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Assessment of phytoplankton and zooplankton communities in Chitgar Lake: Implications for water quality and biodiversity conservation

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ABSTRACT

This study investigates the abundance, diversity, and seasonality of phytoplankton and zooplankton in Chitgar Lake, Tehran. Over four sampling stations from 2014 to 2019, 69 genera across seven phyla of phytoplankton and 46 genera across ten phyla of zooplankton were identified. Bacillariophyta dominated the phytoplankton, while Rotatoria led the zooplankton community, indicating their crucial roles in the lake's food web. Seasonal patterns revealed significant peaks in phytoplankton during spring and in zooplankton during summer, with a notable decline in zooplankton populations during autumn. Statistical analyses demonstrated a balanced ecosystem characterized by moderate species diversity, as indicated by Shannon-Wiener and Margalef indices. Water quality assessments indicated a healthy environment, with mean dissolved oxygen levels of 8.21 mg/L and a pH of 7.94, suggesting suitable conditions for aquatic life. The absence of thermal stratification and moderate nutrient concentrations point to a relatively stable ecosystem, although caution regarding potential nutrient enrichment is warranted as it increases the risk of algal blooms. These findings emphasize the intricate interplay between biological communities and environmental factors in Chitgar Lake, providing essential insights for future ecological assessments and management strategies. Continuous monitoring is imperative to ensure the lake's biodiversity and health amidst potential ecological pressures, contributing to the sustainable management of this water body.

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1. Introduction

Lakes play a vital role in maintaining biodiversity and ecosystem services, yet they are increasingly threatened by human activities and environmental changes. One pressing issue is the decline in water quality, often caused by nutrient runoff, which can lead to eutrophication and harmful algal blooms. These phenomena not only disrupt the balance of aquatic ecosystems but also pose risks to aquatic life and human health. Understanding the dynamics between phytoplankton and zooplankton—key components of the aquatic food web—is essential for addressing these challenges and ensuring the resilience of lake ecosystems (Liu et al., 2010). Phytoplankton, the microscopic plants that drift in the water, serve as primary producers, harnessing sunlight to convert energy through photosynthesis. This foundational role supports a diverse range of organisms, including zooplankton, which are microscopic animals that graze on phytoplankton. By occupying a critical trophic level, zooplankton act as intermediaries, facilitating the transfer of energy from primary producers to higher trophic levels, including fish. Their feeding habits are pivotal in regulating phytoplankton populations and preventing excessive blooms that can lead to detrimental shifts in ecosystem health. However, the structuring and abundance of these communities are closely tied to lake water quality parameters.

Factors such as nutrient availability—especially phosphorus and nitrogen—significantly affect algal growth. Elevated nutrient levels can trigger harmful algal blooms, ultimately disrupting the entire aquatic ecosystem. Water clarity, pH, dissolved oxygen levels, and temperature fluctuations further influence the dynamics of phytoplankton and zooplankton communities. Understanding how these variables interact is crucial for predicting ecosystem responses to changes, addressing eutrophication, and developing effective conservation strategies (Sabater-Liesa et al., 2018; Mishra et al., 2019; Zhang et al., 2020; Baker et al., 2020; Kovalenko et al., 2023).
Moreover, trophic cascades—where changes at higher trophic levels significantly impact lower levels—can profoundly affect phytoplankton and zooplankton populations. For instance, the decline of top predators may lead to increased small fish populations, which further consume more zooplankton, resulting in higher phytoplankton levels (Liu et al., 2024). This intricate web of interactions reinforces the need for long-term monitoring of phytoplankton and zooplankton communities to detect shifts and identify early warning signs of ecosystem imbalance. This study aims to explore the abundance, diversity, and seasonality of phytoplankton and zooplankton in Chitgar Lake—a fully artificial recreational lake in Tehran. By assessing water quality parameters and their relationship with these communities, we hope to contribute valuable insights for better managing and conserving this vital ecosystem.

