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Seasonal dynamics of zooplankton in a eutrophic fish pond of Bangladesh in relation to environmental factors

Abstract

Zooplankton is crucial for transmitting energy from primary producers to higher trophic levels. A study was done in a Bangladesh eutrophic fish pond to know zooplankton's seasonal dynamics in relation to environmental factors. There were 11 different zooplankton genera, which belong to three major classes: Copepoda, Rotifera, and Cladocera. Peak abundance of zooplankton was found in the spring and winter, respectively. Cluster analysis clearly indicated zooplankton abundance during the spring and winter. Rotifera was the main dominant group in the total zooplankton population. Copepoda and Cladocera had a lower abundance than those of Rotifera. During the study period, environmental factors were observed monthly. The total zooplankton abundance showed a positive correlation only with pH and a negative correlation with transparency, dissolved oxygen, phosphates, nitrates, and temperature during Pearson's correlation coefficient analysis. The canonical correspondence analysis also indicated that pH, transparency, and temperature significantly affect the abundance of zooplankton groups. Therefore, further research on the influence of environmental factors on different species of zooplankton is strongly suggested for achieving sustainable fish production from eutrophic fish ponds.

Keywords: zooplankton, seasonal dynamics, environmental factors, eutrophic ponds

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Introduction

Zooplankton is a major component of all aquatic ecosystems, including freshwater, coastal and marine ecosystems.[1] Microscopic zooplankton is known as the core of food chains and food webs and the primary natural food for fish and shellfish in all aquatic habitats.[2] Zooplankton has recently gained recognition as a crucial bio-indicator of ecological integrity.[3] Because of their high density, short life span, drifting nature, high species variety, and diverse tolerances to environmental stress, zooplankton is exploited as indicator organisms for the biological, chemical, and physical processes in the aquatic ecosystem.[4] The presence of zooplankton also affects ecosystem dynamics by regulating atmospheric carbon dioxide levels.[5] Seasonal and geographic dominance of specific zooplankton taxa reveal the relative importance of various water parameters and provide an early sign of a biological response to environmental and climatic changes.[6]

In recent decades, eutrophication has become a serious ecological problem in aquatic ecosystems.[7,8] Eutrophication, defined as the increased rate of primary production and accumulation of organic matter, usually results from the excessive addition of nutrients that cause an undesirable change in ecosystems, food webs, water quality, and aquatic chemistry.[9,10] One of the first consequences of eutrophication is increased phytoplankton blooms caused by enhanced nutrients.[11] Nutrient enrichment and high phytoplankton blooms affect water bodies by deflecting the physical and chemical properties of water and aquatic community structure.[12,13] Changes in the zooplankton community composition and a reduction in species diversity are the main effects of eutrophication in aquatic environments.[14,15]

Bangladesh, one of the leading fish-producing countries, ranks fifth in aquaculture production worldwide according to the FAO report "The State of World Fisheries and Aquaculture 2020."[16] Natural and artificial fish ponds are important to aquaculture development and the livelihood of underprivileged fish farmers in Bangladesh. The zooplankton communities in a pond determine aquaculture's productivity.[17]

In eutrophic freshwater fish ponds in Bangladesh, zooplankton is particularly prevalent and highly sensitive to environmental changes in water bodies. The physicochemical variables such as temperature, pH, DO, total alkalinity, free CO_2, water depth, light, and nutrient status[18] are the principal parameters affecting the presence, composition, and abundance of particular zooplankton in fish ponds. Zooplankton's growth and survival performance are influenced mainly by temperature, which changes seasonally. Zooplanktons inhabiting the pond surface layer move to deeper layers when the surface water becomes warm due to high temperatures and reflect decreasing abundance trends in the water surface.[19] Aquatic nitrogenous and phosphorus nutrients also regulate the diversity and distribution of zooplankton.[20]

Some scientific research has been done in different ponds and lakes in Bangladesh,[2,17,18] although none of these investigations has thoroughly explained the existence, quantity, and seasonal dynamics of zooplankton. To make the fisheries sector sustainable and safe, extensive research is required on the aquaculture inputs used in ponds, influential environmental factors, and their effects on zooplankton. So, the present research on the seasonal dynamics of zooplankton in relation to environmental factors was aimed to determine which factors highly influence the increase or decrease of zooplankton production from the fish ponds.

