

Environmental characterization of two ecologically distinct Gangetic oxbow lakes using zooplankton taxonomic indices through comparative approach for wetland monitoring

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Abstract

The present investigation attempted environmental characterization of two ecologically distinct oxbow lakes through zooplankton taxonomic indices using a comparative approach. These closed and seasonally open oxbow lakes are subjected to eutrophication due to different nutrient concentration and eco-hydrological characteristics. The zooplanktons are closely link with surrounding environment throughout their life cycles and change rapidly, hence act as potential indicator of eutrophication. The study examined the assemblage pattern of zooplankton community and trophic state of two ecologically distinct oxbow lakes based on eco-hydrological factors and community structure of rotifers and planktonic crustaceans seasonally over a period of 2 years. Comprehensive trophic state index (mTSI), rotifer trophic state index (mTSI_{ROT}) and Crustacean based indices (TSI_{CR}) were used to assess the degree of eutrophication. The Kruskal-Wallis test confirmed the heterogeneity of the eco-hydrological factors between the oxbow lakes. Both lakes showed transition from high meso-eutrophic to moderately eutrophic state with mTSI, mTSI_{rot} and mTSI_{cr} values of 54.90±11.71 and 56.95±15.64, 59.55±4.54 and 60.26±4.48, 55.79±4.76 and 60.00±4.03 in Khalsi (seasonally open) and Akaipur (closed) respectively. The Canonical Correspondence analysis (CCA) revealed water quality parameters comparison NO₃⁻N, water temperature and pH have contributed more in enhancement of abundance of eutrophication indicator species *Brachionus* and *Keratella*. An overview of worldwide use of rotifer and crustacean based indices in assessment of TSI has also been synthesized. The use of these zooplankton indices to evaluate the trophic status of the ecologically distinct lakes is highly recommended for water quality assessment and management.

1. Introduction

The oxbow lakes are characterized by shallow depth, high sediment nutrient, high productivity, well mixing of nutrient (Janseen et al. 2014; Tang et al. 2018, 2019). These lakes offer a plethora of ecosystem services for livelihood and nutritional security to the riparian communities (Sarkar et al. 2020; Das et al., 2021). These provide safety from natural calamities, serve as habitat for larval rearing, nutrient recycling, water for domestic and irrigation purpose, fishing activities and also considered as “Kidney of ecosystem” due to its efficient sinking capacity to inhale major agricultural runoff (Sarma and Dutta 2012; Meena et al. 2019; Karnatak et al., 2020; Sarkar et al., 2020, 2021a; Sarkar et al., 2021b).

Oxbow lakes, mainly distributed in eastern and northeastern India are important fishery resources. The fisheries in these lakes are enhanced and managed by integrated resource revival practice based on a combination of fisheries (culture based fisheries, enclosure culture), agriculture, horticulture practices and other jute ratting practices (Chaudhuri et al. 2008; Ghosh and Biswas 2015). Despite of huge potential these water bodies are neglected and being used irrationally. A number of wetland health assessment tools have been applied i.e. macrobenthos based multimetric indices (Meena et al. 2019), phytoplankton indices (Roshith et al. 2018), water quality index (WQI) (Sharma and Bora, 2020), biomonitoring and bioassessment (Sanyal et al., 2015), fish assemblage and fisheries (Sandhya et al., 2016; Sandhya et al., 2019) etc. They have limitations in terms of real time application such as high fluctuations due to climatic and water quality factors. Anthropogenic pressures resulting from agriculture and industrial developmental activities have accelerated degree of eutrophication of freshwater ecosystem worldwide (Junk et al. 2014). Different types of bioindicator are widely used to assess the aquatic ecosystem health using physical, chemical and biological parameters comprehensively (Oh et al. 2017). Trophic state is one of the most important characteristics to classify nutritional load of an aquatic ecosystem (Jekatierynczuk-Rudczyk et al., 2014; Dembowska et al., 2015; Ejsmont-Karabin et al., 2016; Wen et al., 2017; Smaoune et al., 2020). Various environmental factors are applied to measure the trophic status of a lake. One of the most widely used trophic status indices for classifying lakes based on total phosphorus (TP), Secchi depth (SD) and concentration of Chl a is Carlson trophic status index (Carlson and Havens, 2005; Abell et al., 2020). Chlorophyll a concentration proxies the phytoplankton biomass which directly involves in signifying the production functions of aquatic ecosystem (Das Sarkar et al., 2021). Easiest one is based on SD but its measures are inclined by both algal and non-algal particulate matters. Zooplankton is one of the important biotic component and a sensitive indicator of water quality, vital for maintaining overall ecosystem productivity and stability of food web (Branco et al., 2002; Kumari et al., 2017; Doukhandji and Arab, 2017; Tang