2. Material and methods

2.1. Study area, sampling and analyzing

The description of Chitgar Lake highlights its unique location in northwest Tehran, surrounded by urban infrastructure and a planted forest. This shallow lake, averaging 3.5 meters in depth and covering an area of 132 hectares, features a maximum depth of 9.5 meters in the southern overflow region, including three islands. To prevent water loss, the lake bed is lined with membrane and textile layers. With a volume of 6,900,000 m^3 at an elevation of 1267.5 meters above sea level, the lake's capacity decreases to around 5,200,000 m^3 by the end of the dry season. As the Kan River supplies fresh water to the lake during the winter through diversion, the water depth experiences annual fluctuations due to evaporation and filling processes. Water quality monitoring in Chitgar Lake commenced at four stations in May 2013, as detailed by Bayat et al., 2019. In this study, phytoplankton and zooplankton samples were collected at four stations as shown in Fig. 1 from 2014 to 2019. The sampling methodology involved the use of a plankton net with a mesh size suitable for capturing zooplankton species present in the water column. At each station, the net was submerged to the lake bed to ensure representative sampling of the zooplankton community. Once the samples were collected, they were preserved using appropriate preservation methods (formalin solution) to maintain the integrity of the plankton organisms. Subsequently, the samples were analyzed in the lab using microscopy techniques to identify and quantify the phytoplankton and zooplankton species present in each sample. The data obtained from these analyses were then used to assess the biodiversity, abundance, and distribution of phytoplankton and zooplankton communities across the study area. This information is vital for understanding ecosystem dynamics and assessing the health of aquatic environments.

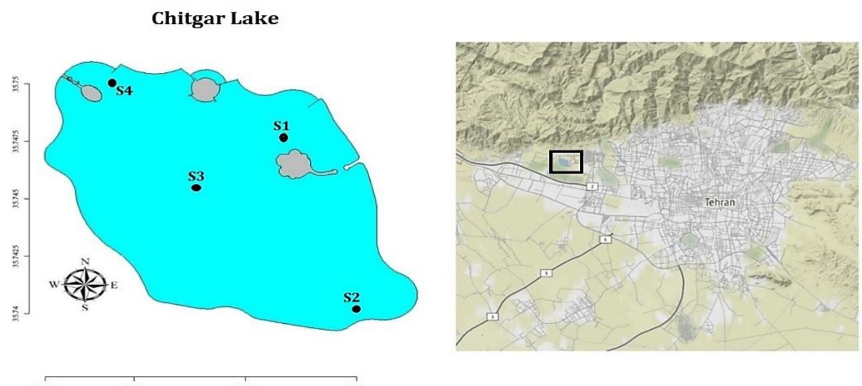

Fig. 1. The Chitgar Lake inside Tehran city and the monitoring stations.

2.2. Data analysis

To assess data, the mean, median, standard deviation, and range of both groups were calculated. Additionally, using biodiversity indices like Shannon–Weiner diversity index (H'), Margalef species richness index (D) and Peilou evenness index (J) can provide insight into the diversity and evenness of species within the community. The Shannon-Weiner Diversity Index is a measure of biodiversity that takes into account both species richness and evenness in a community. It provides a single value that represents the diversity of species present in a particular environment. The Margalef Species Richness Index is a measure used to quantify the number of different species present in a community or ecosystem. It focuses on species richness without considering the abundance or evenness of these species. The Pielou Evenness Index is a measure of how evenly individuals are distributed among different species in a community. It provides an indication of the balance or uniformity of species abundances. The formulas are as follows (Eqs 1 to 3):

$$H' = -\Sigma(Pi * \ln(Pi)) \qquad (1)$$

where *Pi* is the proportion of individuals in the i^{th} species and *ln* is the natural logarithm. The higher the value of *H'*, the greater the diversity of species in the community.

$$D = (S - 1) / \ln(N) \qquad (2)$$

where *S* is the total number of species in the sample and *N* is the total number of individuals in the sample. A higher value of *D* indicates greater species richness in the community.

$$J = H' / \ln(S) \qquad (3)$$

where *H'* is the Shannon-Weiner Diversity Index and *S* is the total number of species in the community. The index ranges from 0 to 1, with 1 representing perfect evenness where each species has equal abundance.

