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Species

Seasonal Dynamics, Diversity, and Environmental Drivers of Zooplankton Assemblages in the Anicut Dam of a Kangsabati River Ecosystem, Paschim Medinipur, India

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To Cite:
Das S, Maity J. Seasonal Dynamics, Diversity, and Environmental Drivers of Zooplankton Assemblages in the Anicut Dam of a Kangsabati River Ecosystem, Paschim Medinipur, India. *Species* 2026; 27: e19s3297
doi:

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Peer-Review History
Received: 21 December 2025
Reviewed & Revised: 07/January/2026 to 15/July/2026
Accepted: 29 July 2026
Published: 12 August 2026

Peer-Review Model
External peer-review was done through double-blind method.

Species
pISSN 2319–5746; eISSN 2319–5754

DISCOVERY SCIENTIFIC SOCIETY

ABSTRACT

This study was conducted to analyze the composition, diversity, and assemblages of zooplankton, as well as to investigate the environmental influences on them across three seasons at the Anicut dam in Paschim Medinipur. Samples of the zooplanktons were collected during three different seasons from each station, along with the measurements of the environmental factors. Eighteen genera of zooplanktons were noted, including Copepoda (43.88%), Cladocera (30.34%), Rotifera (23.41%), and Amoebozoa (2.35%). Zooplankton density was found to be statistically different ($p < 0.05$) among the seasons, with the highest value (165.91±10.73 ind.mL^{-1}) recorded in the pre-monsoon and the lowest value (60±3.01 ind.mL^{-1}) in the monsoon seasons. Diversity indices indicated moderate diversity, ecological stability, and habitat suitability, with generally low dominance. Three major clusters were formed from the cluster analysis for the seasons (Pre-monsoon, Monsoon, Post-monsoon), and Major assemblages cluster during post-monsoon and pre-monsoon. In ordination analysis, the results show that pre-monsoon and post-monsoon zooplankton assemblages have similarities compared to monsoon assemblages, which can be seen from their proximal relationship in the ordination plot. Maximum seasonal difference occurred between monsoon and pre- and post-monsoon assemblages. Seasonal fluctuations in flow and turbidity during the monsoon season affected the assemblages of zooplanktons through flushing effect, whereas the steady nature of post-monsoon season helped develop a healthy assemblage of zooplanktons. Examples of zooplanktons that showed strong association with monsoon included *Platyias sp.*, *Mytilina sp.*, *Keratella sp.*, and *Chydorus sp*. while those showing strong associations with post-monsoon included *Daphnia sp.*, *Centropyxis sp.*, *Lecane sp.*, *Asplanchna sp.*, and *Moina sp*. On the other hand, *Diaptomus sp.*, *Thermocyclops sp.*, *Brachionus sp.* and *Lepadella sp*. were strongly associated with pre-monsoon environmental conditions, hence seasonal differentiation. Environmental variables were statistically different among seasons ($p < 0.05$).

Keywords: Biodiversity indices, Environmental variables, Seasonal fluctuation.

1. INTRODUCTION

The regulation of rivers through the use of dams and reservoirs has greatly altered freshwater ecosystems across the world. The construction of dams alters the flow regime, disrupts the movement of sediments, alters the water temperature, and limits the movement of aquatic species downstream, resulting in major ecological changes downstream. Today, about 8,000–9,000 km3 of water is stored within reservoirs across the globe, and reservoirs play an essential role in providing water security, generating electricity, and managing floods. Yet, these constructions have contributed to habitat fragmentation and alteration of riverine biodiversity. It has been observed that about 37% of the world's long rivers (>1,000 km) today are free-flowing (Grill et al., 2019; Couto and Olden, 2018). The construction of dams and reservoirs causes fragmentation, changes in hydrological regime, loss of longitudinal connectivity, modification of sedimentation, nutrient cycling, and habitats (Anderson et al., 2018; Grill et al., 2019). This leads to decreased ecological integrity and freshwater ecosystem functionality in sustaining biodiversity and providing ecosystem services, hence leading to reduced aquatic biodiversity and ecosystem functions (Rosmaria, 2025; Belletti et al., 2020). Despite its continued role as an essential method in developing water resources it has been increasingly noted that damming is among the biggest human influences on freshwater ecosystems, putting aquatic organisms at risk via habitat change, changes to flow regime, and blockages for dispersal (Bogardi et al., 2020). The dam plays a crucial role in managing water for numerous human activities such as irrigation, consumption, industrial use, and aquaculture. Located on the Kangsabati River in the Paschim Mednipur district, the Anicut Dam was reconstructed on January 15. 01. 2018. The primary aim of this dam is to provide sufficient water for crop cultivation in rural areas. Six blocks, including Kharagpur-I, Kharagpur-II, Narayangarh, Pingla, Debra, and Panskura, along with municipalities and various industries, benefit from its supply. The hydrological changes induced by dams are some of the most important anthropogenic influences on freshwater environments. The construction of dams affects the natural flow of rivers, alters temperature regimes, and modifies the distribution of sediments, thus creating a considerable impact on habitat structures and trophic interactions (Sabo et al., 2018). Though an individual dam creates local environmental change, a cascade of dams causes a series of environmental impacts like river fragmentation, hydrological connectivity, and sediment retention, thus impacting whole river systems (Zhang et al., 2020). These changes create a situation where river heterogeneity is diminished, floodplains are modified, and biotic homogenization occurs. Zooplanktons are a suitable tool for assessing the presence of plastic components in ocean waters (Alfonso et al., 2023).

