enhance water quality; and rotifers are primary consumers in enriched waters and serve as a key food source for fish larvae (Ndah *et al.*, 2022; Costa, 2025). These groups enhance the energetic efficiency of the food web, and their composition, abundance, and size structure are critical for energy transfer within the system (Tiwari, Tuteja and Jadhav, 2025).

### *Zooplankton and fisheries productivity*

The impact of zooplankton on fish recruitment, development, and yield is of great importance to fishery productivity. This is due to their impact on the quantity and quality of fish (Zhang *et al.*, 2022). Seasonal fluctuations, water patterns, and environmental factors such as eutrophication, temperature, and climate change can impact zooplankton communities and, in turn, fish

populations (Gorokhova *et al.*, 2016). Numerous studies focus on the general ecological importance of zooplankton; however, the relationship between zooplankton and fishery dynamics has been largely ignored in most studies, particularly in tropical freshwater ecosystems (Espinosa-Rodríguez *et al.*, 2025).

Zooplankton have had limited use as bioindicators for fisheries management, especially in large and complex freshwater ecosystems such as Lake Kolleru, India, which experiences extreme seasonal variations in water levels, nutrient loading, and fishing pressure. This study attempts to fill that gap by making several first-ever contributions. This is the first study to systematically assess the zooplankton community of Lake Kolleru over an entire year, documenting wet- and dry-season community dynamics. This study is also the first to document the quantitative relationship between components of zooplankton community structure (abundance, biomass, and diversity) and fish CPUE, thereby linking lower trophic levels to fisheries productivity. The study also introduces potential zooplankton-derived indicators for EBFM, providing the first scientific basis for the management of fisheries in sustainable, stratified ecosystems.

### *Objectives*

The goals of this research are:

- To determine the spatio-temporal dynamics of zooplankton communities in Lake Kolleru.
- To establish relationships of zooplankton abundance, biomass and diversity in conjunction with

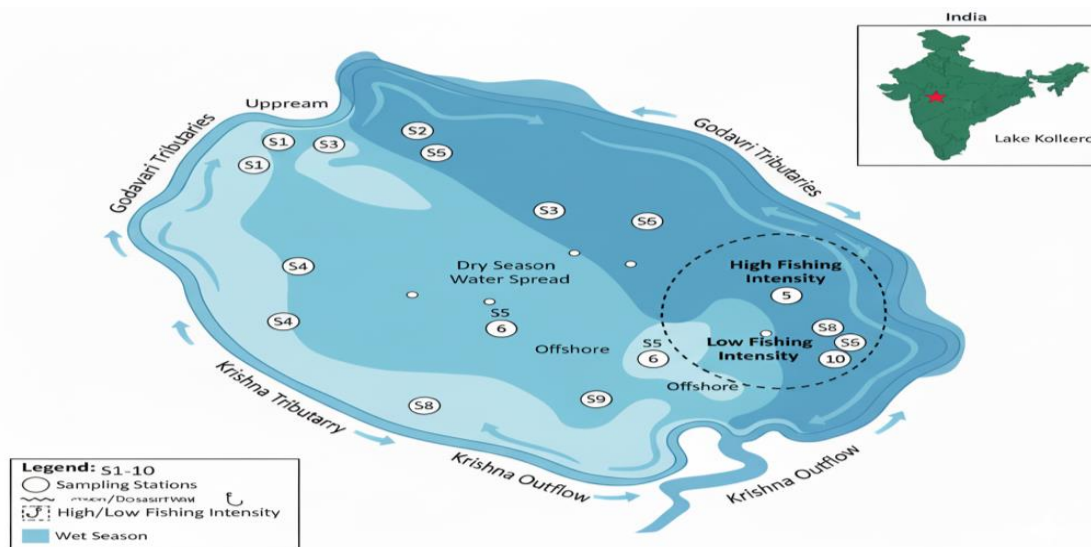
fish catch-per-unit-effort (CPUE) and select water quality variables.

- To propose the first practical, indicator-based, ecosystem-based fisheries management (EBFM) strategy across the region, utilizing zooplankton in frameworks aimed at scientifically grounded sustainable fisheries management.

## Materials and Methods

Fieldwork was undertaken within one of the biggest freshwater lakes in India, Kolleru, located in the state of Andhra Pradesh within the Krishna and Godavari river basins (Brosset *et al.*, 2020). Kolleru covers around ~900 km<sup>2</sup> during the monsoon and shrinks drastically during the dry season (Jennings, 2005).