3. Results and discussion

A total of 69 genuss and 7 phyla of phytoplankton and 46 genus and 10 phyla of zooplankton were found in all samples from Chitgar Lake. The Bacillariophyta group exhibited the highest number of taxa, comprising 27 genera, followed by Chlorophyta with 20 genera and Cyanophyta with 10 genera in the phytoplankton category. In terms of zooplankton, Rotatoria led with 22 genera, followed by Arthropoda with 9 genera. Fig. 2 presents the abundance of various phyla of the two distinct groups over the years from 2014 to 2018, showcasing seasonal variations. In zooplankton, the abundance of Annelida, Ciliophora, and Rotatoria showed significant peaks during the summer months of 2015 and 2017, indicating favorable conditions for growth during warmer seasons. Conversely, in phytoplankton trends, with Bacillariophyta peaking in the spring of 2016, while Chlorophyta experienced significant growth in the autumn of 2018. The phytoplankton and zooplankton communities displayed distinct seasonal patterns and spatial variations across four sampling stations (S1-S4) throughout the four seasons (Figs 3 and 4). Regarding phytoplankton, the highest abundance was recorded during spring at station S2, with Bacillariophyta dominating, while the lowest abundance occurred in fall at station S4. In contrast, the zooplankton community showed a significant absence in fall, indicating an unsuitable environment for their survival during this season. The dominance of Bacillariophyta across all seasons suggests their resilience and adaptability to the lake's diverse environmental conditions. Similarly, the prevalent Cladocera and Rotatoria in the zooplankton community, except in autumn, highlight their adaptability and crucial roles in the lake's food web. The variations in abundance across seasons for both phytoplankton and zooplankton underscore the influence of seasonal factors such as temperature, sunlight, and nutrient availability on their populations. The higher abundance in spring can be attributed to favorable conditions, while the decline in summer may be linked to increased competition and elevated water temperatures. Naselli-Flores and Barone (2000) report similar findings regarding seasonal variation of phytoplankton in man-made lakes, noting that phytoplankton populations were highest in summer.

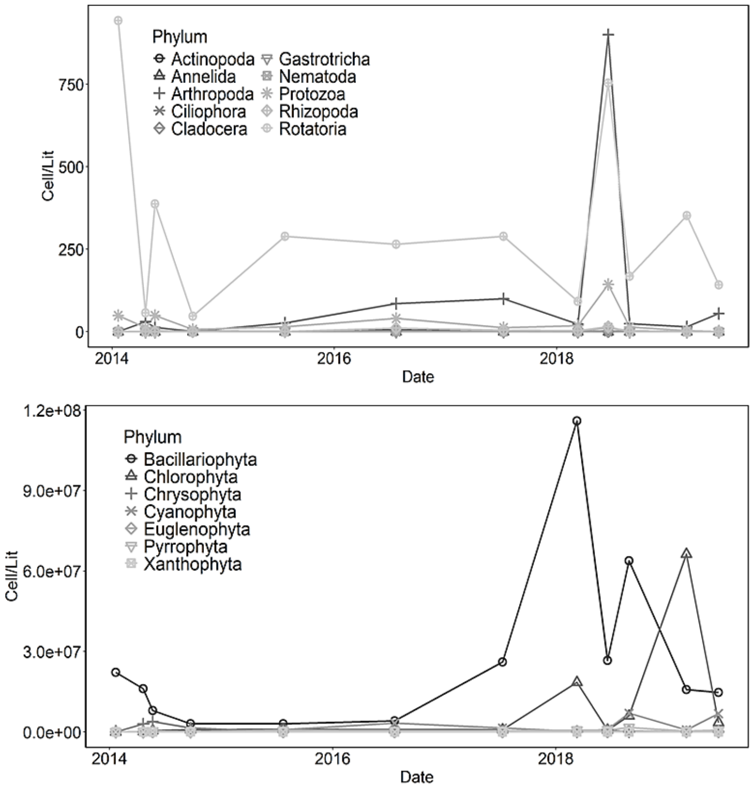

Fig. 2. Time series of zooplankton (top) and phytoplankton (bottom) populations in Chitgar Lake.