et al. 2019; Smaoune et al., 2020). Trophic status of lakes based on zooplankton such as Rotifers and Crustaceans have been widely used to assess degree of eutrophication in shallow lakes worldwide (Ejsmont-Karabin, 2012; Jekatierynczuk-Rudczyk et al., 2014; Dembowska et al., 2015; Ejsmont-Karabin et al., 2016; Smaoune et al., 2020) and found promising in assessing trophic status of lake.

Although, several reports are available on zooplankton based diversity indices including abundance, community structure from India (Ganesan and Khan 2008; Sharma 2009, 2011; Sharma and Sharma 2012) and Bangladesh (Biswas and Panigrahi 2015), however, studies limited to the diversity indices for the lakes. A few studies have attempted relation between species richness and assemblage pattern based on macrozoobenthos as well as rotifers to evaluate the wetland health (Kumari et al. 2017; Meena et al. 2019; Ejsmont-Karabin, 2012; Dembowska et al., 2015), crustacean (Jekatierynczuk-Rudczyk et al., 2014; Xiong et al., 2016). Therefore, in the present study Rotifer trophic state index (TSI_{ROT}) and crustacean trophic status index (TSI_{CR}) developed by Ejsmont-Karabin (2012) and modified by Ejsmont-Karabin and Karabin (2013) respectively have been used to estimate ecological quality standard of the two different type of shallow open water bodies. This is promising tool in management of lake, understanding about the trophic status and features of Lake can be ascertained.

Rotifer and crustaceans based indices for evaluating the degree of eutrophication and relationship of index with environmental factors are promising for shallow lakes. In the view of above, the present investigation was an attempt to determine spatio-temporal patterns and trends of physico-chemical factors by perusal of zooplankton structured taxonomic indices for revealing spatiotemporal dynamics mediated intensity of eutrophication in two lower Gangetic Oxbow lakes. Thus, lake managers and policy makers to develop guidelines for ecosystem based fisheries management approach for oxbow lakes could utilize outcomes of the study.

2. Materials And Methods

2.1 Study area

Two Oxbow lakes Khalsi and Akaipur located $25^{\circ}59'54.02''N$ $88^{\circ}38'27''E$ and $23^{\circ}05'14.14''N$ $88^{\circ}42'56.22''E$, West Bengal, India, respectively (Fig. 1) were selected for study during March 2014- February 2016, Whereas the period were divided as pre-monsoon (March to May), monsoon (June to August), post-monsoon (September to November) seasons and Winter (December- February) respectively. Major activities in the catchments of both lakes include; intensive agriculture, habitat for birds, cattle, orchards and human habitation. These lakes are subjected to culture based fisheries management practices involving stocking of both indigenous and exotic carp seed to provide livelihood support to the 500 and 300 fishers families, respectively (Meena et al., 2019). Both the lakes are located in the lower Gangetic deltaic regions that subjected to the influence of runoff from agricultural land and domestic wastes, silt materials from the catchment due to jute retting, bathing, washing etc. Both the selected lakes are ecologically distinct. Akaipur oxbow lake has lost its perennial connectivity with the flushing channel, while Khalsi oxbow lake still maintains a feeble connectivity with the adjacent rivulet facilitating annual flushing. Dominant submerged macrophytes (*Hydrilla verticillata*, *Ceratophyllum demersum*, *Vallisneria* sp. and floating aquatic vegetations (*Eichhornia crassipes*, *Pistia stratiotes*, *Nelumbo nucifera*, *Salvinia molesta*, *Lemna* etc.) have occupied a greater part of Khalsi wetland (40-45%) distinguishing it from Akaipur, where only sporadic occurrence of aquatic plants was noticed (10-15%) during the study period. Floating and submerged macrophyte is providing setlater and breeding habitat for many small indigenous fish species in lakes. Water Framework Directive (WFD) has provided guidelines for standard sampling frequency to effectively monitor biotic and abiotic variables of a lake (EC, 2000). The sampling frequency to address the seasonal variability and inter-annual changes are followed as per guidelines of WFD.