The natural kinetics throughout evolution have transformed into provider of ecosystem services such as (Healthy water, biodiversity and productivity) and that are more vital to social, economic and natural environmental structure of human population such as productive water, biodiversity and healthy water (Kang et al., 2023). Due to the dam construction, aquatic environments, primarily rivers, are the most endangered natural ecosystems globally, due to the creation of the dam (Wu et al., 2019). Biodiversity of Zooplankton is essential due to the role of the Zooplankton group to keep the aid of the ecosystem good is unique health because every species play a distinctive character (nutrients recycling, food production for others and soil fertility maintenance) in the aquatic ecosystem (Rahman et al., 2025). Zooplankton diversity is indeed highly sensitive to water quality, and a variety of physicochemical parameters can directly affect their distribution and abundance (Oparaku et al., 2022). It is proposed that the time-related variation of zooplankton diversity in the anicut dam is considerably affected by variations in physical parameters over time. Currently water resources are being wasted due to the factory being built on the banks of the river and the garbage of the city is coming to the river dam, where most of which contains plastic and thermocol. Thus, the current research used zooplanktons as bio-indicators to determine the impacts of hydrological regulation due to an anicut dam during different seasons. In this context, the objectives of the current research include (i) studying the seasonal dynamics and diversity of zooplanktons, (ii) investigating the environment factors of zooplankton functional diversity in various seasons, and (iii) determining the assemblage pattern of environmental variables and zooplanktons in an anicut dam. The seasonal difference in the assemblage structure of zooplankton indicates the importance of the dam for the control of the environmental parameters in the dam. As a result of the water management activities and changes in the environmental parameters, the creation of favorable conditions for the development of the plankton communities becomes possible, especially in the post-monsoon season.

2. MATERIALS AND METHODS

Study area

The anicut dam of the Kangsabati River in the Paschim Medinipur district (Figure 1), West Bengal, is the site of the current survey. Pre-monsoon (February, March, April and May), monsoon (June, July, August, September) and post-monsoon (October, November, December, January) are the three seasons in which the diversity of zooplankton is studied. Samples will be collected at three stations of the anicut dam (Table 1). Three stations were selected: S 1 Gandhi Ghat (Figure 2), S 2 Najarganj (Figure 3) and S 3 Istriganj (Figure 4).

Table 1. Showing the sampling sites.

SN.	Sampling site	Co-ordinates
1.	Gandhi ghat near dam (Fig-2)	22.40215091°N 87.34036955°E
2.	Najarganj(Fig-3)	22.40141989°N 87.31252333°E
3.	Istriganj (Fig-4)	22.40986559°N 87.2961699°E

Figure 1. Map showing study area.

Figure 2. Showing sampling site-1 Gandhi ghat near dam

Figure 3. Showing sampling site-2 Najarganj

Figure 4. Showing sampling site-3 Istriganj

Sampling

We will collect water samples once a month. All samples will be collected in the morning time (7:00–7:30 a.m.), 40 liters of water sample filtered through nylon Plankton net (mesh size 90 μm) from the littoral zone of water bodies in selected sampling stations in each month from Anicut Dam. A total of 480L of water was gathered across each season (four months and three locations). Water samples were stored in 500 mL bottles with 4% formalin and then concentrated to a final volume of [60mL] (we concentrated each sample by 5mL) using sedimentation and siphoning techniques (APHA, 2012). Monthly sampling was enough to describe the variations of the physicochemical properties, zooplanktons, which made it possible to assess the environmental condition of the dam environment. Even though there were no short-term variations in the data collected, the sampling rate was high enough to assess the aquatic health and environmental variation.

Measurement of environmental parameters

Environmental parameters of the river were resolved in the laboratory including temperature (WT) (We have used a Centigrade Thermometer), TDS (We have used Konvioneer pen type Tds 0012 Digital TDS Meter), Hardness, Free CO2, Phosphate, Nitrite, Alkalinity, Ammonia and pH were calculated by Water Testing Kit (Transchem AgritechPvt. Ltd.).

Identification and counting

To aid in the identification of the samples, Eosin stain was introduced to the samples to obtain an even pink coloration throughout after being left for the whole night. To perform the identification, 1mL of the stained sample was placed in the S-R counting cell using a micropipette before covering the cell with a glass cover slip to prevent the formation of air bubbles. After settling the sample for 10 min, the zooplanktons were identified using a microscope (Magnus MLX 40x magnification) and various monographs, textbooks, and journal articles on the subject matter to genus levels (Goswami, 2004; Mojumder et. al., 2020). 36 sub-samples from the concentrated sample were identified in the S-R cell, and the cell density was calculated as follows (APHA, 2012).

$$D_{mL} = \frac{N}{Va}$$

Where, D is the density ind.mL^{-1}, N is the total number of individuals counted and Va is the total volume analyzed (mL).

$$D_L = \frac{N \times Vc}{Va \times Vf}$$

Where, D_L is the density ind.L^{-1}, N is the total individuals counted, Vc is the total concentrated sample volume (60mL), Va is the total analyzed volume (36mL) and Vf is the volumes of total water filter each season (480 L).

Statistical methods

The variations in terms of numbers and types of zooplankton during various seasons were statistically analysed by employing one-way ANOVA in the IBM SPSS Statistics package. The level of statistical significance was taken at the value of $p < 0.05$. The variations in physicochemical variables depending on seasons were studied by employing PAST software, version 4.17 (Paleontological Statistics). The structure of the community of zooplankton was determined through the calculation of the Shannon-Wiener diversity index, Pielou's evenness index, Margalef's species richness index, and Simpson's dominance index through PAST, version 4.17 (Hammer et al., 2001). The correlation between the composition of zooplankton and physicochemical characteristics was revealed through CCA analysis. Seasonal groupings of communities were determined by employing hierarchical cluster analysis.