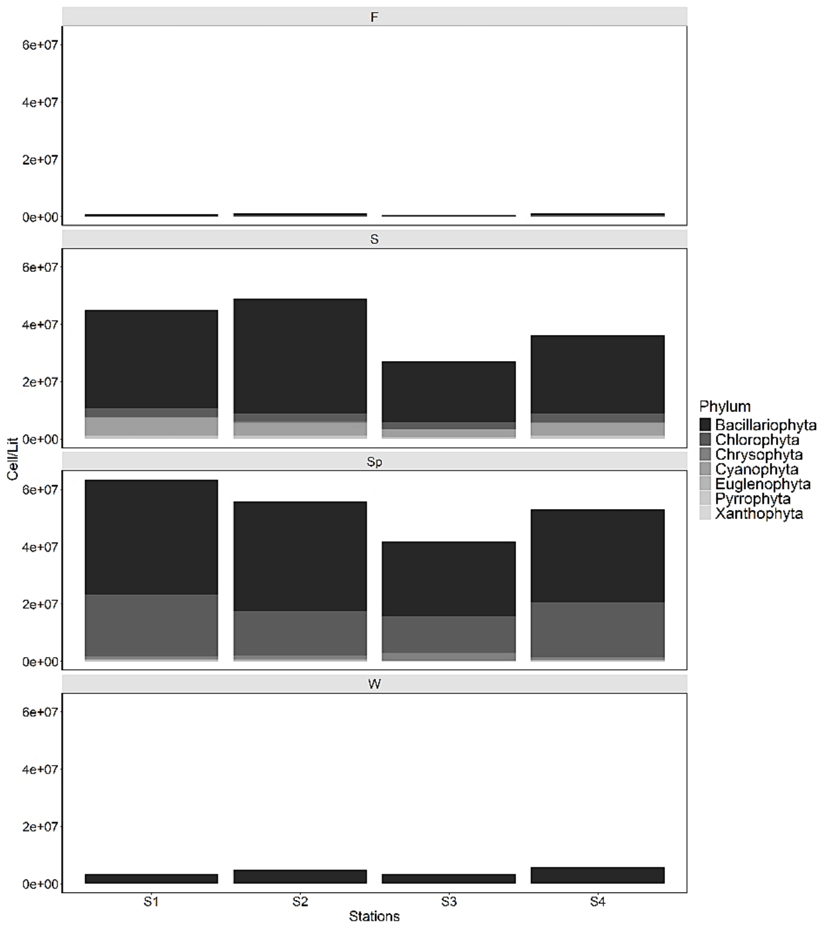

Fig. 3. Zooplankton distribution at different stations and seasons.