Materials and methods

Study area

The research was conducted in a fish pond of Mymensingh (24°45'14″N and 90°24'11″E) district, Bangladesh (Figure 1). The fish pond was selected considering the climatic condition and surrounding environment. The average annual temperature in the sampling site is 26.41°C. The area of the pond was 3440 m^2 and the average depth was

6 ft (Figure 2). There were no inlet or outlet facilities in the pond. The pond received domestic wastes, silt particles, plastic materials, and decomposed organic nutrients through sullage connections from the adjacent houses. Besides, surface run-off and slums wash were also entered into the pond. Due to nutrient-rich water and high population densities in conjunction with rudimentary sanitation facilities, the pond could be considered eutrophic. Anthropogenic stressed conditions were prevalent during the study period.

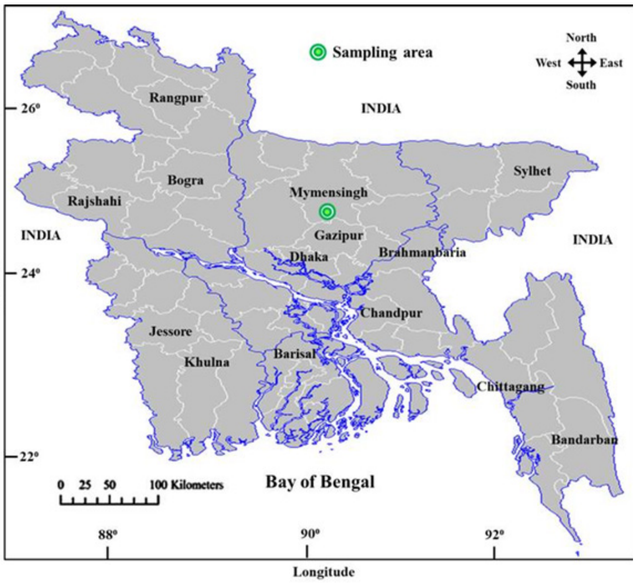

Figure 1 Study area showed in the map of Bangladesh.

Figure 2 Sampling pond located in the Mymensingh region of Bangladesh.

Moreover, the pond was multi-purposely used intensively and extensively for fish farming, personal hygiene, washing of utensils and clothes, and fostering a domestic, animal, and other domestic purposes by the locals. Additional fertilizer and supplementary feed were rarely used for fish culture, but sometimes lime was used during heavy bloom of phytoplankton and pond preparation.

Zooplankton study

Water samples were collected from March 2021 to February 2022, covering six seasons: spring (March-April), summer (May-June), rainy season (July-August), autumn (September-October), late autumn (November-December), and winter (January-February) (https://en.banglapedia.org/index.php/Season). In the study, three sampling points in the pond were selected, and three replicates of water samples were taken between 10:00 am to 11:00 am at a monthly interval on every 15th day of each month for biological analyses of pond water. A total of 108 samples were collected from the pond, where nine were collected monthly. In each month, 10 liters of subsurface water (under 1ft) of the pond from each sampling site was collected and concentrated to 100 ml by passing through a conical-shaped monofilament nylon zooplankton net of 70 µm mesh size and 30 cm diameter at the mouth to collect the zooplankton. The collected zooplankton samples were preserved in 10% buffered formalin.

For species identifications, the buffered formalin preserved sample was gently shaken to re-suspend all materials and was allowed to settle for 1 min. Then 2–3 drops were removed from the middle of the sample and placed on a glass slide.[21] Taxonomic determination of zooplankton was performed with a phase-contrast microscope (Olympus, Japan) at 40 X magnification, with a bright field and phase contrast illumination on living materials and samples preserved with formaldehyde. Zooplankton identification was done up to the genus and species level where possible following the standard descriptions of Conway et al.[22] Altaff[23] and Yousif Al-Yamani et al.[24] The counting of zooplankton cells was done in a 1ml Sedgewick-Rafter counting chamber following the sedimentation method of Utermöhl.[25] The counted results were summarized as individuals per liter.