3. RESULTS

Eighteen zooplankton taxa belonging to the orders Rotifera, Copepoda, Cladocera, and Amoebozoa were recorded from this study. The greater diversity in the variability of rotifers than in that of copepods and cladocerans could be because of their shorter life cycles and faster reproduction rates, as well as their tolerance of changes in environmental factors. Rotifers react promptly to changes in the seasons, in terms of food availability, temperature, and water quality, and thus can adapt themselves to different niches. The longer generations and habitat specialization among copepods and cladocerans make their seasonal variations lesser (Table 2). It was found that the zooplankton abundance varied significantly between seasons, showing high densities during the pre-monsoon season, then the post-monsoon and monsoon seasons. From among all taxa recorded, copepods comprised the dominant taxon. *Thermocyclops sp*. recorded the highest densities in all seasons, with the maximum density being 33.52 ± 9.89 ind.mL-1 (4190 ind.m-3) during pre-monsoon, followed by 12.36 ± 5.62 ind.mL-1 (1545 ind.m-3) during post-monsoon, and 9.00 ± 3.86 ind.mL-1 (1125 ind.m-3) during monsoon. *Nauplii* and *Diaptomus sp*. were also prominent in the zooplankton community composition, especially during the pre-monsoon. In the order Cladocera, *Diphanosoma sp*. recorded the highest abundance during pre-monsoon (maximum density of 16.77 ± 7.02 ind.mL-1, 2096 ind.m-3), followed by *Bosmina sp*. (14.36 ± 8.83 ind.mL-1, 1795 ind.m-3). Among the various rotifer taxa, the dominant rotifer was *Brachionus sp*., which ranged from 2.61 ±1.72 ind.mL-1 in monsoon to 7.58 ±3.39 ind.mL-1 in pre-monsoon. The other rotifer genera present in the water body include *Lecane sp*., *Lepadella sp*., *Asplanchna sp*., *Mytilina sp*., *Platyias sp*., *Polyarthra sp*., and *Keratella sp*. *Centropyxis sp*., an amoebozoan, was found in all the seasons studied and showed relatively low abundance in comparison with other groups, with density varying from 1.86 ± 0.89 to 3.22±1.69 ind.mL-1. Thus, the zooplankton community structure was dominated by copepods, followed by cladocerans, rotifers, and amoebozoans, respectively. Seasonal trends observed indicated higher productivity in the pre-monsoon. The maximum average water temperature (27.85±0.12), pH (7.7±0.08) and ammonia (0.19±00) were recorded in pre-monsoon, maximum phosphate (0.07±00) and tds (112.83±0.82) in monsoon and nitrite (0.05±0.006), alkalinity (91.66±2.08), hardness (86.66±1.61) and free carbon dioxide (16±0.33) in post-monsoon (Table 3). There were fluctuations in the number of zooplanktons depending on the seasons, with higher population numbers occurring during pre-monsoon, followed by post-monsoon seasons, while the lowest population numbers occurred during the monsoon season (Figure 5). There was a sudden drop in the number of zooplanktons during the monsoon season due to the influence of rainfall. There were high numbers of zooplanktons during the post-monsoon season due to recovery from the effects of the monsoon. Standard error shows the variation within samples. As presented in (Figure 6), the dominant group during the study periods is the Copepod which formed 50.17% of the total zooplankton composition in pre-monsoon seasons. It has undergone a gradual decrease in its relative contribution.

The proportion of Rotifera increased from 20.62% in pre-monsoon seasons to 27.59% in monsoon seasons and stabilised slightly during post-monsoon seasons. The proportion of cladocera experienced a gradual increase from 27.84% in pre-monsoon seasons to 34.82% in post-monsoon seasons. Of the three groups studied, amoebozoa was the least prevalent in both seasons and accounted for less than 5% of the entire zooplankton community that he results indicate an alteration in community structure such that the dominant group copepoda decreased while rotifera and cladocera became more abundant in post-monsoon seasons. In sampling station, station - I show that copepod 45%, cladocera 32%, rotifer 20% and amoebozoa 3%, in station-II show that copepod 46%, cladocera 30%, rotifer 22% and amoebozoa 2%, in station III show that copepod 39%, cladocera 28%, rotifer 31% and amoebozoa 2% (Figure 7a,b and c). The waste produced in picnic zones and industrial activities like iron and steel manufacturing in gokulpur along the banks of Kangsabati River in Kharagpur at station-III. At station-II, as well as station-I, zones with plastic and domestic waste pollution are characterized by raw sewage and nutrient runoff which is the main cause of eutrophication (high densities of water hyacinths) and promotes the development of rotifer species. (Figure 8), Display the importance of species variety, evenness, richness and dominance indices of zooplankton in Anicut Dam, Kangsabati River, Paschim Medinipur. In pre-monsoon, the Shannon-Weiner index, Pielou evenness index, Margalef richness index and Dominant index for zooplankton were 2.47, 0.66, 1.95 and 0.11 respectively. In monsoon, there were 2.70, 0.83, 2.21 and 0.07 respectively. In post-monsoon were 2.71, 0.83, 2.11 and 0.07 respectively. Canonical Correspondence Analysis (CCA) showed (Figure 9) unique relations of different zooplankton taxa to environmental variables for each of the three periods (Pre-monsoon, Monsoon, and Post-monsoon). CCA is one of the methods widely used for the study of relations of species to the environment and for the identification of principal environmental gradients affecting species compositions. Temperature, pH, and ammonia appeared to be the principal environmental factors affecting the distribution of zooplankton along the positive part of Axis 1. Pre-monsoon samples occurred in proximity to temperature vectors, thus revealing that this period had high water temperatures.

Among other taxa located along the vectors of these variables were *Brachionus sp*., *Lepadella sp*., *Thermocyclops sp*., *Diaptomus sp*., *Nauplius*, *Bosmina sp*., and *Diaphanosoma sp*. On the other hand, phosphate and Total Dissolved Solids (TDS) had a positive correlation with Axis 2, and these were found to be mostly related to the Monsoon season. Organisms like *Mytilina sp*., *Keratella sp*., *Platyias sp*., and *Chydorus sp.* were closer to these environmental factors since they preferred environments that had more nutrient input and suspended materials as a result of monsoons. Organisms like *Moina sp*., *Asplanchna sp*., *Alona sp*., *Lecane sp*., *Daphnia sp*., and *Polyarthra sp*. fell along the negative portion of Axis 1 because they had less relation to temperature and nutrients. *Daphnia sp*. and *Lecane sp*. were further away from the environmental vectors, which meant that they either had broad-tolerant abilities or were under the influence of some other ecological factor. The Post-monsoon season was placed between these vectors due to mixed environmental conditions. The seasonal study on the abundance of zooplankton exhibited clear differences in zooplankton abundance over time. High abundance of zooplankton was registered during the Pre-monsoon, while the Post-monsoon and Monsoon periods came second and third, respectively. It means that the Pre-monsoon period exhibited conducive environmental factors that led to better growth and production of zooplankton. Taxonomic composition revealed that the major taxonomic group of zooplankton was Copepoda, followed by Cladocera, Rotifera, and Amoebozoa. The high dominance of copepods was exhibited by the *Nauplii*, *Thermocyclops sp*., and *Diaptomus sp*. In contrast, cladocerans and rotifers were composed of several genera such as *Bosmina sp*., *Diaphanosoma sp*., *Daphnia sp*., *Brachionus sp*., *Keratella sp*., and *Lecane sp*. It implies that copepods are very important for the ecosystem studied. A combination of heat maps and hierarchical clustering (Figure 10) helped identify clear seasonal and taxonomic trends in the zooplankton community. Seasonal clustering clearly shows that the communities from the monsoon season and post-monsoon season share similar characteristics, while the pre-monsoon community clustered separately due to major restructuring of the zooplankton community across different seasons. The heat map helped classify *Nauplii, Diaptomus sp.,* and *Thermocyclops sp.* as the most abundant taxa that showed significantly high abundance during the pre-monsoon seasons. Several taxa such as *Bosmina sp*., *Diaphanosoma sp*., *Daphnia sp*. and *Asplanchna sp*. shared similar distribution patterns, suggesting that they may have similar ecological preferences.