2.2 Water sample collection

Seasonal water quality sampling such as water temperature transparency, pH, dissolved oxygen (DO), electrical conductivity (EC), total alkalinity, total hardness; major dissolved nutrients such as nitrate (NO_3^-) and phosphate (PO_4^-) and Chlorophyll a (Chl a) concentrations were collected from 3 different fixed sites of each lakes. To analyze the physicochemical quality, major nutrients and Chl a concentration, 1,000 ml water was collected in plastic bottles with double stoppers from each sampling station. Water temperature, pH, conductivity was measured using a multi-parameter pcstest 35 (Eutech) in situ; water transparency was measured by using Secchi-disc. Dissolved oxygen was measured following modified Winkler's method (Strickland and Parsons 1972). The dissolved inorganic nutrients (NO_3^- and PO_4^-), total alkalinity and total hardness were analysed in laboratory following standard methods (APHA 2005). For chlorophyll a (Chl a) measurement standard spectrophotometric method (HACH Spectrophotometer, DR 2800, Germany) was used (APHA 2005).

2.3 Plankton data collection and analysis

The sampling protocol for zooplankton was followed as prescribed by Sharma and Sharma (2012) respectively. Taxonomic identification to the lowest possible taxon using standard keys was carried out following standard literature Koste (1978), Battish (1992), Segers (1995) and Nogrady & Segers (2002) for rotifers Edmondson (1959), Victor and Fernando (1979), Sehgal (1983), Benzie (2005) and Dussart Defaye (2001) for cladocerans and copepods. Verification and confirmation of taxonomic nomenclature was follows for rotifers International Commission on Zoological Nomenclature (<http://iczn.org/lan/rotifer>), the Cladocerans (Kotov et al. 2013) and Copepods (Walter and Boxshall 2018). Abundance of zooplankton was expressed as ind/l. Aliquot of 5ml sample out of 50ml sample (50 ml sample concentrated from 5litres of lake water) were taken randomly after mixing, used for counting in a Sedgewick-Rafter chamber under an inverted microscope (Zeiss-Winkel) .

Biovolumes of zooplankton were assessed following equations based on geometrical formulae best fitted for each body shape (Ruttner-Kolisko 1977). Thirty organisms of each selected species were selected randomly of same taxon, length, width and height were measured and best fitted geometrical shape formulae were applied. Biovolume of each taxon was converted to fresh weight assuming a specific density of (1×10^{-6}). The fresh weight (FW) was later converted to dry weight (DW) (Schindler and Noven 1971; Bottrell et al. 1976). Biomass of ostracods was calculated following Lehette and Hernández-León (2009). Biovolume of Copepod nauplii were assumed 0.400 μg as suggested by Hawkins and Evans (1979). Zooplankton biomass calculated by multiplying wet weight of individual zooplankton with abundance. Phytoplankton biomass was assessed based on chlorophyll a estimation following Vörös and Padisák (1991).