Analysis of environmental factors

Environmental factors (temperature, pH, and DO) were measured using a HI-9829 multi-parameter meter. The transparency was measured using a Secchi disc provided with a graduated rope and measuring tape. Phosver 3 and Nitraver 5 powder pillows were used to measure nutrient concentrations such as phosphate-phosphorus and nitrate-nitrogen in 25 ml filtered water samples using a direct reading spectrophotometer (DR/2010, HACH, Loveland, CO, USA).[26]

Statistical analysis

The data were analyzed statistically using Microsoft Excel 2010, SPSS Version 21 (Statistical Packages for the Social Sciences), and PAST Version 3 (The Paleontological Association, London. UK). The correlation between zooplankton abundance and environmental factors was conducted following Pearson's correlation method in SPSS. The significance levels were 0.05% and 0.01%. Based on Bray-Curtis, a cluster analysis was undertaken to elucidate the similarity of zooplankton abundance in different seasons. Canonical correspondence analysis (CCA) was applied to explore the seasonal distribution of the zooplankton groups with the environmental parameters.

Results

Occurrence and abundance of zooplankton

In the natural plankton assemblage within the pond, the zooplankton population was identified and composed of 11 genera belonging to 3 major classes, namely Copepoda, Rotifera, and Cladocera (Table 1). Rotifera was the most dominant of the zooplankton groups, followed by Copepoda and Cladocera. The monthly variations of total zooplankton in the pond water are presented in Figure 3. The maximum number of zooplankton was found in April (59.33±22.59 x 10^3 individuals/l), and the minimum was noted in October (10.33±2.08 x 10^3 individuals/l).

Table 1 List of zooplankton obtained from the pond

Zooplankton groups	Taxa under each group
Copepoda	*Cyclops, Diaptomus,* and Nauplii
Rotifera	*Asplanchna, Brachionus, Filinia, Polyarthra* and *Trichocerca*
Cladocera	*Diaphanosoma, Sida* and *Moina*

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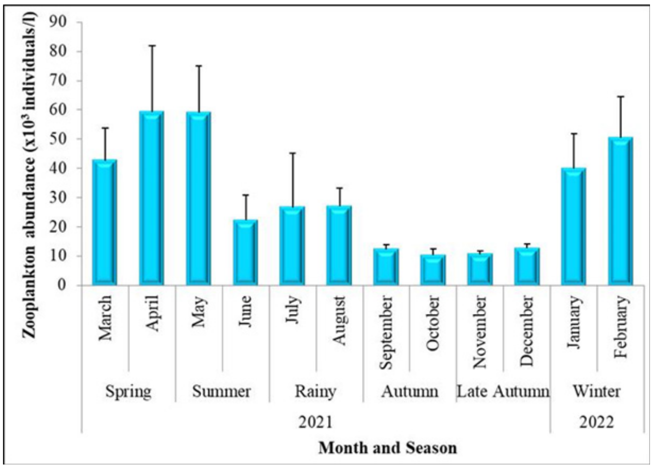

Figure 3 Monthly variation of total zooplankton in the studied pond.

Group-wise occurrence and abundance of zooplankton

Rotifera

Rotifera ranked first concerning both the number of genera and abundance. A total of 5 genera and nine species were found in Rotifera. *Brachionus* was the most dominant genus, followed by *Asplanchna, Filinia, Polyarthra*, and *Trichocerca*. *Brachionus budapestensis, Brachionus forficula, Brachionus caudatus, Brachionus angularis, Brachionus calyciflorus, Filinia passa, Polyarthra remata,* and *Trichocerca capucina* were the commonly occurring species of Rotifera. The abundance of Rotifera was noted to vary from 5.66-45×10^3 individuals/l. The highest abundance of Rotifera was found in April and the lowest was noted in November (Figure 4).

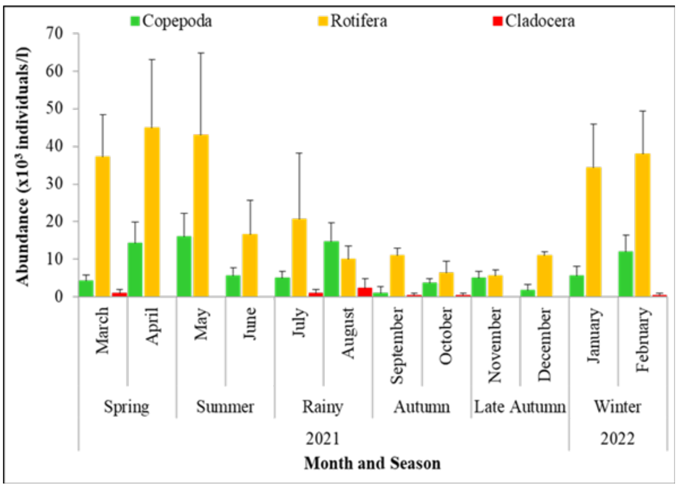

Figure 4 Monthly variations of different zooplankton groups in the studied pond.