Table 2. Seasonal variation in abundance and density of different species of zooplankton groups (mean ± SD, ind.mL-1) and density (ind.m-3) across three seasons.

Taxa	Species	Pre-monsoon		Monsoon		Post-monsoon	
		Ind.mL^{-1}	Ind.m^{-3}	Ind.mL^{-1}	Ind.m^{-3}	Ind.mL^{-1}	Ind.m^{-3}
Rotifer	*Lecaene sp.*	5.75±1.59	720	2.91±1.33	364	5.41±2	676
	Lepadella sp.	4.25±2.23	530	1.38±0.68	173	1.55±0.80	194
	Asplancha sp.	3.08±1.85	385	2.08±1.29	260	3.66±2.20	458
	Mytilina sp.	4±1.95	500	2.33±1.30	291	2.58±1.51	323
	Platiyas sp.	3.33±1.78	416	2.11±0.82	264	1.72±0.81	215
	Polyarthra sp.	2.88±1.59	360	1.16±0.87	145	2.02±1.44	253
	Brachionus sp.	7.58±3.39	948	2.61±1.72	326	2.91±1.97	364
	Keratella sp.	3.33±1.58	416	1.94±1.09	243	2.27±1.46	284
Copepod	*Thermocyclops sp.*	33.52±9.89	4190	9±3.86	1125	12.36±5.62	1545
	Copepod nauplii	22.25±7.13	2781	8.33±3.10	1041	10.22±4.34	1278
	Diaptomus sp.	27.47±13.71	2809	5.72±3.23	715	7.80±3.35	975
Cladocera	*Bosmina sp.*	14.36±8.83	1795	4.61±3	576	6.80±3.89	850
	Diphanosoma sp.	16.77±7.02	2096	4.77±3.64	596	7.97±3.51	996
	Moina sp.	4.11±2.99	514	3.02±1.84	378	4.94±3.22	618
	Chydorus sp.	3.75±2.45	469	1.88±1.28	235	2.30±1.65	288

	Daphnia sp.	2.63±1.43	329	1.80±0.82	225	4.11±2.22	514
	Alona sp.	4.55±2.04	569	2.41±0.87	301	3.66±1.95	458
Amoebozoa	*Centropyxis sp.*	2.25±1.59	281	1.86±0.89	233	3.22±1.69	403

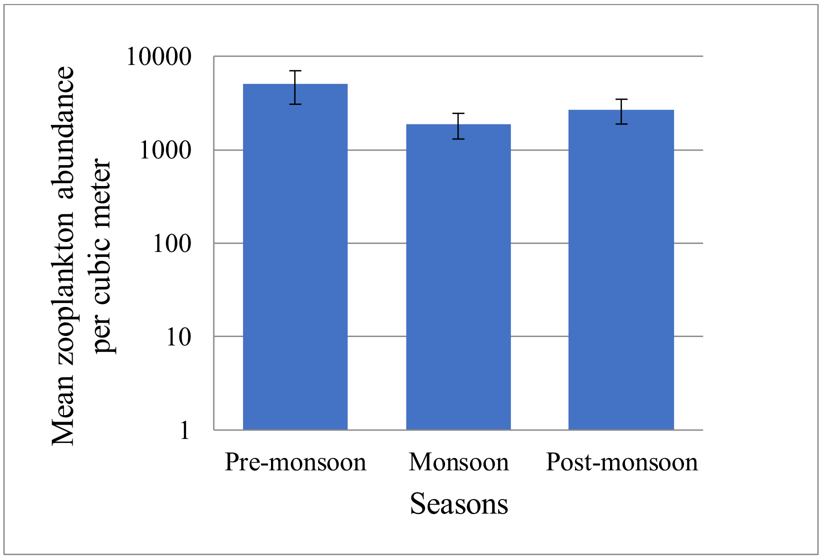

Figure 5. Mean (± SE) abundance of zooplankton (individual's m^{-3}) across three seasons in anicut dam.

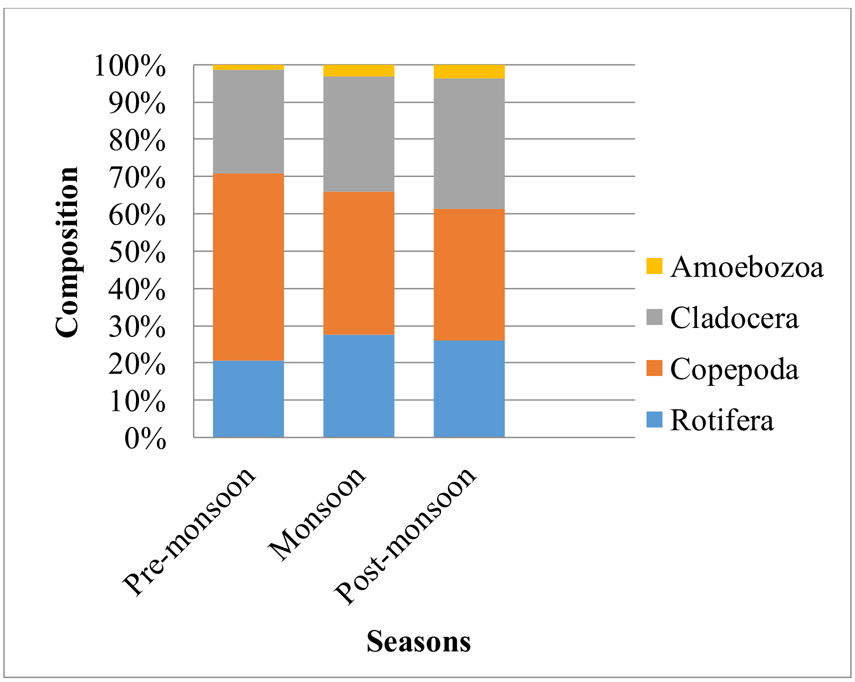

Figure 6. Relative distributions (%) of zooplankton taxa across three seasons in anicut dam of Kangsabati River of Paschim Medinipur.