To determine the ecological indices, number of zooplankton taxa present in each season was included in calculation excluding copepod nauplii and unidentified zooplankton. The commonly used index for biological system was Shannon-Wiener diversity index (H'), computed to characterize species diversity of zooplankton community. Shannon-Wiener diversity index was used both for comparing two distinct water bodies on temporal and spatial scale and to evaluate the health of water bodies. Index value greater than 3 indicates clean water while values in the range of 1–3 are indicates moderate pollution (Mason 1996).

Species diversity and homogeneity were calculated using the Shannon-Wiener diversity index H' (Shannon and Wiener, 1949) using the following equations:

$$H' = -\sum_i P_i (\ln P_i)$$

Where, P_i is the probability of the i^{th} species

The Margalef's richness index (Margalef, 1958) indicates species richness computed by considering number of species.

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

Where, D= Margalef's richness index, S= number of species and N= Total number of individuals

Evenness index J' (Pielou, 1966), which indicates the degree of evenness of distribution of species in a sample, was determined by following formula

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

Where, H' = Shannon diversity index and S = total number of species in a sample, across all samples in database.

The numeric trophic state index (TSI) was used for qualitative assessment of trophic states for the lakes (Carlson 1977 and Adamovich et al. 2016). The wetland trophic status classified on a numerical scale between 0-100 is given in Table 1.

Table 1
The topographic details and land use pattern of Oxbow lakes

Information	Khalsi	Akaipur
Area of lakes (Ha)	65	28
Coordinate	25°59'54.02"N 88°38'27"E	23°05'14.14"N 88°42'56.22"E
Bioclimate	Semi-Aride	Semi-Aride
Pre-monsoon season	March-May	March-May
Monsoon season	June-August	June-August
Post-monsoon	September-November	September -November
Winter	December-February	December-February
Mean depth (cm)	177	160
Managed by society	KhalsiUdvastuMatsyjiviSamanvayaSamittee Ltd	AkaipurDwarvasini Fishermen Cooperative Society Ltd
River connectivity	Ichhamati river	Ganga river
Water salinity	Freshwater	Freshwater
Connectivity with river channel	Seasonally open	Closed
Macro-vegetation	Floating, submersed and marginal	Floating, submersed and marginal
Water use	Irrigation, Fisheries, Domestic, Cattle bathing, washing and Jute rating	Fisheries, Cattle bathing, washing and Jute rating
Fisheries management	Culture based fisheries, enclosure culture	Culture based fisheries, enclosure culture
Dominant species	Small Indigenous fish Pethia sp. Puntius sp. Chanda sp.	Small Indigenous fish Pethia sp. Puntius sp. Chanda sp.

$$mTSI = (TSI_{Chl-a} + TSI_{TP} + TSI_{SD})/3$$

The individual trophic state index (TSI) of Chlorophyll a (Chl-a), total phosphorus (TP) and Secchi disk transparency (SD) were calculated as follows.

$$(1) TSI_{Chl-a} = 9.76\ln(Chl-a) + 30.91$$

$$(2) \text{ TSI}_{\text{TP}} = 14.43 \ln(\text{TP}) + 4.15$$

$$(3) \text{ TSI}_{\text{SD}} = -14.39 \ln(\text{SD}) + 59.91$$

Rotifer is one of the biotic components, which is used as an indicator of aquatic ecological health (Ejmont-Karabin, 2012). Rotifer community structure have been used for rotifer trophic status index (TSI_{ROT}) by following equations given by (Ejmont-Karabin, 2012)

$$(1) \text{ TSI}_{\text{ROT1}} = 5.38 \ln(\text{Nr}) + 19.28; \text{ where Nr number of rotifer (ind/l)}$$

$$(2) \text{ TSI}_{\text{ROT2}} = 5.38 \ln(\text{B}) + 64.47; \text{ where B biomass of rotifer (mg ww /l)}$$

$$(3) \text{ TSI}_{\text{ROT3}} = 3.85(\text{B}/\text{Nr})^{-0.318}$$

$$(4) \text{ TSI}_{\text{ROT4}} = 0.144 \text{ TECTA} + 54.8; \text{ percentage of spineless form (tecta) in abundance of } \textit{Keratella cochlearis}$$

$$(5) \text{ TSI}_{\text{ROT5}} = 0.203 \text{ IHT} + 40.0; \text{ number of species contributed to the high trophic status indicator group}$$

The mean value of TSI (mTSI_{ROT}) obtained from of above five equation is used as an indicator of Ecological status of lakes.