Copepoda

In Copepoda, a total of 3 genera and 5 species were found. Nauplii were the most dominant, followed by *Cyclops* and *Diaptomus*. *Cyclops strenuus, Cyclops scutifer, Diaptomus* spp., and Nauplii were the commonly occurring species of Copepoda. The abundance of Copepoda was noted to vary from 1-16×10^3 individuals/l. The highest abundance of Copepoda was found in May and the lowest was noted in September (Figure 4).

Cladocera

The lowest number of Cladocera was obtained during the study period, as they occurred occasionally. A total of 3 genera and 4 species of Cladocera were found. *Moina* was the most dominant genus, followed by *Diaphanosoma* and *Sida*. *Moina micrura* and *Moina macrocopa* were the most frequently occurring species of Cladocera. The abundance of Cladocera was noted to vary from 0-2.33×10^3 individuals/l. The maximum abundance of Cladocera was found in August and it was entirely absent for several months (Figure 4).

Seasonal variation of zooplankton

Zooplankton was observed throughout the year, and evidence of seasonal fluctuation was visible. Zooplankton abundance was found to be highest in the spring season (Figure 5). After spring, a decreasing trend in zooplankton abundance was found, and the lowest abundance was noted in autumn. Again, peak zooplankton abundance was found in the winter season.

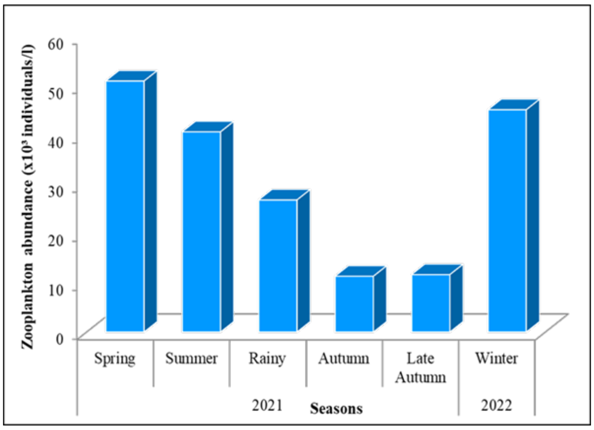

Figure 5 Seasonal variations of zooplankton in the studied pond.

Among different zooplankton groups, Rotifera abundantly occurred in all seasons (Figure 6). Rotifera showed their maximum abundance during spring and comparatively minimum abundance during autumn. On average, Copepoda showed moderate abundance in all seasons. The maximum abundance of Copepoda was found in the summer season. In most seasons, Cladocera appeared in a lower abundance than the two other zooplankton groups (except summer and autumn). No Cladocera were recorded in the summer and autumn seasons.

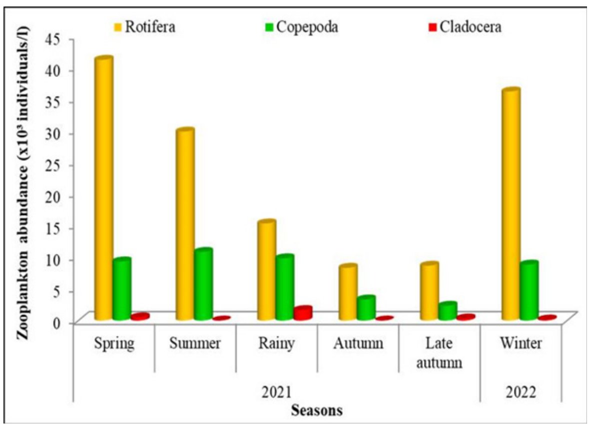

Figure 6 Seasonal abundance of different groups of zooplankton.

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In order to reveal the similarities among seasons, cluster analysis (CA) was performed based on the total abundance of the zooplankton community. Cluster analysis was carried out using the Bray–Curtis similarity. At a similarity of 75%, three significant clusters were found among seasons (Figure 7). The large cluster contained three seasons (summer, winter, and spring), one cluster contained two seasons (autumn, late autumn), while another cluster (rainy) remained isolated.