Table 3. Season-wise mean value and standard error of physicochemical parameters from February 2024 to January 2025.

Parameters	**Pre-monsoon**	**Monsoon**	**Post-monsoon**
pH	7.7±0.08	7.45±0.02	7.57±0.05
Water temperature (°C)	27.85±0.12	25.35±0.19	20.82±0.07

Hardness ($mg{\cdot}L^{-1}$)	82.5±0.79	71.25±00	86.66±1.61
Alkalinity ($mg{\cdot}L^{-1}$)	78.33±2.02	82.5±1.25	91.66±2.08
Ammonia ($mg{\cdot}L^{-1}$)	0.19±00	00±00	0.13±00
Nitrite ($mg{\cdot}L^{-1}$)	0.04±0.002	0.025±0.001	0.05±0.006
Phosphate ($mg{\cdot}L^{-1}$)	0.009±0.001	0.07±00	0.013±0.004
TDS (ppm)	98.25±0.64	112.83±0.82	101.41±1.46
Free CO_2 ($mg{\cdot}L^{-1}$)	5.66±0.31	9.33±00	16±0.33

Note: The one-way ANOVA test showed statistically significant differences between groups ($F_{8,18} = 232.40$, $p < 0.001$). The effect size was extremely large ($\omega^2 = 0.986$). Even though the heterogeneity of variances was detected by Levene's test based on means ($p = 0.003$), even Welch's ANOVA showed statistically significant differences between groups ($F = 913.10$, $p < 0.001$

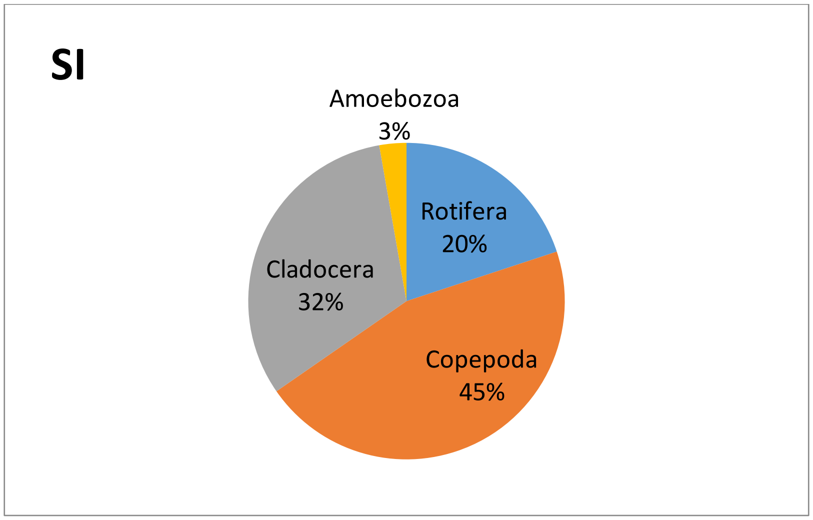

Figure 7a. Sampling station -I (SI) show that copepod 45%, cladocera 32%, rotifer 20% and amoebozoa 3%.

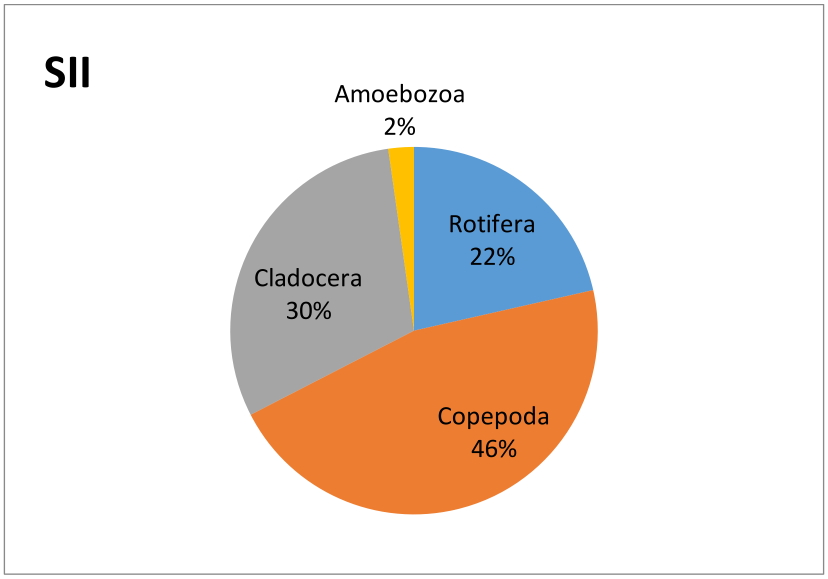

Figure 7b. Sampling station-II (SII) show that copepod 46%, cladocera 30%, rotifer 22% and amoebozoa 2%