Crustacean based indices (TSI_{CR}) was developed by Ejsmont-Karabin & Karabin (2013) for estimation of Crustacean based trophic status indices has followed for Trophic index of lakes is given below;

$$(6) \text{ TSI}_{\text{CR1}} = 25.5 \text{ Nr}^{0.142}; \text{ where Nr number of crustacean abundance (ind/l)}$$

$$(7) \text{ TSI}_{\text{CR2}} = 57.6 \text{ B}^{0.081}; \text{ where B total wet cyclopoid biomass (mg/l)}$$

$$(8) \text{ TSI}_{\text{CR3}} = 40.9 \text{ CB}^{0.097}; \text{ percentage of cyclopoid biomass in the total crustacean biomass}$$

$$(9) \text{ TSI}_{\text{CR4}} = 58.3(\text{CY}/\text{CL})^{0.071}; \text{ CY/CL: ratio of cyclopoids (CY) to cladoceran biomass (CL)}$$

$$(10) \text{ TSI}_{\text{CR5}} = 5.08 \ln(\text{CY}/\text{CA}) + 46.6; \text{ ratio of cyclopoids (CY) to calanoid biomass (CA)}$$

2.5 Statistical analysis

Statistical analysis was applied on dataset of environmental and biological factors to the know the spatio-temporal variability of the studied lakes. The Spearman's bivariate correlation test was performed to explain the level of significant relationship among the environmental factors. Krushkal- Wallis test at the level of significance (5%) were used for analysis of difference among the physico-chemical water quality parameters between the oxbow lakes using SPSS 16.0. Canonical correspondence analysis (CCA) is well known multivariate method to explain the biological identified assemblage and environmental factors. The statistical analysis was performed in R (R Development Core Team 2018).

3. Results

3.1 Variations among environmental factors

During the study period, the physical and chemical water quality parameters were obtained for two years, the stations of each seasons were grouped and presented in the form of average value for both the lakes separately. Correlogram of environmental variables based on their relationship depicted in Figure 2. The size of a circle indicates the strength of the correlation and the colour indicates the direction of correlation (that is, blue = positive, orange to red = negative). Only significant correlations ($P < 0.01$) are shown in the Figure 2. The correlation statistical analysis shows highly correlated

between the variables EC and Alk ($P < 0.01$, $r = 0.85$), between EC and Hard ($P < 0.01$, $r = 0.83$), Hard and Temp ($P < 0.01$, $r = 0.73$). It was also found that $\text{PO}_4^- \text{P}$ was positively correlated with Depth ($P < 0.01$, $r = 0.66$), with Hard, Alk and EC. On the other hand, N:P were strongly negatively correlated with $\text{PO}_4^- \text{P}$ ($P < 0.01$, $r = -0.72$).

The spatio-temporal variations of each physico-chemical parameter for the both oxbow lakes are given in the Figure 3. The physico-chemical parameters measured for each lakes reflect a spatial difference in majority of variables have been confirmed by performing Kruskal-Wallis test ($P < 0.05$) except Temp, Depth, Chl a, $\text{NO}_3^- \text{N}$ and N:P ($P > 0.05$). The average water temperature (Temp) recorded during the study indicated that there is no spatial significant difference between two lakes ($P = 0.51 > 0.05$). The maximum average value (34.4°C) was recorded during PRM 2015-16 in Khalsi lake while minimum average value (22.3°C) were recorded during WIN 2015-16 in Akaipur lake. The mean value of Depth is variable ($P > 0.05$) but insignificant. The maximum depth of both the lakes was recorded during MON season of 2015-2016 and minimum during PRM of the same year. The average Chl a recorded during this study indicate that there is no heterogeneity in two lakes ($P = 0.25 > 0.05$). The maximum average Chl a value ($11.6\mu\text{g/L}$) was recorded during PRM 2015-16 in Khalsi lake while minimum average Chl a value ($1.4\mu\text{g/L}$) were recorded during PRM 2014-15 in Akaipur lake. The average value of $\text{NO}_3^- \text{N}$ and N:P recorded in the studies both lakes shows no significant difference ($P > 0.05$) between the lakes. The minimum N:P ration was recorded during the MON 2015-2016 and minimum $\text{NO}_3^- \text{N}$ in WIN 2014-2015 in Akaipur lake.