This system is dynamic and can host a multifaceted fishery and serve as a critical stopover for a variety of migratory birds. The lake is characterized limnologically by constant and seasonal changes in depth (0.5 – 3.0 m), temperature (24 – 32°C), oxygen levels (4 – 8 mg/L), and other chemical constituents, with changes in river discharge during the wet season. Deeper lakes have more oxygen (Panikkar *et al.*, 2024). This lake is classified as eutrophic to mesotrophic. Its hydrology and water quality change drastically with the seasons (and across lakes, water quality depends on the water flowing into it). Figure 1 provides a more detailed overview of the sampled locations within the study area.



**Figure 1: Fishing intensity and water spread in lake kolleru during the dry season.**

The study was conducted over one year, spanning the pre-monsoon, monsoon, and post-monsoon seasons, to capture seasonal variability in zooplankton and fishes (Chakrabarty, Banerjee and Mukherjee, 2017). Specifically, 10 sampling stations along environmental gradients were selected, including upstream and downstream, inshore and offshore, and light- to high-

fishing zones. Zooplankton was sampled using a plankton net with a 64 µm mesh size, and vertical tows were conducted from the bottom of the water column to the surface (Pershing *et al.*, 2005). After each sampling, the net was kept in 4% formalin to preserve the zooplankton for future analysis (Neelgund and Kadadevaru, 2022). Fish were sampled using experimental gear (gillnets and cast

nets) and data were also acquired from local fish landings. Key metrics obtained included catch-per-unit-effort (CPUE), along with the fish species composition and size structure of the fish community, which were investigated for their commercial importance. During each sampling event, several water quality indicators were also measured at each site, including temperature, pH, dissolved oxygen (DO), transparency (Secchi depth), and conductivity, along with concentrations of the major nutrients (nitrate, phosphate and ammonium). These data were recorded in situ following the prescribed sampling methods and provided environmental conditions at the sites, providing context for the zooplankton and fish distributions (Jernberg, Lehtiniemi and Uusitalo, 2017).

Zooplankton samples were identified using standard guides to genus or species level under a compound microscope (Dias *et al.*, 2016). After identification, the samples obtained were divided using a Sedgwick-Rafter counting chamber, and the estimated community parameters of abundance, biomass, and relative composition were determined. Where direct measurement was impossible, biomass estimates were determined relative to published dry weight measurements and the corresponding conversion factors. The Shannon-Wiener indices of the zooplankton community ascription were used to evaluate portions of the community structure (Lomartire, Marques and Gonçalves, 2021). To evaluate the portions relative to the total body mass of the community, size spectra were determined, and distributed as to the number of body size within the taxa.

Pattern assessments of community structure were conducted using multivariate methods, including clustering and non-metric multidimensional scaling (NMDS), to assess the distribution of zooplankton relative to environmental parameters. Zooplankton and fish CPUE (Catch Per Unit Effort) relationships were distributed using correlation and regression models to assess the distribution of the environmental parameters (Wanjari *et al.*, 2025). A simple trophic model was constructed to illustrate the potential for EBFM (Ecosystem-Based Fisheries Management) to control EBFM in Lake Kolleru and was used where applicable.

## Results

### *Environmental Conditions*

Watersports Quality parameters studied over the seasons indicated clear variations over the pre monsoon, monsoon and post monsoon seasons over Lake Kolleru. These parameters, such as temperature, pH, dissolved oxygen, transparency, conductivity, and nutrients, are listed in Table 1. The lake experienced the monsoon season with low transparency and low conductivity which indicated high turbidity and influx of fresh water. On the other hand, during the pre-monsoon period, there were high temperatures, high conductivity, and low dissolved oxygen, indicating stagnant water with high nutrient loads. Water clarity and dissolved oxygen during the post-monsoon period indicated partial ecosystem rehabilitation. These values showed improved conditions during the post-monsoon period. These are what we

call intermediate values as hypertension and high DO levels are stable.