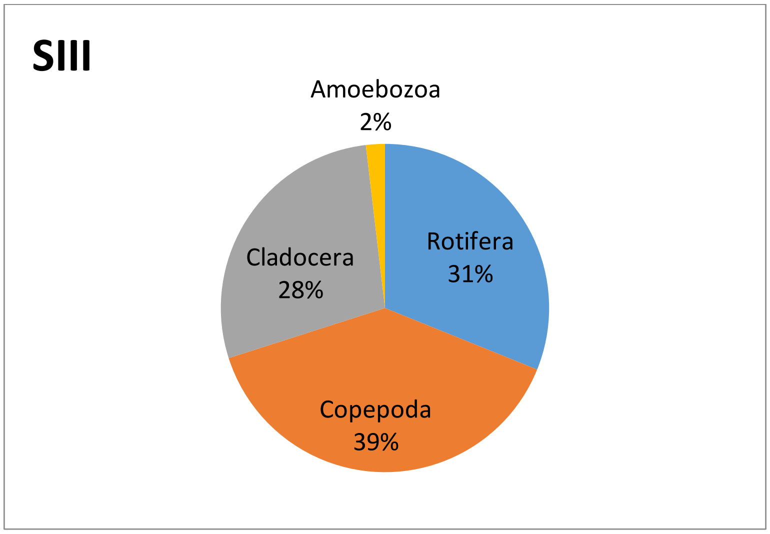

Figure 7c. Sampling station-III (SIII) show that copepod 39%, cladocera 28%, rotifer 31% and amoebozoa 2%

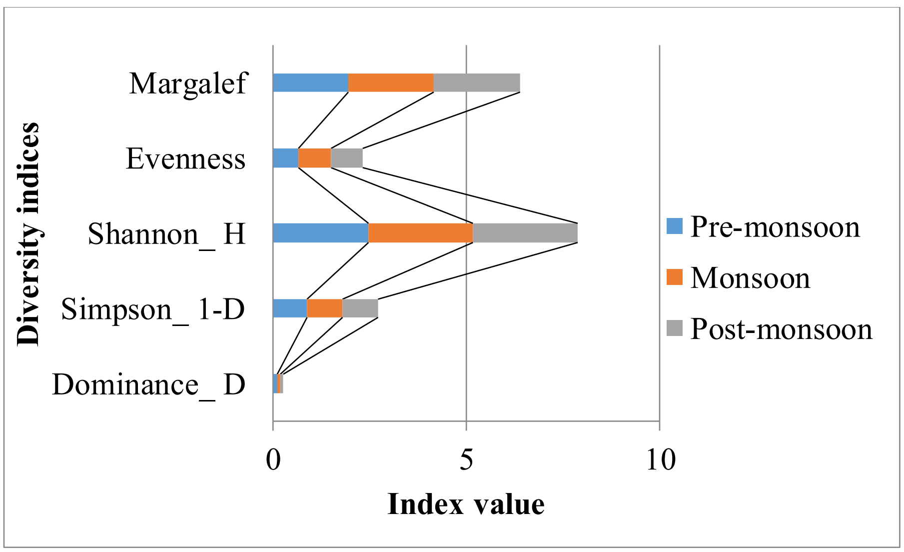

Figure 8. Diversity index in three seasons at anicut dam of Kangsabati River from February 2024- January 2025.

4. DISCUSSION

CCA ordination analysis results show that the dynamics of physicochemical parameters affected the zooplankton structure in the selected ecosystem. Of all tested environmental parameters, temperature proved to be one of the most influential factors affecting the distribution of the species, evidenced by a long vector correlated with the Pre-monsoon season. Temperature is a well-known important ecological factor influencing the metabolism, growth, reproduction, and successions of freshwater zooplankton (Wetzel, 2001; Lampert and Sommer, 2007). The association between *Brachionus sp*., *Lepadella sp*., *Thermocyclops sp*., and *Diaptomus sp*. and the temperature vector shows that these species favour warm conditions where primary productivity increases. *Brachionus sp*. and *Lepadella sp*. being found on the positive side of the first axis indicates that they live in relatively warmer and more productive water. This conclusion is in line with past research suggesting that the density of rotifers such as those belonging to the genus *Brachionus sp*. increases in warm and highly nutritious waters (Gama-Flores et al., 2020), who noted that rotifers' abundance tends to increase with increasing temperatures and nutrients. Rotifers can react quickly to changes in the environment because of their short life cycle (Sarma & Nandini, 2026). The significant positive relation between *Diaptomus sp*., *Bosmina sp*., and *Diaphanosoma sp*. and both pH and ammonia levels indicates that these species prefer moderately alkaline conditions and environments that have high nutrient content. Previous research revealed that abundance of cladocerans and copepods increases in productive ecosystems, where high nutrient content stimulates phytoplankton production and consequently provides more food for zooplanktons (Dodson et al., 2000; Jeppesen et al., 2011). Relation to ammonia can be associated with increased cycling and decomposition processes taking place within an ecosystem. Monsoon season appeared to correlate significantly only with phosphate and TDS. The cause of high phosphate levels as well as the high levels of dissolved solids is due to an increase in the watershed runoff during times of heavy rains that deliver dissolved materials, sediments, and nutrients to the water body (Li et al., 2025). Such taxa as *Mytilina sp.*, *Keratella sp.*, *Platyias sp.*, and *Chydorus sp.* had positions adjacent to phosphate and TDS vectors, which means that these species are adapted to nutrient-rich environments. Similar trends have been observed during research conducted on tropical freshwater systems in which the species richness of rotifers and cladocerans is higher during monsoon months (Rahman et al., 2025). The increase in precipitation and runoff during this period makes the water bodies enriched in nutrients, thus promoting the productivity of zooplankton populations. Additionally, the introduction of allochthonous organisms and the formation of microhabitats during this period have contributed to the richness of rotifers and cladocerans. Because of the distance of the above-listed zooplankters from the dominant environmental vectors, their association with the physicochemical factors is weak. Thus, other ecological factors like predation pressure, competition, prey quality, diversity of habitats, and even hydrological processes could influence the distribution of these zooplanktons. According to (Lampert and Sommer, 2007) the dynamics of zooplankton communities depend on both biotic and abiotic interactions and could not always be reflected by measured factors.