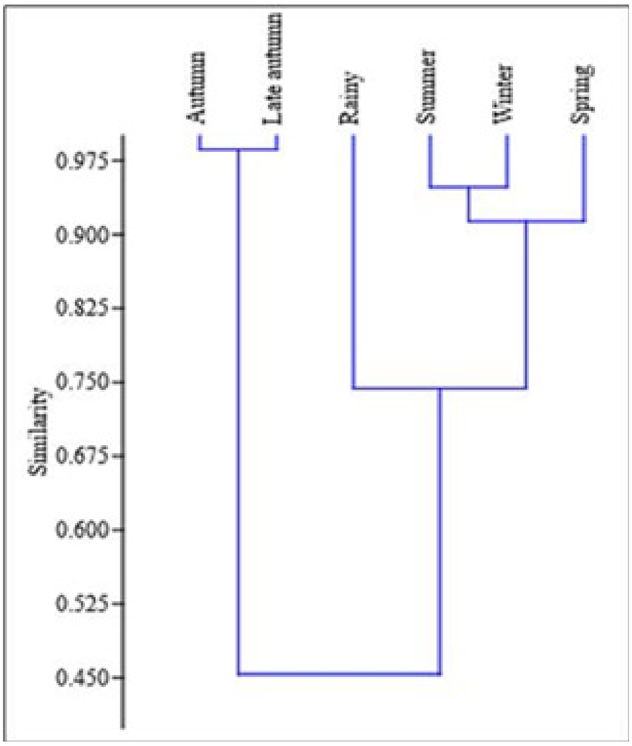

Figure 7 Dendrogram showing clusters based on the Bray-Curtis similarity matrix of six seasons.

Environmental factors

The values of environmental factors were found to vary in different months (Figures 8 & 9). The water transparency ranged from 12.5±5 cm to 35.5±1 cm. The transparency was highest recorded in August, and the lowest was in April. The water temperature ranged from 20.06±0.11 □C to 30.56±0.23 □C. The water temperature reached its highest value in May, whereas the lowest was recorded in January. Alkaline pH values were recorded during the study period from March 2021 to February 2022. The values of water pH were recorded as maximum (8.73) and minimum (7.53) in December and August, respectively. The DO concentration varied from 0.93±0.25 mg/l to 8.93±1.10 mg/l. DO was noted to be highest in March and lowest in June. The NO_3-N concentration varied from 0.039±0.03 mg/l to 0.36±0.16 mg/l. The highest NO_3-N value was observed in June, and the lowest was in May. The PO_4-P concentrations varied from 0.077±0.02 mg/l to 0.57±0.16 mg/l. The lowest concentration of PO_4-P was detected in February, while the highest values were observed in July.

Relationship between zooplankton and environmental factors

Pearson's correlation coefficient analysis observed the relationship between zooplankton and environmental factors (Table 2). Zooplankton abundances were only positively related to pH (r = 0.220). It showed a significantly negative relationship with the rest of the environmental factors, including NO_3-N (r = -0.662, P < 0.05), PO_4-P (r = -0.581, P < 0.05), transparency (r = -0.339), temperature (r = -0.031) and DO (r = -0.180).

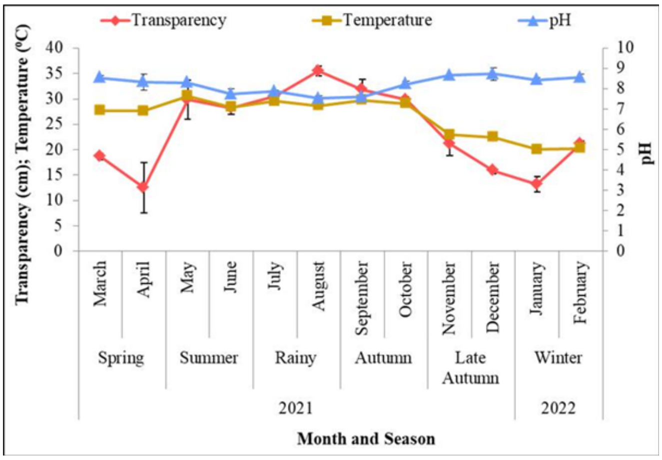

Figure 8 Variations in transparency, temperature, and pH in the studied pond.

