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Investigating the Seasonal Dynamics of Zooplankton Abundance in Relation to Water Quality Parameters

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Abstract

Zooplankton communities play a vital role in aquatic ecosystems, serving as indicators of water quality and primary consumers in the food web. Environmental conditions and different nutrient concentrations affect their diversity and abundance. This research investigates the seasonal abundance of four major zooplankton groups including Protozoa, Rotifera, Cladocera, and Copepoda about key water quality parameters across six seasons: summer, spring, rainy, late autumn, autumn, and winter. Zooplankton samples were collected monthly over one year, and their abundance was analyzed alongside water temperature, pH, dissolved oxygen, transparency, and nutrient levels. The results show that the total zooplankton density ranged from 1,250 to 4,870 individuals/L, with the highest abundance observed in summer (4,870 ind./L) and the lowest in winter (1,250 ind./L). Protozoa dominated in the rainy season (42.3%), while Rotifera had the highest percentage in summer (38.6%). Cladocera showed peak abundance in autumn (22.5%), whereas Copepoda was most abundant in late autumn (19.2%). Higher temperatures and nutrient levels in summer coincided with increase in zooplankton abundance, whereas colder temperatures in winter led to a decline in population density. The findings highlight the zooplankton communities' dynamic nature and their relationship with environmental conditions, emphasizing the need for continuous monitoring to support freshwater ecosystem management.

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Introduction

Zooplankton is crucial to aquatic ecosystems as primary consumers, linking higher trophic levels, including fish and other aquatic species, to primary producers such as phytoplankton (Shi et al., 2020). As primary consumers, Zooplankton regulates the populations of phytoplankton by grazing, thereby preventing algal blooms and maintaining ecological balance. Zooplankton also plays a role in nutrient cycling as it recycles organic substances through feeding and excretion, thereby influencing the total productivity of freshwater systems (Butts et al., 2022). Zooplanktons are very sensitive to the influences of their environment and react to changes in water chemistry, temperature, and other hydrographic parameters in very obvious ways (Ndah et al., 2022; Karimov et al., 2024). Investigating the relationship among zooplankton abundance and parameters of water quality provides essential information on ecosystem health, stability, and food webs, and it could be associated with environmental stressors (El-Metwally et al., 2022).

The abundance and diversity of zooplankton are affected by various biotic and abiotic factors, and water quality parameters have a significant role in influencing their population dynamics (Okan & Christian, 2024). The seasons exhibit temporal changes in temperature, dissolved oxygen, pH, turbidity, and nutrient concentrations, which affect zooplankton distribution and abundance. Indeed, zooplankton serves as good bioindicators of environmental changes (Bakhtiyar et al., 2020). Seasonal changes have a major effect on the abundance and composition of zooplankton. Temperature, nutrient availability, and hydrological conditions vary at seasons to affect reproductive cycles, growth rates, and community structure (Nwinyimagu et al., 2021). Plankton and standing crop production vary with the rainfall patterns that also affect salinity, nutrient loads, and flushing rates of water (Robles et al., 2015). Through the biological pump, zooplankton fixes carbon in the detection of climate change, but in return, it is also among the most vulnerable to its effects. All these factors and problems can cause some disturbance in their role in the carbon cycle such as altered food source and increased temperature. Observing the temporal change in the composition of zooplankton communities is important (Damotharan et al., 2024). Seasonal dynamics knowledge forms an essential basis for monitoring freshwater ecosystems as well as achieving sustainable water resources management (Yin et al., 2022; Gridnev et al., 2020).

Almeida et al., (2020) demonstrated how zooplankton populations would be utilized as an indicator to measure the quality of water in four Portuguese reservoirs. Investigations were conducted on seasonal patterns, phytoplankton communities, and physical and chemical characteristics, and the obtained results reflected the good ecological potential with sporadic declines caused by changes in total phosphorus and dissolved O2 levels (Rajalakshmi et al., 2024). The reaction of zooplankton communities to changes in water quality, trophic status, and water level suggest that the Water Framework Directive (WFD) measurements could not represent all the changes happening in the aquatic ecosystem.