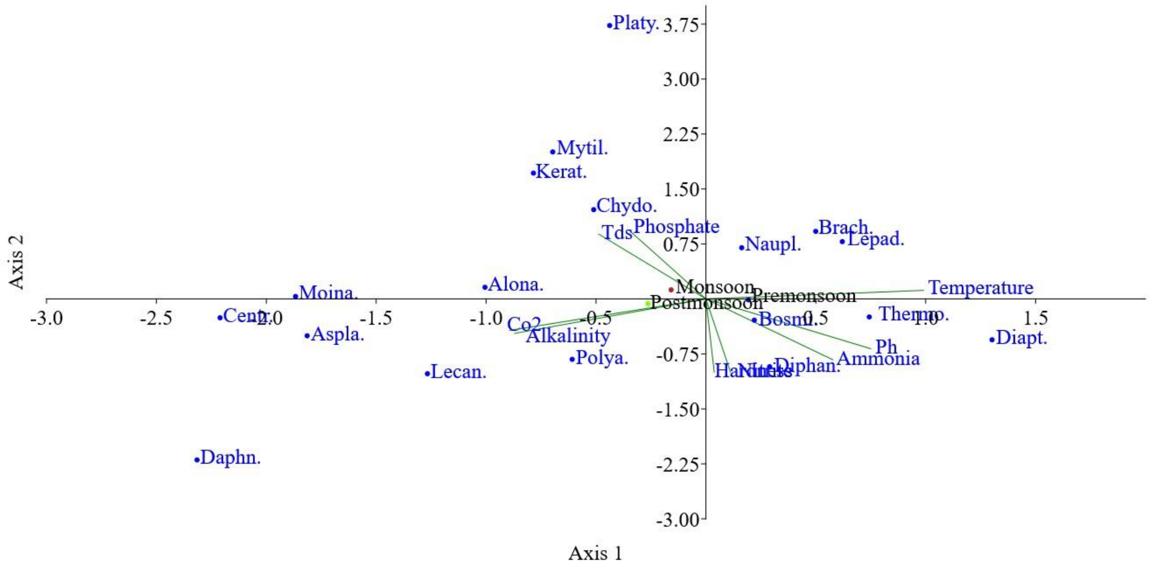

Figure 9. Canonical correspondence analyses between environmental parameters and genera of zooplankton in Anicut Dam, Paschim Medinipur.Chydo = *Chydorus* sp.; Polya = *Polyarthra* sp.; Lepad = *Lepadella* sp.; Kerat = *Keratella* sp.; Daphn = *Daphnia* sp.; Aspla = *Asplancha* sp.; Mytil = *Mytilina* sp.; Platy = *Platyias* sp.; Cent = *Centropyxis* sp.; Alon = *Alona* sp.; Brach = *Brachionus* sp.; Lecan = *Lecane* sp.; Moina = *Moina* sp.; Diapt = *Diaptomus* sp.; Ther = *Thermocyclops* sp.; Naupl = Nauplius larvae; Bosmi = *Bosmina* sp.; Diphan = *Diphanosoma* sp.

Post-monsoon is positioned near the centre of the ordination plot, meaning that its environmental characteristics are between pre-monsoon and post-winter. This indicates that the post-monsoon zooplankton community depends on both the available nutrients from the monsoon period and improved water quality. Transitional positions were observed for zooplankton in lakes due to seasonal changes influencing zooplankton composition and succession (Wetzel, 2001). In general, the results of CCA indicate that temperature, phosphate, TDS, pH, and ammonia were significant environmental parameters influencing the spatial variation in zooplankton, where temperature was the main controlling parameter during the pre-monsoon and nutrients played more significant roles during monsoon. These results reveal that changes in environmental parameters during seasons significantly affect zooplankton distribution, emphasizing that environmental factors are vital in the establishment of biodiversity patterns in freshwaters (Ji et al., 2025). Hardness and nitrite had negative associations with Axis 2 and had more affinity with *Bosmina sp.* and *Diaphanosoma sp.* Hardness is one of the essential physicochemical components of water, which refers to the water content of calcium and magnesium ions. The high hardness level in water could influence physiological processes, growth, and skeleton formation in cladocerans (Wetzel, 2001). The affinity of *Bosmina sp.* and *Diaphanosoma sp*. to hardness implies that this zooplankton could be more advantageous under a mineralized environment. In a similar vein, nitrite had a negative effect on Axis 2 and was found to be related to taxa located in the vicinity of the lower-right quadrant of the ordination plot. Nitrite is an intermediary compound in the process of nitrogen metabolism and could be formed because of the decomposition of organic matter and microbial action (Dodds and Whiles, 2020). Slightly elevated levels of nitrite would help zooplankton populations indirectly by promoting higher productivity levels via nutrient cycling. Nonetheless, highly elevated levels of nitrite could create physiological pressures on aquatic organisms. These results suggest that, despite the dominance of temperature and phosphate, hardness and nitrite had some impact on shaping zooplankton assemblages. Vectors of hardness and nitrites, on the other hand, appear to be relatively short compared to vectors of temperature and phosphates. Thus, their effect on variation was relatively weaker, while temperature, phosphates, pH, and ammonia were found to play significant roles in determining the distribution of the zooplankton population in your study area. This should be highlighted in your manuscript discussion. The results of the current study clearly showed that the zooplankton abundance was highest during the Pre-monsoon season and next highest during the Post-monsoon season. The high zooplankton abundance in Pre-monsoon could have been due to high water temperatures, enhanced productivity of phytoplankton, and relative stability of water hydrology (factors that are favorable for zooplankton production and development). On the contrary, the decrease in the population of zooplankton during the monsoon period might be linked to greater quantities of water in terms of both volume and turbulence, thus decreasing the amount of time that plankton remain in the water column (Wetzel, 2001).