The recorded average pH values throughout the study period are illustration homogeneity in nature ($P < 0.05$). The minimum average value 7.4 was recorded at the Khalsi lake in PM 2015-2016 and the maximum average value 8.9 was recorded in the Akaipur lake during POM 2015-2016. The results show that EC follows a significant spatial variation ($P < 0.05$) between the lakes. The recorded the highest EC Value ($416\mu\text{S/cm}$) during PRM 2015-2016 in Khalsi. The minimum average value of $117\mu\text{S/cm}$ was recorded in WIN 2014-2015 in the Akaipur. The average levels of DO show a very marked spatial variation between the lakes ($P < 0.05$). The highest DO concentration was recorded in WIN season 2014-2015 in both the lakes and minimum in MON 2-15-16. The mean SD levels show a great variation ($P < 0.01$). The Akaipur were recorded very low levels of transparency (SD) in both the years of study during PRM compare to Khalsi in same season. The maximum level in Khalsi was recorded in PM 2014-2015 with 127 cm. our result shows that the Khalsi is more transparent than Akaipur. The variation of Alk (total alkalinity during our study is very remarkable ($P < 0.01$). The minimum average value was recorded in the POM 2014-2015 in Akaipur and maximum PRM 2015-2016 in Khalsi. The average value of Hard (total hardness) shows that there is spatial heterogeneity between the lakes ($P < 0.01$). The highest mean value (170 mg/L) of Hard was recorded in PRM 2015-2016 in the Khalsi and minimum (34.6 mg/L). The Khalsi recorded very high level of $\text{PO}_4^- \text{P}$ content than Akaipur during 2014-2015. The mean value of $\text{PO}_4^- \text{P}$ content significantly varies between the lakes ($P < 0.05$). The maximum $\text{PO}_4^- \text{P}$ content was recorded during MON 2015-2016 in Akaipur followed by POM in Khalsi for the same year.

3.2 Spatio-temporal variation of diversity and community characteristics of zooplankton

A total of 68 species of zooplankton were identified in the two oxbow lakes; Khalsi (54 species) and Akaipur (45 species), including Rotifera (47 species), Cladocera (12 species), Copepoda (2 orders), Ostracoda (2 species) and Protozoa (5 species). Only 3 species were *Filinia longispina*, *B. fulcatus*, *Keratella cochlearis* of rotifer was recorded throughout the study period. Species richness was recorded more in Khalsi than Akaipur lake. Relative abundance of *B. fulcatus* and *B. budapestiensis* were more than 10% each while *B. budapestiensis* is absent in Khalsi lake. *K. longisetata* was recorded in all seasons except premonsoon in Khalsi lake while absent in Akaipur lake. *K. quadrata* was found abundant in Akaipur lake where as absent in Khalsi. The maximum 14 species such as *Filinia longispina*, *Brachionus rubens*, *B. fulcatus*, *B. forficula*, *Keratella cochlearis*, *K. tropica*, *Bosmina longirostris*, *Polyarthra vulgaris*, *Ceriodaphnia cornuta*, *Moina branchiate*, *M. micrura*, *Mesocyclops sp.*, *Phyllodiaptomus sp.* and *Centropyxis aculeate* were commonly found in both the lakes. *Polyarthra vulgaris* was occasionally recorded in warmer season from premonsoon to postmonsoon and absent in winter.