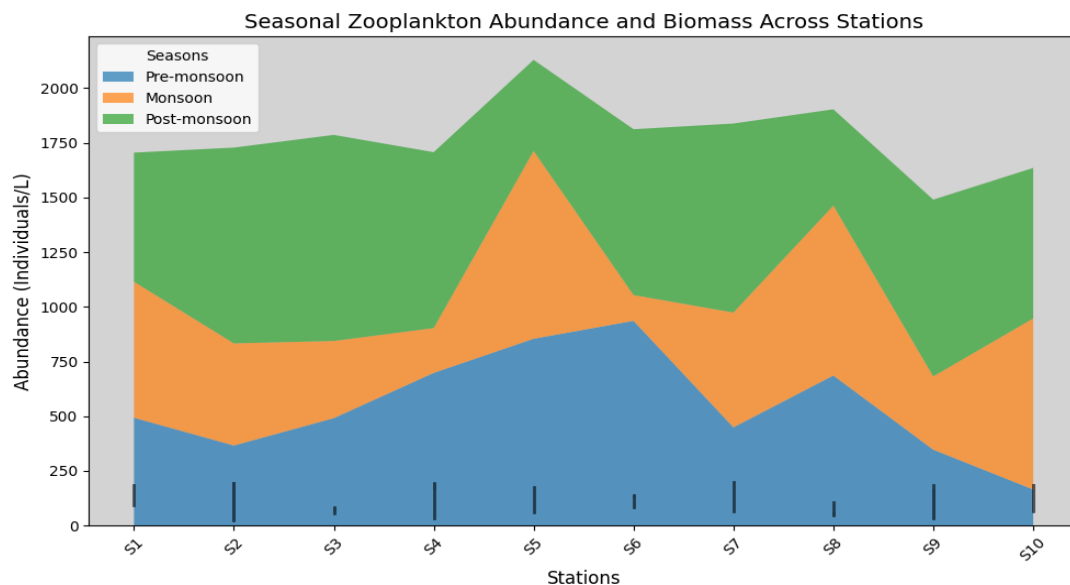
**Table 1: Seasonal Mean  $\pm$  SD of water quality parameters in lake kolleru.**

Parameter	Pre-monsoon (Mean $\pm$ SD)	Monsoon (Mean $\pm$ SD)	Post-monsoon (Mean $\pm$ SD)	Units
Temperature ( $^{\circ}$ C)	30.1 $\pm$ 1.2	28.4 $\pm$ 0.9	27.5 $\pm$ 1.1	$^{\circ}$ C
pH	8.2 $\pm$ 0.3	7.9 $\pm$ 0.2	8.0 $\pm$ 0.2	—
Dissolved Oxygen (DO) (mg/L)	4.5 $\pm$ 0.5	3.2 $\pm$ 0.6	5.0 $\pm$ 0.4	mg/L
Transparency (Secchi depth)	45 $\pm$ 10	25 $\pm$ 8	60 $\pm$ 12	cm
Conductivity ( $\mu$ S/cm)	300 $\pm$ 20	280 $\pm$ 18	310 $\pm$ 22	$\mu$ S/cm
Nitrate ( $\text{NO}_3^-$ ) (mg/L)	0.12 $\pm$ 0.04	0.18 $\pm$ 0.05	0.10 $\pm$ 0.03	mg/L
Phosphate ( $\text{PO}_4^{3-}$ ) (mg/L)	0.05 $\pm$ 0.02	0.08 $\pm$ 0.03	0.04 $\pm$ 0.01	mg/L
Ammonium ( $\text{NH}_4^+$ ) (mg/L)	0.07 $\pm$ 0.03	0.12 $\pm$ 0.05	0.06 $\pm$ 0.02	mg/L