Shi et al., (2020) assessed the composition of zooplankton communities in China's Yellow Sea between 2014 and 2018. Each of the three assemblages found was associated with fluctuations in seasonal temperatures. Group 2 comprised both tropical and low-temperature species, whereas Group 1 comprised moderate water column temperatures. Group 3 contained several jellyfish. Warmer temperatures in 2016–2017 led to increased zooplankton abundance. Physical changes and the organization of the zooplankton community itself attest to the regime shift in 2016–2017.

Nandy & Mandal, (2020) analyzed the community of zooplankton formation in the Indian Sundarbans estuary waters, and it was dominated by 56 species of planktonic copepods and few meroplankton groups. The highest abundance was observed during winter. Key environmental factors controlling spatiotemporal fluctuations in zooplankton abundance were temperature, salinity, dissolved oxygen, pH, and nutrients (Lahon & Chimpi, 2024). Long-term monitoring of ecologically fragile habitats and a rich variety of zooplankton in the estuary complex dominated by mangroves were emphasized.

Al et al., (2020) established the research of zooplankton communities in the northern Bay of Bengal, coastal waters of Bangladesh that stressed the fact that the distribution pattern of the species varied highly from season to season. The dominant taxa include copepods, amphipods, shrimps, Acetes, and mysids. A correlation between the ecological state of the water and the temporal fluctuation in species distribution and community structure was discovered. From the given results, patterns of zooplankton distribution could be used as bioindicators of the quality of marine water.

Yermolaeva et al., (2021) conducted research on zooplankton in the Ob River emphasizing that, temperature had a substantial impact on the species richness and abundance of cladocerans and rotifers. As pH drops, zooplankton abundance rises in response to phosphate and nitrate concentrations. Copepod populations were favorably correlated with dissolved oxygen and oxidizable organic compounds, whereas their development was inhibited by a rise in chemicals that were difficult to oxidize. As it was downstream from floodplain lakes, high water levels had a good impact on the river's zooplankton abundance.

Bișinicu et al., (2024) used semi-quantitative models to examine how environmental conditions affected planktonic species along the Black Sea coast of Romania. To examine the connection between phytoplankton, zooplankton, and environmental conditions, eleven years' worth of data were used and also to find developmental trends, variables such as phytoplankton species and marine reporting units were employed. Fewer components and connections in phytoplankton blooms with a higher number of species and growth-influencing elements were discovered.

Mutethya et al., (2024) examined the ecological community structure and water quality of urban rivers. The largest concentrations of heavy metals were found in summer and winter, whereas the lowest were found in spring. Rotifers and cladocerans were the most common filter feeders in each season. The results were essential for managing and monitoring the quality of the water.

Yousef et al., (2024) analyzed how environmental conditions were controlling the zooplankton diversity and density over the Nile River at Shattura Village. Samples of zooplankton were taken by choosing three localities having varied environmental features. The order followed Rotifera (54.73%), and after the order came Copepoda, with a difference of 13.1, followed by Cladocera at 20.59, and then Ostracoda was 8.9%. The abundance of zooplankton peaked during the summer months but reduced in winter. The Rotifera dominated the zooplankton community, which was greatly influenced by seasonal fluctuations. Transparency, pH, conductivity, biological oxygen demand (BOD), and dissolved oxygen were important influencing factors. Research on zooplankton communities often lacks a comprehensive analysis of their seasonal dynamics about multiple water quality parameters across different seasons.

Most research are limited to a particular zooplankton group or environmental factor, leaving out the interactions between factors such as pH, temperature, transparency, dissolved oxygen, and nutrients, which could have an impact on zooplankton abundance over a year. This research is intended to bridge this gap by looking at the seasonal abundance of four major zooplankton groups about key water quality parameters over one year to gain an enhanced understanding of their ecological dynamics.

Organization of the study: The next section outlines the materials and methods. Then the results section presents the findings of the research. Finally, the discussion and conclusion sections provide an interpretation of the results and summarize the key insights derived from the research.