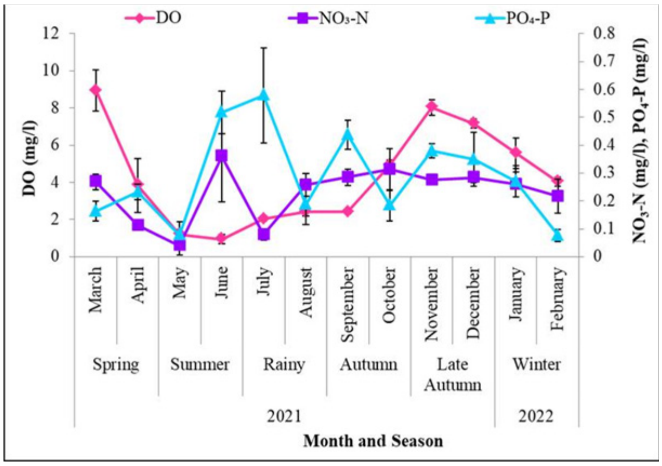

Figure 9 Variations in DO, NO_3-N, and PO_4-P in the studied pond.

Canonical correspondence analysis (CCA) was used to evaluate the relationship of the zooplankton groups with the environmental parameters. Canonical correspondence analysis (CCA) was performed using six environmental parameters and three zooplankton groups (Figure 10). The eigenvalue of axis 1 (0.03) showed an 81.81% correlation, and axis 2 (0.008) showed an 18.19% correlation between the environmental parameters and different zooplankton groups. Transparency, temperature, and pH have a significant impact, while DO, NO_3–N, and PO_4-P showed a comparatively moderate impact on the abundance of different zooplankton groups in conformity with CCA. Cladocera was positively correlated with temperature and transparency, while Copepoda showed close affinity to NO_3-N and Rotifera showed close affinity to the PO_4-P.

Discussion

Occurrence and abundance of zooplankton

Natural and man-made ponds are one of the main features of Bangladesh. To varying degrees, pond water is intensively and extensively used for fish culture.[27] The health of pond water can be determined owing to several zooplanktonic groups.[28] Most fish get their energy from zooplankton, especially in their larval stages, because they rely on it as their primary source of nutrition once the yolk sac is absorbed.[29] Regarding biodiversity and biomass, rotifers, cladocerans, and copepods are the best examples.[30] Since they are the primary phytoplankton consumers, they play a crucial function in the trophic web by transporting matter and energy.[31]

During the present study, 11 zooplankton genera belonging to 3 groups were identified, namely Copepoda, Rotifera, and Cladocera, in the studied pond. Several previous studies in Bangladesh have reported similar zooplankton groups such as Cladocera, Rotifera, and Copepoda in pond water.[17,18,32–34] The Lakshadweep Archipelago in India (56 species, 7 groups) and a man-made lake in Malaysia (27 species, 3 groups) had higher zooplankton communities than those in the present study, which can be attributed to diverse habitats.[35,36] The variation in zooplankton genera in the present study compared to other studies could arise from differences in the nutrient status, pond bottom, and embankment soil quality, meteorological factors, and the massive growth of phytoplankton in pond water.

Table 2 Pearson's correlation coefficient between zooplankton abundance and environmental factors

	Zooplankton	Transparency	Temperature	DO	pH	NO_3-N	PO_4-P
Zooplankton	1						
Transparency	-.339	1					
Temperature	-.031	.682*	1				
DO	-.180	-.629*	-.533	1			
pH	.220	-.772**	-.660*	.754**	1		
NO_3-N	-.662*	-.004	-.265	.339	-.062	1	
PO_4-P	-.581*	.166	.158	-.193	-.399	.191	1

**Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed).

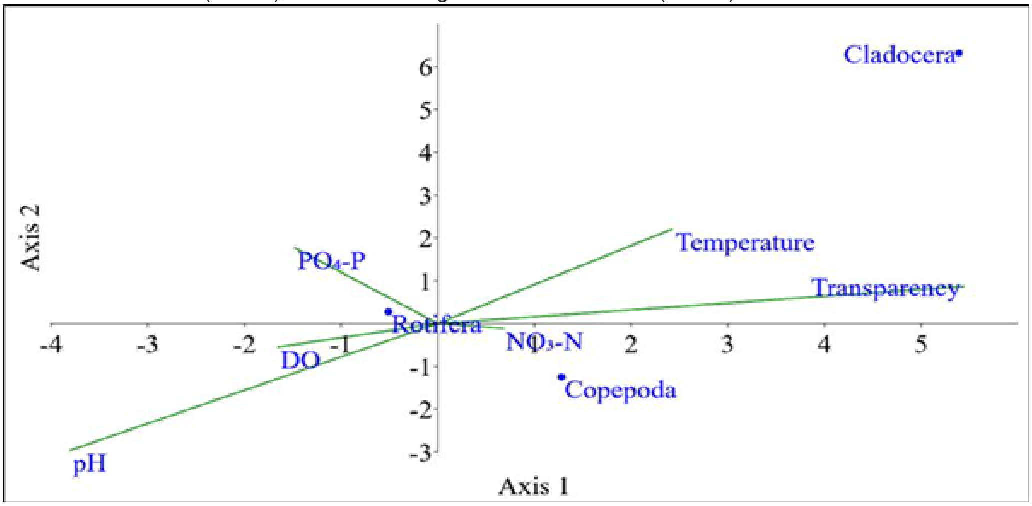

Figure 10 CCA biplot between different zooplankton groups and environmental parameters.

The presence of various zooplankton groups predicted and determined the status of water bodies.[28,37] The Rotifera group dominated zooplankton abundance in the present study, followed by Cladocera and Copepoda. Adeyemi[38] reported a similar high dominance of Rotifera in Ajeko stream, North Central Nigeria, and Omowaye et al.[39] in Ojofu Lake, Nigeria. Zooplankton community distribution within water bodies varies with time due to their proficiency in quick response to even slight environmental changes and vertical migration, which is an almost universal phenomenon.[17,40] Previous research findings claimed that zooplankton distribution is non-homogenous in limnetic waters and probably related to food availability and avoidance of predators.[2]

Seasonal dynamics of zooplankton

Though the different seasons of the year in Bangladesh are not as distinct as those of temperate countries due to climate change and global warming, zooplankton exhibits significant seasonal abundance. The seasonality of zooplankton in aquatic ecosystems influences various biotic components, making them helpful in determining aquatic ecosystem quality. Only 11 zooplankton genera of three groups in different seasons indicated the moderate ecological condition of the eutrophic fish ponds in Bangladesh.[41]

The highest abundance of zooplankton was found in spring and winter, and the lowest was in autumn in the studied pond. A similar abundance of total zooplankton in spring and winter was found by Islam et al.[42] and Shi et al.,[43] which was different from that of the other studies,[18,44,45] where they recorded a higher abundance of zooplankton in the summer season in aquaculture ponds. The variation in seasonal abundance of zooplankton among the results of the different studies could arise due to cyanobacterial blooms, lower dissolved oxygen, and poor water quality in the fish ponds.[46]

Rotifera dominated the zooplankton community, and the mean abundance of Rotifera was also found to be highest in spring and lowest in autumn in the present study. One study found the highest abundance of Rotifera in spring and a lower abundance in winter in the river Yamuna (Delhi), India. In contrast, another study found the maximum abundance of Rotifera during summer and the minimum during winter in Shahanoor Dam, Amravati District, India.[47,48] Moreover, the seasonal abundance of Copepoda and Cladocera was not so marked because of the high density of Rotifera. This seasonal variation among the zooplankton groups may be due to the difference in the nutrient status, chemical qualities of water and density, and species composition of fish stocked.

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The cluster analysis (CA) revealed three major clusters with a similarity of 75% in the present study. The zooplankton clusters generated by combining the seasons indicated that seasons in a cluster have similar conditions depending on the degree of similarity. On the contrary, the seasons that remained isolated in a single cluster showed differences in the abundance of zooplankton. This may be due to differences in the environmental parameters and the different kinds of biological cycles of zooplankton species that did not coincide with them.[49]

Influence of environmental factors on zooplankton

Despite considerable sensitivity to environmental changes, zooplankton species have generally been overlooked in studies of biological responses to changing environments.[50] Various physicochemical parameters influence the zooplankton population, including water transparency, temperature, pH, dissolved oxygen, and nutrients. Water transparency is an important factor in fish ponds, indicating the presence or absence of plankton density. Water transparency level often depends on the quantity of phytoplankton, zooplankton, and suspended organic and inorganic particles. Many researchers found a negative relationship between zooplankton and transparency.[18,45] A similar correlation between zooplankton and transparency has been found in our study. Besides, water transparency was observed to be considerably lowest in April, possibly due to the peak abundance of cyanophytes in that month.