The 21 species/genera viz. *Polyarthra dolicoptera*, *Filinia longiseta*, *F. opoliensis*, *T. longiseta*, *P. quadricornis*, *B. Calycifluous*, *B. caudatus f. austerogenitus*, *K. longiseta*, *K. tropica*, *Mytilina mucronata*, *M. ventralis*, *Lecane unguulate*, *Testudinella patina*, *Synchaeta sp.*, *A. herricki*, *Leydigia sp.*, *Cypris sp.*, *Stenocypris sp.*, *Diffugia corona*, *Vorticella sp.* and *Colpodia colpodia* are recorded only in Khalsi lake with varying abundance and frequency. A total of 10 species /genera viz. *K. quadrata*, *T. cylindrica* *P. multiappendiculata*, *Lepadella patella*, *L. ploenensis* *L. luna*, *Alona verrucosa*, *Notholca sp.*, *Asplanchna brightwelli* and *Diaphanosoma* were observed only in Akaipur lake with varying seasonal abundance and frequency (Table 2). Out of 12 species / taxa of cladocerans *Ceriodaphnia cornuta*, *Moina branchiate* and *M. micrura* were recorded few in number during monsoon seasons in Khalsi lake. *Mesocyclops sp.* and *Phyllodiatomus sp.* were recorded throughout the study period but higher abundance during monsoon and pos-tmosoon. Number of naupli was decreased in 2015-16 as compared to 2014-15.

Table 2. Relative abundance, frequency, and seasonality of rotifers encountered in the different oxbow lakes between April 2014 and March 2016

S.N	Name of Species	Khalsi Oxbow lakes					Akaipur Oxbow lakes				
		RA	RFSeasonally				RA	RF Seasonally			
			PRM	MON	POM	WIN		PRM	MON	POM	WIN
1	<i>Scaridium lingicaudum</i>	+	C	-	-	O	+	A	-	R	-
2	<i>Polyarthra vulgaris</i>	+	O	O	O	-	+	O	O	O	-
3	<i>P. multiappendiculata</i>	-	-	-	-	-	+	R	-	-	A
4	<i>P. dolicoptera</i>	+	O	O	-	F	-	-	-	-	-
5	<i>Filinia longispina</i>	+	O	R	O	O	+	O	R	R	O
6	<i>F. terminalis</i>	+	-	O	F	O	+	R	R	F	F
7	<i>F. longiseta</i>	+	-	-	C	O	-	-	-	-	-
8	<i>F. opoliensis</i>	+	-	-	-	A	-	-	-	-	-
9	<i>Trichocerca similis</i>	+	-	O	C	-	+	-	-	F	F
10	<i>T. longiseta</i>	+	-	-	-	A	-	-	-	-	-
11	<i>T. cylindrica</i>	-	-	-	-	-	+	-	R	A	-
12	<i>T.sp</i>	+	O	R	O	R	-	-	-	-	-
13	<i>Anuraeopsis fissa</i>	-	-	-	-	-	+	-	-	A	-
14	<i>Platyias polycanthus</i>	+	O	R	O	R	+	-	A	-	R
15	<i>P. quadricornis</i>	-	-	-	-	-	-	-	-	-	-
16	<i>Cephalodella gibba</i>	+	R	F	O	-	+	-	-	A	-
17	<i>Brachionus rubens</i>	+	R	O	R	O	+	-	C	R	O
18	<i>B. fulcatus</i>	+	R	O	R	O	++	R	F	R	O
19	<i>B. forficula</i>	+	-	O	R	O	+	R	R	R	F
20	<i>B. budapestiensis</i>	-	-	-	-	-	++	C	R	R	R
21	<i>B. Calycifluous</i>	+	R	F	-	O	-	-	-	-	-
22	<i>B. patulus</i>	+	F	-	-	F	+	-	F	-	O
23	<i>B. quadridentatus</i>	-	-	-	-	-	+	R	O	R	O
24	<i>B. caudatus f. austerogenitus</i>	+	-	O	-	F	-	-	-	-	-
25	<i>B. caudatus</i>	+	-	O	R	F	+	O	R	R	O
26	<i>B. diversicornis</i>	+	R	O	-	F	+	O	-	O	F
27	<i>B. angularis</i>	+	-	O	-	C	+	-	-	-	A
28	<i>Keratella cochlearis</i>	+	O	F	O	R	+	R	F	R	O
29	<i>K. quadrata</i>	-	-	-	-	-	+	O	R	O	O
30	<i>K. longiseta</i>	+	-	R	F	F	-	-	-	-	-
31	<i>K. tropica</i>	+	O	O	O	A	+	-	C	R	O