Materials and Methods

This section describes the zooplankton sampling, identification of functional groups, and measurement of water quality parameters. Further, methods for data collection and preservation along with analytical techniques are explained in subsequent sections.

Sampling Collection and Preservation

Sampling collection: The fluctuation in the abundance of zooplankton with seasons was determined by monthly sampling over one year. Sampling was done at various intervals within the site to ensure an adequate sample for the community as a whole. A mesh size of $50\ \mu m$ plankton net was used, which filtered water from various depths to take into account vertical distribution patterns. Temperature, pH, and other water quality parameters were recorded at each sampling site during each collection period to correlate zooplankton abundance with environmental conditions.

Vertical Tow Method: The standard method of zooplankton sampling was the vertical tow. The complete fauna of zooplankton was taken from all the different layers of the water through the deployment of 50 µm mesh plankton net at surface, mid-water, and bottom depths. Then lower down the net to the target depth and slowly pull up for 2-3 minutes so as to get a representative sample of zooplankton. And check the net for clogging for avoid lose or distort the sample.

Preservation: Samples were conserved in a 4% formalin solution after collection to prevent decomposition and ensure the integrity of the zooplankton. After preservation, where zooplankton groups were identified, enumerated, and classified into genera. This method of preservation facilitated the accurate identification and classification of zooplankton and the preservation of their physical characteristics for further analysis.

Zooplankton Functional Group Identification and Counting

The functional groups of zooplankton are the morphological, behavioral, or phonological traits determining its ecological role and fitness within its habitat. Zooplankton has been classified based on criteria such as reproduction, feeding strategy, trophic level, and interaction with other species. The plankton cells have been counted in the Sedgwich-Rafter (S-R) cell in a binocular light microscope, which requires an experienced eye for species recognition. To identify the organisms, a series of pencil and ink drawings of the observed species were created on postcards. A dropper was used to extract 1 milliliter of concentrated plankton from each preserved sample for the quantitative analysis, which was then put in the S-R cell's counting chamber. Because the S-R cell is easily manipulable and yields reasonably repeatable data when used with a calibrated microscope, it was chosen for plankton counts. The dimensions of the Sedgwick-Rafter cell are roughly 50 mm by 20 mm by 1 mm. The bottom's overall volume is 1000 mm^3 or 1 ml, and its total area is roughly 1000 mm.

Four Major Zooplankton Groups

Four major groups of zooplankton were the focus of the research: Rotifera (differentiated by the mastax, foot, and corona), Cladocera (identified by body shape, carapace structure, and appendages), Copepoda (identified by cylindrical body and swimming appendages), and Protozoa (identified by body form, motility, and specialized structures like pseudopodia or cilia).

- ***Protozoa:*** As the primary consumers and decomposers in freshwater ecosystems, protozoa are single-celled creatures that are frequently found in aquatic settings. Different physical characteristics, including body form, motility, and the presence of specialized structures like pseudopodia or cilia, were used to identify protozoa. The samples frequently contained the taxa Euplotes, Vorticella, and Paramecium.

- ***Rotifera:*** Small, multicellular animals called rotifera are characterized by their ciliary, wheel-like structure, which they use for feeding and locomotion. Rotifera were differentiated in this research by their unique features, such as the mastax (jaws), foot, and corona. Many genera were identified, including Polyarthra, Keratella, and Brachionus.

- ***Cladocera:*** Water fleas, or cladocerans, are crustaceans that occupy a significant role in freshwater food webs. These organisms swim through their large antennas and bivalve carapace. The cladocera were differentiated from one another according to the form of their body, the pattern of their carapaces, and their appendages. Included among the genera found were Moina, Bosmina, and Daphnia.

- ***Copepoda:*** Most of the zooplankton system is formed of small crustaceans, such as copepods, that have distinctive swimming appendages and a cylindrical body with several parts. The common genera include Calanus, Diaptomus, and Cyclops.

Water Quality Parameters

- The environmental variables that were measured to understand how they affect zooplankton abundance are given in detail below. Figure 1 gives the list of parameters.