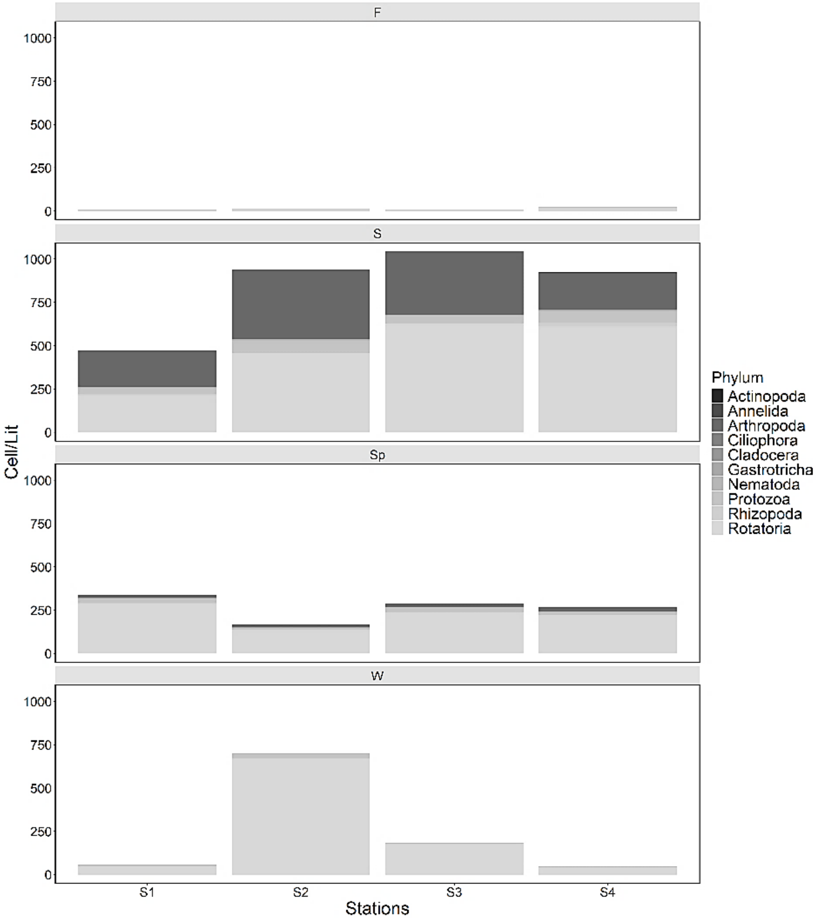

Fig. 4. Zooplankton distribution at different stations and seasons.

Table 1. Summary statistics of Phytoplankton by phylum, seasons, and stations.

Phylum	Mean	Median	Max	Min	SD
Bacillariophyta	1,008,502	120,000	25,350,000	20,000	2,972,772
Chlorophyta	589,643	45,000	15,840,000	20,000	2,159,606
Chrysophyta	372,200	280,000	1,940,000	20,000	406,120
Cyanophyta	160,926	60,000	1,880,000	20,000	278,982
Euglenophyta	47,857	40,000	240,000	20,000	48,851
Pyrrophyta	80,128	50,000	280,000	20,000	71,278
Xanthophyta	30,000	20,000	60,000	20,000	20,000
Season					
Fall	112,653	60,000	680,000	20,000	142,869
Summer	384,611	60,000	19,520,000	20,000	1,567,594
Spring	1,231,593	120,000	25,350,000	20,000	3,427,250
Winter	697,500	60,000	4,940,000	20,000	1,389,015
Station					
S1	722,782	80,000	25,350,000	20,000	2,828,704
S2	710,423	80,000	20,900,000	20,000	2,621,256
S3	489,530	75,000	13,850,000	20,000	1,587,917
S4	569,112	80,000	16,400,000	20,000	2,019,357

The statistical analysis of both zooplankton and phytoplankton provides valuable insights into the variations of these organisms based on phylum, seasons, and sampling stations (Tables

1 and 2). In zooplankton, different phylogenetic groups exhibit distinct patterns, with Rotatoria showing higher mean concentrations compared to others like Actinopoda, reflecting variability in cellular density. Seasonal trends indicate that winter has the highest mean cell concentration of 57.6, while spring demonstrates a more consistent distribution. Furthermore, station-based analysis reveals notable spatial heterogeneity, with stations S2 and S3 presenting higher mean concentrations and variability. Similarly, phytoplankton data reveal significant variations, with Bacillariophyta having the highest mean concentration of 1,008,502 cells/L, while Xanthophyta exhibits the lowest at 30,000 cells/L. Seasonal patterns show spring with the highest mean cell concentration of 1,231,593 cells/L and fall with the lowest at 112,653 cells/L. In stations, data indicate spatial variability, particularly with S1 and S2 displaying higher mean concentrations, and S1 having the peak mean of 722,782 cells/L. Standard deviation values across both groups highlight the dynamics in cell concentrations, emphasizing how phytoplankton and zooplankton populations respond to ecological factors. Understanding these variations is crucial for ecological assessments and monitoring efforts, shedding light on the ecological significance of these communities in aquatic ecosystems. Diversity and evenness indices for phytoplankton and zooplankton are shown in Table 3.