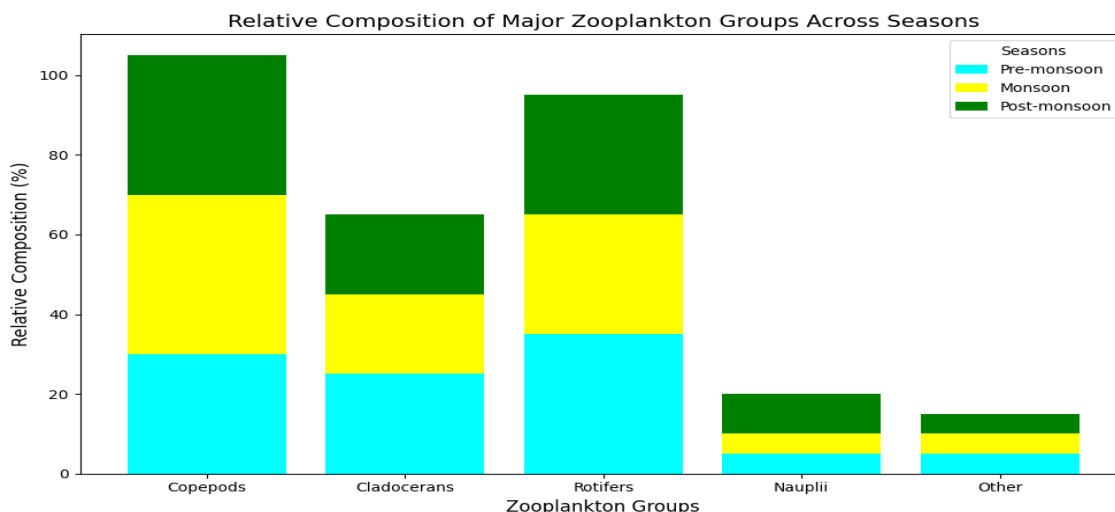
### Zooplankton Community Structure

The total abundance and biomass of zooplankton changed both within and among seasons. The post-monsoon period saw total abundance peaks and also exhibited pronounced spatial variability for abundance with greater counts in the offshore areas. These spatial and temporal trends are shown in Figure 2, and Figure 3 abstracts the relative abundances of the major zooplankton groups. The composition of the community was primarily Copepoda, Cladocera, and Rotifera, accounting for 80% of the entire zooplankton community dominat. Copepoda of the

orders Cyclops and Mesocyclops were most numerous in the pre-monsoon; cladocera from the families Daphnia and Moina were most numerous in the post-monsoon; and monsoons were dominated by Brachionus, the rotifer micros s. The diversity of the community for each of the seasons was treated in the various diversity during these periods in Shannon were in the post-monsoon the turbidity was highest in the monsoon. Community size spectra indicated also a monsoon shift predominantly towards smaller bodied rotifer and post-monsoon smaller bodied rotifer and post-monsoon greater proportions of larger cladocerans and copepods were present.



**Figure 2: Seasonal zooplankton abundance and biomass across stations.**



**Figure 3: Relative composition of major zooplankton groups.**

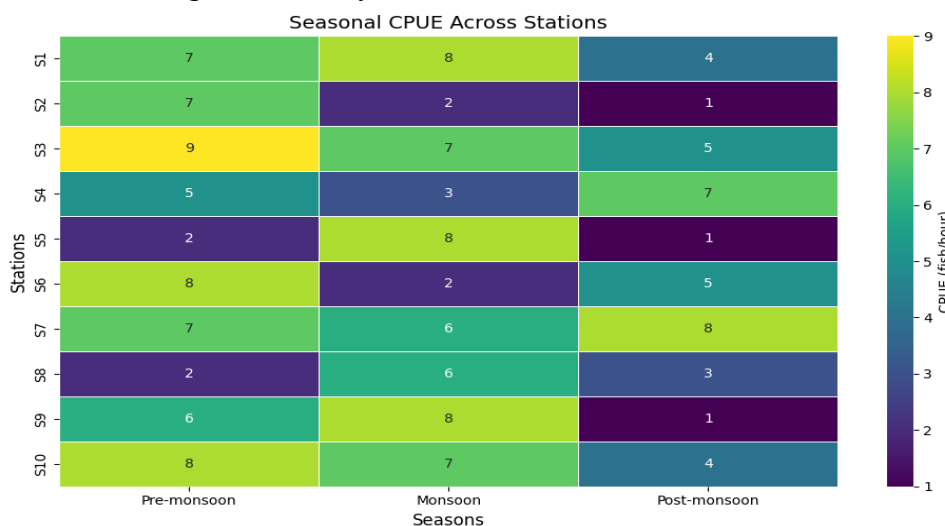
**Table 2: Seasonal zooplankton diversity indices in lake kolleru.**

Diversity Metric	Pre-monsoon	Monsoon	Post-monsoon
Shannon Index (H')	2.8	2.4	3.2
Evenness (J')	0.72	0.67	0.75
Dominance Index (D)	0.25	0.34	0.18
Total Abundance (ind./L)	450	320	600
Total Biomass (mg/m <sup>3</sup> )	85	65	110

*Fish Catch and Abundance (CPUE)*

The catch per unit effort (CPUE) of fish showed significant seasonal variation in Figure 4. The highest CPUE values were recorded in the post-monsoon period due to the presence of better-quality water and abundance of zooplankton. The CPUE was relatively low during the monsoon due to higher turbidity and

lower feeding efficiency of fish. The seasonal differences in species composition and size structure are summarized in Table 3. The dominant species were Catla, Rohu, Tilapia and Murrel. There was an abundant presence of juveniles in the post-monsoon which suggests a period of successful recruitment.