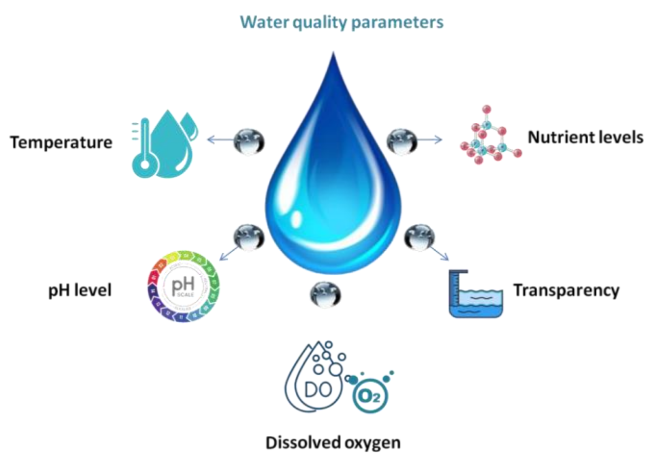


Figure 1. List of water quality parameters

- ***Water temperature:*** A digital thermometer was utilized to measure the temperature of water at each sampling location. During each sample event, temperature measurements were made at the top, mid-water, and close to the bottom to record any vertical variation that might have an impact on the distribution of zooplankton.

- ***pH:*** A portable pH meter was used to measure the water's pH to determine how acidic or alkaline it was. Since pH levels have a direct effect on zooplankton and other aquatic creatures' metabolic activities, pH are extremely important.

- ***Dissolved oxygen:*** A portable oxygen meter was used to measure the amount of dissolved oxygen. Aquatic species, including zooplankton, depend on oxygen to survive, and varying oxygen levels can influence the distribution and activity of zooplankton.

- ***Transparency:*** Transparency was measured using a Secchi disk. Since it is correlated with suspended particle matter and algae content, which in turn affects zooplankton abundance, this measure was utilized as an indicator of water clarity and overall productivity.

- ***Nutrient levels:*** The availability of important nutrients for primary production was gauged using nutrient concentrations measured by standard techniques, including nitrates, phosphates, and silicates. Zooplankton, as primary consumers, is directly affected by greater phytoplankton growth and development due to increased nitrogen.

Data Analysis

An analysis of variation in zooplankton abundance concerning seasons and it’s with environmental factors was conducted. Significant differences in zooplankton abundance between seasons were assessed using Tukey's post-hoc test and one-way ANOVA. The percentage composition of major zooplankton groups was calculated for each season, and patterns of dominance were evaluated. Statistical analyses were conducted using SPSS with a significance level set at $p < 0.05$.

Result

Table 1 presents the seasonal variation in the abundance of zooplankton, highlighting changes in the relative percentages of groups. The total zooplankton density ranged from 1,250 ind./L in winter to 4,870 ind./L in summer, indicating strong seasonal fluctuations. Protozoa were dominant during the rainy season (42.3%), whereas Rotifera exhibited peak abundance in summer (38.6%). Cladocera reached their highest proportion in autumn (22.5%), while Copepoda had a maximum presence in late autumn (19.2%). These variations suggest a close relationship between zooplankton composition and environmental conditions such as temperature, nutrient availability, and seasonal hydrological changes.

Table 1. Seasonal variation in zooplankton abundance (ind./L)

Season	Protozoa (%)	Rotifera (%)	Cladocera (%)	Copepoda (%)	Total Zooplankton (ind./L)
Spring	35.2	32.8	18.5	13.5	3,620
Summer	28.4	38.6	20.1	12.9	4,870
Rainy Season	42.3	30.2	15.4	12.1	3,980
Autumn	30.5	33.1	22.5	13.9	3,540
Late Autumn	29.7	31.8	19.3	19.2	2,730
Winter	27.1	34.5	20.8	17.6	1,250