Table 2. Summary statistics of Zooplankton by phylum, seasons, and stations.

Phylum	Mean	Median	Max	Min	SD
Actinopoda	2	1	3	1	1
Annelida	1	1	1	1	NA
Arthropoda	10	3	244	1	30
Ciliophora	2	2	2	2	NA
Cladocera	1	1	1	1	0
Gastrotricha	2	1	3	1	1
Nematoda	2	1	9	1	2
Protozoa	9	4	56	1	12
Rhizopoda	2	2	6	1	1
Rotatoria	18	3	415	1	40
Season					
Fall	3.43	2	11	1	3.33
Summer	13.8	3	244	1	29.1
Spring	7.94	2	125	1	17.4
Winter	57.6	9	415	1	105
Station					
S1	9.78	3	93	1	19
S2	18.2	2.5	415	1	56.1
S3	15.8	3	244	1	34.2
S4	11	4	126	1	22.5

Table 3. Diversity and evenness indices for phytoplankton and zooplankton.

Phytoplankton			Zooplankton		
H'	D	J	H'	D	J
2.12	2.36	0.55	2.50	5.11	0.65

The analysis of biodiversity indices for Chitgar Lake and its zooplankton community indicates a balanced ecosystem characterized by a moderate level of species diversity, richness, and evenness. The Shannon-Wiener diversity index for phytoplankton is 2.12, suggesting a reasonable variety and an even distribution of species within the lake, while the Margalef species richness index of 2.36 signifies a moderate to high level of species richness. In the zooplankton community, the H' index rises to 2.5, indicating a moderate to high level of species diversity, complemented by a Margalef species richness index of 5.11 that reflects a rich variety of species. The Pielou evenness index for phytoplankton is 0.55, while the zooplankton community shows a slightly higher evenness index of 0.65, suggesting a moderate balance in the distribution of individuals among species in both communities.

3.1. Water quality of Chitgar Lake

Water quality is assessed through various statistical variables that provide insights into the health of aquatic ecosystems. Table 4 presents key statistical parameters of the Chitgar Lake water quality. DO is crucial for aquatic life, with a mean value of 8.21 mg/L indicating a healthy environment. The minimum DO recorded is 5.81 mg/L, which is the threshold for many species, while the maximum value of 11.6 mg/L suggests periods of high productivity, possibly due to photosynthesis from aquatic algae and phytoplankton (Murphy et al., 2017). The pH level, averaging 7.94, falls within the optimal range for most aquatic organisms, indicating a balanced ecosystem conducive for most aquatic life. The median pH of 7.88 further supports this stability, suggesting that the water is neither too acidic nor too alkaline. Water temperature is a significant factor that influences the dynamics of aquatic environments, as it affects the metabolism and reproduction of organisms and speeds up the degradation of organic matter (Liti, 2002). Temperature readings show that the average surface temperature is 19.9°C, while the temperature at depth is slightly lower at 19.7°C. This similarity indicates that there is no thermal stratification in the lake, which is beneficial for maintaining a uniform habitat for aquatic species. The lack of stratification allows for better mixing of nutrients and oxygen throughout the water column, promoting a more dynamic ecosystem. Fasil et al. (2011) reported the same results regarding stratification in shallow lakes. Nutrient concentrations are also critical for assessing water quality. The mean nitrate level is 5.01 mg/L, which can indicate nutrient enrichment, while ammonium levels average 0.222 mg/L. TN and TP levels are 1.82 mg/L and 0.59 mg/L, respectively, suggesting potential for algal blooms if nutrient levels rise significantly, but remain below thresholds for severe eutrophication, as highlighted by the maximum TP of 0.20 mg/L. Chl-*a* concentration, at 50 µg/L, reflects the amount of phytoplankton in the water, serving as an indicator of primary productivity. Its mean concentration of 4.33 µg/L reflects a moderate amount of phytoplankton present, often corresponding to adequate light and nutrient conditions for primary production. These statistical variables collectively illustrate the water quality of the lake, highlighting a healthy ecosystem with no thermal stratification, which supports a balanced aquatic environment conducive to diverse life forms. Regular monitoring of these parameters is essential for effective management and conservation efforts (Lan et al., 2024; Neumann et al., 2024).