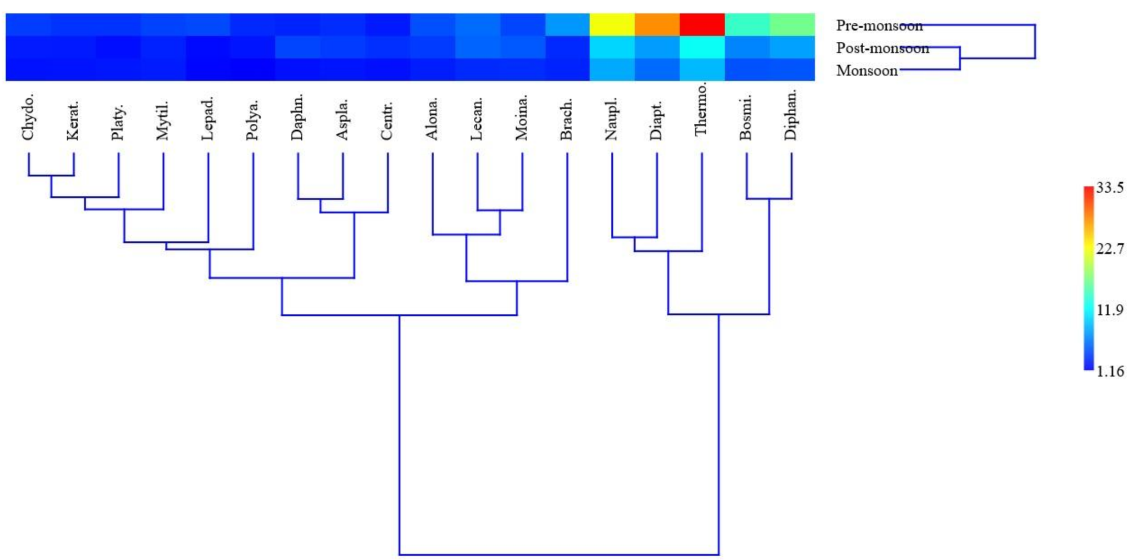

Figure 10. Bray-Curits analysis of zooplankton genera of anicut dam, Kangsabati River, PaschimMedinipur. Chydo = *Chydorus* sp.; Polya = *Polyarthra* sp.; Lepad = *Lepadella* sp.; Kerat = *Keratella* sp.; Daphn = *Daphnia* sp.; Aspla = *Asplancha* sp.; Mytil = *Mytilina* sp.; Platy = *Platyias* sp.; Cent = *Centropyxis* sp.; Alon = *Alona* sp.; Brach = *Brachionus* sp.; Lecan = *Lecane* sp.; Moina = *Moina* sp.; Diapt = *Diaptomus* sp.; Ther = *Thermocyclops* sp.; Naupl = Nauplius larvae; Bosmi = *Bosmina* sp.; Diphan = *Diphanosoma* sp.

The prevalence of Copepoda species throughout the investigation shows that they are highly adaptable to the prevailing conditions. Copepods usually form the dominant zooplankton population in freshwater ecosystems because of their large ecological range, efficient feeding mechanisms, and abundance of food sources (Allan and Castillo, 2007). Besides, copepod nauplii account for a significant proportion of abundance since they demonstrate continuous reproduction and fast population turnover (Ravera, 2001). The second group in terms of abundance, Cladocera, had considerable seasonality of occurrence because of favourable conditions related to the food supply and physicochemical characteristics of the environment. Cladocerans are known as excellent filter feeders with a positive response to an increase in phytoplankton biomass, which is used as an indicator of high ecosystem productivity (Dodson et al., 2000). Thus, the occurrence of the following taxa can be explained by their abundance of *Bosmina sp., Diaphanosoma sp.,* and *Daphnia sp.* The third abundant species was Rotifera, and its occurrence displayed significant seasonality. Rotifers have rapid reproductive rhythms and short life cycles, which allow them to quickly adapt to changing conditions (Sarma & Nandini, 2026). Low relative abundances of amoebozoa species could be due to the specific niche occupied by such species in terms of preferred habitats and type of organic substrates. Protozoans are known to depend on available microbial food sources and habitat characteristics rather than environmental variables affecting metazoan zooplankton (Wetzel, 2001). On balance, a well-organised zooplankton community structure characterised by copepods, followed by cladocerans, rotifers, and amoebozoans, is evident in the current study. The increased relative abundance during the Pre-monsoon period further emphasises the impact of seasonality on the regulation of zooplankton. This trend is consistent with findings made in tropical and subtropical freshwater ecosystems due to favourable environmental conditions such as increased temperature and productivity (Jeppesen et al., 2011; Lampert and Sommer, 2007).

5. CONCLUSION

There is seasonal variation in the composition of zooplankton and water quality in the Anicut Dam ecosystem. High zooplankton density, copepod dominance, and water temperature in the pre-monsoon period showed favorable conditions for growth of a few dominant species, leading to low diversity. The increased TDS and phosphate in the monsoon period affected rotifer density. In the post-monsoon period, there was an increase in the density of cladocerans and amoebozoans with high diversity. The increased alkalinity, nitrite, and free CO_2 in the post-monsoon period affected community structure. Clustering analysis showed that pre-monsoon and post-monsoon periods were more alike compared to monsoon periods, indicating the impact of the season on the environmental gradients in determining the structure of zooplankton communities. The dam ecosystem is moderately productive and ecologically stable in general, although anthropogenic effects from human activities such as picnics in the area and industrial activities may affect the community composition. Continuous monitoring of biological and physicochemical parameters is necessary for the sustainability and conservation of aquatic biodiversity within the ecosystem.

The future studies should emphasize the long-term studies of planktons, fish communities, and water quality as a response to growing pressures from humans and climate variations. The implementation of bio-indicator based assessments as well as multivariate analysis would be useful for better evaluation of ecosystem health.

Acknowledgement

We wish to express our sincere gratitude to Vidyasagar University for providing the necessary facilities and support throughout the course of the study. We are also thankful to the Department of Fisheries Sciences for the technical assistance and cooperation. Finally, we are grateful to all those who contributed directly or indirectly to the successful completion of this research.

Author contributions

All authors have read and approved the final version of the manuscript. The authors believe that this manuscript represents honest work done by us.

Funding

This research did not receive any external funding like specific grant from funding agencies in the public, commercial, or nonprofit sectors.

Conflict of Interest

The author declare that they have no conflicts of interest, competing financial interest or personal relationship that could have influenced the work reported in this paper.

Informed consent

Not applicable.

Ethical approval & declaration

In this article, as per the Zooplankton associated ethical regulations followed in the Department of Fishery Sciences, Vidyasagar University, Midnapore 721102, West Bengal, India; the authors observed the Seasonal Dynamics, Diversity, and Environmental Drivers of Zooplankton Assemblages in the Anicut Dam of a Kangsabati River Ecosystem, Paschim Medinipur, India. The ethical guidelines for Zooplankton & National Biodiversity Authority Guidelines are followed in the study for observation, identification & experimentation.

Data and materials availability

All data associated with this study will be available based on the reasonable request to corresponding author.

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