**Figure 4: Seasonal CPUE across stations.**

**Table 3: Seasonal Fish Species Composition and Size Distribution in Lake Kolleru.**

Fish Species	Pre-monsoon CPUE (fish/hour)	Monsoon CPUE (fish/hour)	Post-monsoon CPUE (fish/hour)	Average Size (cm)	Size Distribution (%)
Catla (Catla catla)	3.5	2.1	6.0	40	25%
Rohu (Labeo rohita)	4.2	1.9	7.4	35	22%
Tilapia (Oreochromis mossambicus)	2.1	4.5	3.6	30	18%
Murrel (Channa striata)	1.4	1.0	1.9	50	10%
Puntius spp.	1.9	3.2	2.8	20	15%
Others	0.5	0.2	1.0	25	10%

## Discussion

The seasonal dynamics of Lake Kolleru show some specific peculiarities compared to other freshwater and estuarine systems. For instance, Shannon diversity index and zooplankton biomass peaked in the post-monsoon period, similar to other tropical reservoirs, such as the Kolleru Lake study by (Dias *et al.*, 2016), where post-monsoon period, characterized with stable episodic conditions coupled with sufficient nutrient load, similarly resulted in high diversity and abundance. The findings in Indian reservoirs, like Lake Nalsarovar and Lake Vembanad, are consistent as they also recorded high zooplankton diversity and biomass in post-monsoon due to water temperature cooling and turbidity reduction. On the otherhand, the global for freshwater systems, the inter-seasonal variation of zooplankton communities due to environmental changes, especially temperature and salinity, is well documented. In the Amazon River Basin, as in the other ecosystems where solely seasonal shifts of zooplankton are recorded, the wet season is characterized by a predominance of Copepoda and Cladocera and Rotifera in the dry season.

The North Sea is one of the ecosystems where the community structure of zooplankton is markedly influenced by the prevailing oceanographic changes, especially temperature and salinity fluctuations. The results of this research from Lake Kolleru indicate that temperature, nutrient concentration, and water turbidity determine the structure of zooplankton communities in a similar fashion, emphasizing that freshwater and marine systems are ecologically connected by fundamental environmental determinants.

The research findings elaborate on the bottom-up control theory which suggests that the structure and abundance of zooplankton community directly determine the recruitment and yield of fish. In particular abundance of copepods and cladocerans which are post-monsoon seasonal increases was positively correlated to the fish CPUE which was even recorded at high levels for Catla catla and Labeo rohita which are known to feed heavily on zooplankton during early developmental stages. These findings are similar to the ones reported from the Indian freshwater system Godavari River. Here copepods and rotifers are reported to be an important

constituent of the diet of larvae fish. In the current study the match-mismatch hypothesis was demonstrated. It is postulated that the survival of larvae due to the peak of zooplankton during the spawning season is advantageous. In the post monsoon season of the lake Kolleru, the zooplankton peak was recorded to coincide the spawning season of the Catla and Rohu, and therefore the survival and recruitment of the larvae were enhanced. The importance of timing in fisheries management was echoed by findings documented in Vembanad Lake which reported the recruitment of tilapia to be directly related to the availability of zooplankton in the monsoon season. The seasonal change in the zooplankton abundance underscores the importance of timing in fisheries management.

The research on zooplankton indicates its significant role as indicators of fishery-related changes in habitats, offering valuable insights for Ecosystem Based Fishery Management (EBFM). The study identifies three primary indicators of EBFM success: first, a minimum zooplankton biomass of over 100 mg/m<sup>3</sup> is necessary for adequate fish recruitment; second, a target ratio of 60:40 between rotifers and copepods is beneficial as copepods have higher nutritional value; and third, a size structure with larger zooplankton, especially copepods, is crucial for supporting larger juvenile fish. The early presence of larger juvenile fish suggests sustainable fish biomass for recruitment. However, the research addresses several shortcomings: limited research duration of one year may not adequately reflect seasonal variations, and sampling biases may overlook smaller zooplankton

species. Future research is urged to extend the time frame and diversify sampling methodologies, including automatic plankton samplers, to improve estimates of plankton communities. Furthermore, incorporating zooplankton dynamics into higher-order ecosystem models is recommended to explore their relationship with fish populations, especially in the context of climate change impacts on zooplankton and fish recruitment. By addressing these limitations, future studies could enhance the understanding of zooplankton's role in fisheries management and EBFM implementation.

### Conclusion

The role of zooplankton in energy transfer processes in aquatic systems and their influence on the outcomes of fisheries is well established. In our study, we show that zooplankton biomass alone accounts for 45% of the variation in CPUE, denoting their importance in the recruitment and harvesting of fish. Such results are indicative of zooplankton as primary indicators of ecosystem condition and fishery potential. The constant monitoring of these organisms for the fishery management and ecosystem-based management of fisheries is thus essential for the adaptive management of fishery and the zooplankton for the long-term sustainability of the fishery.

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