Table 4. Statistical analysis of key water quality parameters.

Variable	DO (mg/L)	pH	Temp. at surface (°C)	Temp. at Depth (°C)	NO_3^- (mg/L)	TN (mg/L)	TP (µg/L)	Chl-*a* (µg/L)
Mean	8.21	7.95	19.94	19.7	5.01	1.82	37.4	4.33
Median	7.88	7.94	22.8	22.5	4.8	1.8	39.1	3.5
Min	5.81	6.99	4	4.2	0.354	0.016	4	0.1
Max	11.6	8.89	30.8	30.3	21.7	6.1	200	59
SD	1.21	0.42	8.08	8.04	3.26	0.82	20	4.25

4. Conclusion

This comprehensive study of phytoplankton and zooplankton communities in Chitgar Lake reveals critical insights into the ecological dynamics of the aquatic ecosystem. The identification of 69 genera across 7 phyla in phytoplankton and 46 genera across 10 phyla in zooplankton highlights the rich biodiversity present in the lake. The dominance of Bacillariophyta within the phytoplankton and Rotatoria in the zooplankton community reflects their essential roles in the food web, suggesting a productive and healthy ecosystem. The average dissolved oxygen level of 8.21 mg/L, coupled with a maximum of 11.6 mg/L, indicates that Chitgar Lake offers a suitable environment for aquatic organisms. These oxygen levels exceed the 5 mg/L benchmark recommended for supporting diverse aquatic life. The prevalence of diatoms, which thrive in nutrient-rich and well-oxygenated habitats, suggests a stable ecosystem with adequate nutrients, while still demonstrating the potential for oligotrophic conditions. This balance is critical as it minimizes the risk of harmful algal blooms, which often emerge under excessive nutrient loading. In terms of zooplankton, the dominance of Rotatoria signals moderate nutrient levels conducive to their growth. Their presence indicates sufficient nutrient availability to support their reproductive rates without creating conditions that favor undesirable algal blooms. This finding aligns with the need for maintaining water clarity and stable conditions, which are vital for a well-structured food web. The peak zooplankton populations observed in warmer months further emphasize how seasonal environmental factors can significantly influence community dynamics. The consistent presence of Bacillariophyta across all seasons reflects their adaptability and suggests resilience in fluctuating environmental conditions. Statistical analyses revealed favorable water quality indicators, including a pH of 7.94, which is optimal for many aquatic species. The absence of thermal stratification promotes nutrient mixing, supporting a dynamic ecosystem, though attention must be paid to rising nutrient concentrations, particularly nitrates and total phosphorus, which pose risks for algal blooms. Biodiversity indices indicate a moderate level of diversity within both phytoplankton and zooplankton communities, favorably positioned in relation to established benchmarks for healthy ecosystems. The strong evenness in species distribution supports ecological resilience, suggesting that Chitgar Lake is maintaining its ecological health despite potential environmental pressures. In summary, this study underscores the intricate interplay between biological communities and environmental conditions in Chitgar Lake. The findings provide a foundation for future ecological assessments and management strategies. Continuous monitoring is essential to preserve the lake's biodiversity and overall health, ensuring sustainability in this vital freshwater resource.

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