The distribution and variety of zooplankton in ponds are significantly impacted by temperature, a biologically significant phenomenon of aquatic systems.[51] When the water temperature is moderate, zooplanktons show their highest abundance.[3,52] In our study, temperature showed less influence on the seasonal abundance of zooplankton. The pH of pond water is a good indicator of its fertility. While alkaline water conditions (pH>7) connected to high primary production support zooplankton development and abundance, low pH encourages decreased zooplankton abundance, reduced biodiversity, and the extinction of some species.[53,54] The present study observed alkaline pH values in pond water, which favor zooplankton abundance. In Noakhali, Bangladesh, Khan et al.[17] recorded abundant zooplankton in naturally occurring ponds with an alkaline pH. Variations in dissolved oxygen concentrations in the studied pond were observed in different seasons. Dissolved oxygen and zooplankton were shown to be negatively correlated. However, Shil et al.[44] and Bashar et al.[18] found positive correlations between zooplankton and DO.

Moreover, the favorable conditions for species survival in ponds, lakes, rivers, or any other aquatic body are regulated by the chemical quality of the water.[55] Mainly, nitrogenous and phosphorus nutrients influence the temporal and spatial changes of zooplankton.[20] In fish ponds in Bangladesh, nutrients from residual aquaculture inputs (cow dung, poultry droppings, fish feeds, fish feces, etc.), sewage, agricultural lands, poultry farm wastes, industrial wastes, etc. are added year after year through surface run-off or with flood water during monsoon months. Excessive nutrient enrichment by adding supplementary feeding, domestic wastes, aquaculture inputs, and surface run-off leads to eutrophication, thereby triggering the fast multiplication of certain algal species to become highly abundant.[27] During the investigation, the concentrations of NO_3-N and PO_4-P were estimated to be lower because of algae's high nutrient absorption ability due to their heavy growth. Additionally, NO_3-N and PO_4-P did not show any significant positive relationship with zooplankton abundance, similar to the findings of other studies.[3,49] The absorption of nutrients by phytoplankton for biological activity may cause lower NO_3-N and PO_4-P concentrations during zooplankton abundance.

The canonical correspondence analysis (CCA) demonstrated a clear relationship between the zooplankton groups and environmental parameters. The CCA identified that pH, transparency, and temperature significantly impact the abundance of zooplankton groups in different seasons. The lower abundance of Cladocera was highly correlated with the environmental parameters. Several previous studies have also shown that zooplankton communities are controlled by different environmental variables.[3,56,57]

Conclusion

The present study provides an overview of the seasonal dynamics of zooplankton and their relationship to environmental conditions in eutrophic fish pond in Bangladesh. The cluster analysis demonstrated that zooplankton for fish are abundantly present during spring and winter seasons in fish pond where efficient and economical aquaculture can be achieved. The total zooplankton abundance was mainly dominated by the genera Rotifera, followed by Copepoda and Cladocera. Environmental factors such as water temperature, pH, and transparency significantly influenced the composition of the zooplankton groups, as revealed by the canonical correspondence analysis. Therefore, more comprehensive research is needed on the culture of different species of various zooplankton groups, the impact of hydrological properties of water on zooplankton culture, and their influence in aquaculture to enhance the functioning and productivity of freshwater bodies for sustainable fish production.

Author contributions

S.S. performed the experiment, collected samples, assisted in data analysis, and wrote the original draft. S.K. supervised the research and reviewed and edited the manuscript. S.M.H, M.S.A, M.S.S. and M.S.N.A. assisted in data analysis and preparing the figures. Y.M. and M.M.H. reviewed and edited the manuscript. All authors reviewed the manuscript.

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Data availability

The data generated in the present study are available on request from the corresponding author.

Declarations

The authors have no known competing financial interests or personal relationships that could have appeared to influence the work mentioned in this article.

Ethical approval

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the instructions for authors.

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Conflicts of interest

The authors declare no conflicts of interest.

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