Figure 2 compares the total abundance zooplanktons across various seasons. The seasonal variations in environmental variables and their possible influence on zooplankton abundance are reported in Table 2. Temperature showed significant seasonal variation ($p < 0.001$), peaking in summer (25.4 ± 1.8) and dropping to the lowest in winter (10.2 ± 1.0). Dissolved oxygen levels were significantly lower in winter (6.7 ± 1.2), which may have contributed to reduced zooplankton density. Nutrient levels were highest in summer (62.5

µg/L ± 9.0), coinciding with peak zooplankton abundance (4,870 ind./L ± 510) in summer. Transparency was also highest in summer (3.2 m ± 0.5) and lowest in winter (1.8 m ± 0.2), further supporting seasonal influences on zooplankton distribution. The p-values from ANOVA indicate significant differences ($p < 0.05$) in environmental parameters, suggesting that abiotic factors strongly regulate seasonal zooplankton dynamics. Figure 3 illustrates the mean and SD of environmental factors across different seasons, it shows (a) autumn, (b) spring, (c) winter, (d) late autumn. Also Figure 4 shows (a) summer, (b) rainy season.

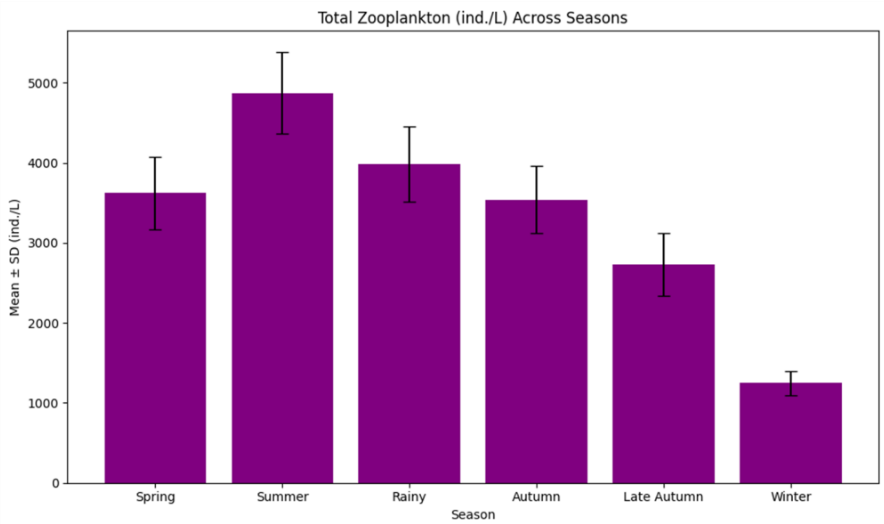


Figure 2. Abundance of zooplankton across various season

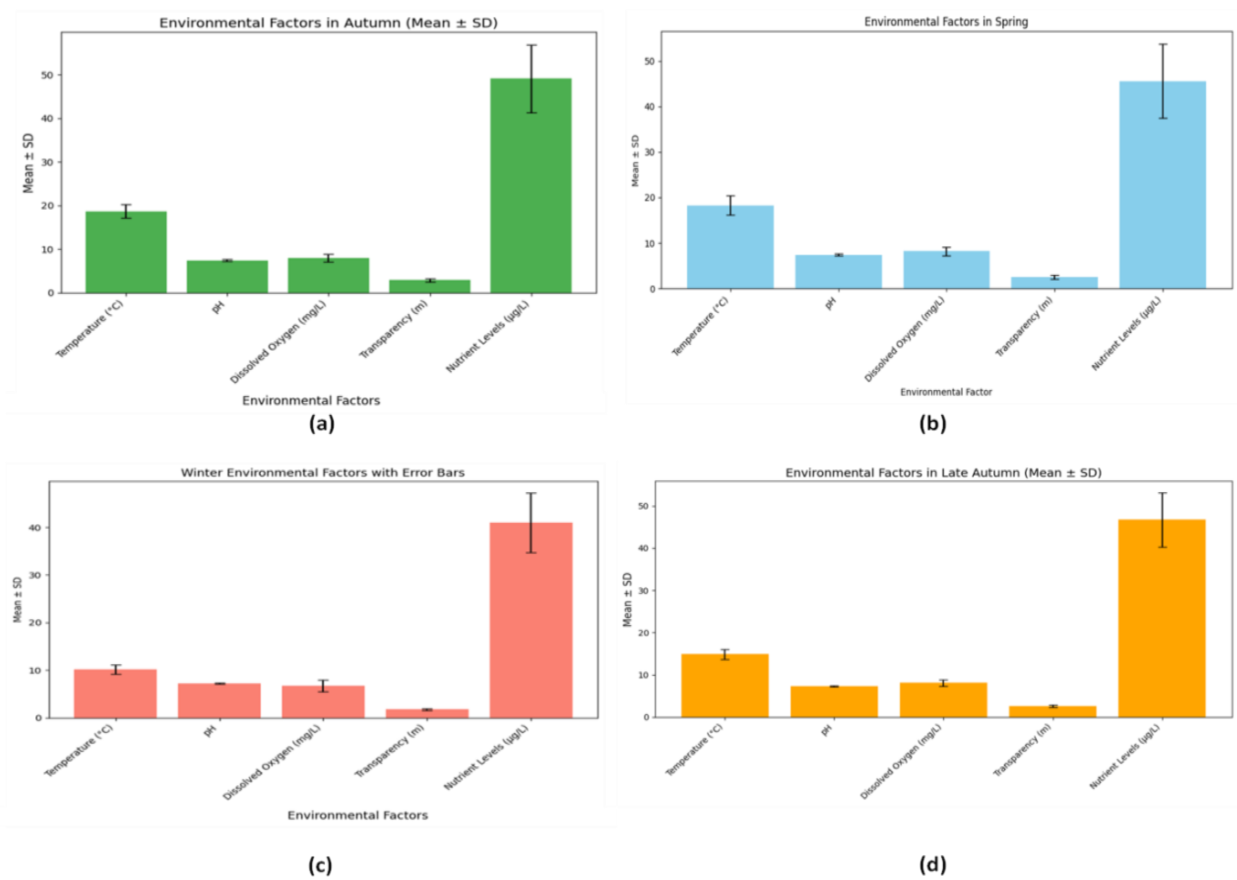
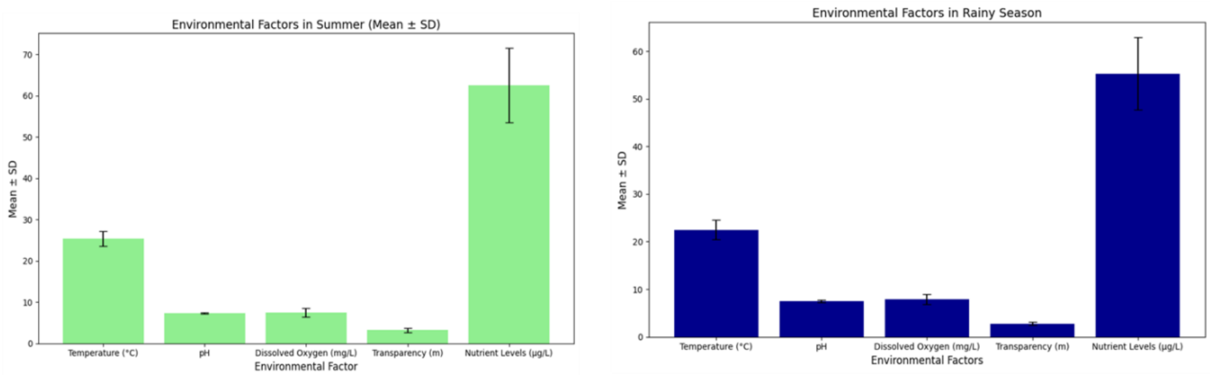


Figure 3. Comparison of environmental parameters in (a) autumn, (b) spring, (c) winter, (d) late autumn



(a) (b)

Figure 4. Comparison of environmental parameters in (a) summer, (b) rainy season

Table 2. Statistical comparison of environmental factors and zooplankton abundance across Seasons

Environmental Factor	Spring	Summer	Rainy	Autumn	Late Autumn	Winter	p-value*
	(Mean ± SD)						
Temperature (°C)	18.3 ± 2.1	25.4 ± 1.8	22.5 ± 2.0	18.7 ± 1.5	14.9 ± 1.2	10.2 ± 1.0	<0.001
pH	7.4 ± 0.2	7.3 ± 0.1	7.5 ± 0.2	7.4 ± 0.2	7.3 ± 0.1	7.2 ± 0.1	0.025
Dissolved Oxygen (mg/L)	8.2 ± 1.0	7.5 ± 1.1	7.9 ± 1.0	8.0 ± 0.9	8.1 ± 0.8	6.7 ± 1.2	0.035
Transparency (m)	2.5 ± 0.4	3.2 ± 0.5	2.8 ± 0.3	2.9 ± 0.4	2.6 ± 0.3	1.8 ± 0.2	<0.001
Nutrient Levels (µg/L)	45.6 ± 8.2	62.5 ± 9.0	55.3 ± 7.6	49.1 ± 7.8	46.7 ± 6.5	41.0 ± 6.3	0.010
Total Zooplankton (ind./L)	3,620 ± 450	4,870 ± 510	3,980 ± 470	3,540 ± 420	2,730 ± 390	1,250 ± 150	<0.001

Discussion

Seasonal dynamics in zooplankton abundance that are strongly related to fluctuations in environmental conditions including temperature, dissolved oxygen, pH, transparency, and nutrient levels have been demonstrated. The total zooplankton density varied from 1,250 individuals/L in winter to 4,870 during summer. The relative abundance of different zooplankton groups showed pronounced seasonal variations. Protozoa were mostly represented during the rainy season, while Rotifera was the most abundant during summer, Cladocera peaked in autumn, and Copepoda showed a marked increase in late autumn. This indicates that environmental conditions, especially temperature, and nutrient availability, are key factors in controlling the abundance of zooplankton. Higher temperatures combined with higher nutrient levels during summer, favor greater zooplankton density probably due to better primary production and food availability. Lower winter temperatures have been associated with decline in zooplankton. Seasonal fluctuations in zooplankton community composition, in which different sets of species were favored at various times of the year, demonstrate the complexity of ecological interactions within aquatic ecosystems. Another, more relevant characteristic of these ecosystems is that temperature, pH, and even transparency become important statistically to outline the dynamic association between zooplankton and their environment. Continuous monitoring of these parameters is vital for better understanding of the impacts of seasonal changes on freshwater ecosystems.

Conclusion

Seasonal fluctuations of zooplankton abundance and their relation to other important water quality indicators were provided. The total number of zooplankton densities determined was ranging from 1,250 individuals/L in the winter to 4,870 individuals/L in the summer. The zooplankton categories exhibited extreme seasonal variability, with Copepoda being the highest in late autumn (19.2%), Rotifera peaking in summer (38.6%), Cladocera in autumn (22.5%), and Protozoa dominating the rainy season (42.3%). The Environment, which involves pH, nutritional levels, and water temperature, is significant to the abundance of zooplankton. Lower abundance resulted from colder winter temperatures, but warmer summer temperatures and higher nutrient concentrations allowed the expansion of zooplankton populations. To evaluate the health of ecosystems and water quality, it is important to monitor zooplankton communities and environmental factors. Seasonal zooplankton composition variability highlights the importance of aquatic food webs and the crucial role such animals play in maintaining ecological balance. Generally, this research stresses the continuous monitoring of zooplankton density and the water quality indicator to support effective management and conservation measures for freshwater ecosystems.

Limitation and Future work: The primary limitation is the variability of the zooplankton population with factors such as predation and microbial interaction, which cannot be measured. These ecological factors should be considered in further research along with the long-term of zooplankton communities in various environments regarding how climate change will influence biodiversity and water quality. Secondly, the study should include all freshwater environments for a more generalized result.

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

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