32	<i>Mytilina mucronata</i>	+	O	O	O	A	-	-	-	-	-
33	<i>M. ventralis</i>	+	O	O	O	A	-	-	-	-	-
34	<i>Monostyla</i> spp.	+	-	O	-	C	-	-	-	-	-
35	<i>Lecaneungulata</i>	+	-	O	-	C	-	-	-	-	-
36	<i>L. bulla</i>	+	-	-	-	A	+	R	-	-	A
37	<i>L. ploenensis</i>	-	-	-	-	-	+	-	-	-	A
38	<i>L. luna</i>	-	-	-	-	-	+	F	O	-	-
39	<i>L.sp</i>	-	-	-	-	-	+	-	R	F	F
40	<i>Testudinella patina</i>	+	O	-	-	F	-	-	-	-	-
41	<i>Lepadella patella</i>	-	-	-	-	-	+	O	O	-	O
42	<i>L. sp</i>	+	-	-	-	A	-	-	-	-	-
43	<i>Synchaeta</i> sp.	+	F	-	-	F	-	-	-	-	-
44	<i>Notholca</i> sp.	-	-	-	-	-	+	-	-	O	O
45	<i>Asplanchna brightwelli</i>	-	-	-	-	49	+	O	-	O	O
46	<i>A. herricki</i>	+	-	F	-	F	-	-	-	-	-
47	1. sp	+	F	-	O	O	+	O	-	O	C
48	<i>Bosmina longirostris</i>	+	O	-	O	F	+	R	-	O	C
49	2. sp	+	-	-	O	C	+	R	R	R	C
50	<i>Ceriodaphnia cornuta</i>	+	R	O	F	R	+	O	-	R	F
51	<i>Moina branchiata</i>	+	-	R	R	C	+	-	-	F	F
52	<i>M. micrura</i>	+	R	O	O	O	+	F	-	O	F
53	<i>Moinodaphnia macleayi</i>	+	-	-	-	A	+	-	-	-	A
54	<i>Alona verrucosa</i>	-	-	-	-	-	+	-	R	R	C
55	<i>A. sp.</i>	+	R	-	-	A	-	-	-	-	-
56	<i>Leydigia</i> sp.	+	-	-	-	A	-	-	-	-	-
57	<i>Daphnia lumhottzi</i>	+	-	R	-	A	+	-	F	R	F
58	<i>Daphnia</i> sp.	+	-	-	-	A	+	-	-	-	A
59	<i>Diaphanosoma</i>	-	-	-	-	-	++	F	R	R	O
60	<i>Mesocyclops</i> sp.	++	R	O	F	R	+	O	F	O	-
61	<i>Phyllodiaptomus</i> sp.	++	R	R	F	F	+	R	R	O	F
62	<i>Cypris</i> sp.	+	-	-	A	-	-	-	-	-	-
63	<i>Stenocypris</i> sp.	+	F	-	F	-	-	-	-	-	-
64	<i>Stylonychia pustulata</i>	+	O	-	C	-	-	-	-	-	-
65	<i>Centropyxis aculeata</i>	+	O	-	C	-	+	R	-	O	C

66	<i>Diffugia corona</i>	+	-	R	F	F	-	-	-	-	-
67	<i>Vorticella sp.</i>	+	-	-	-	A	-	-	-	-	-
68	<i>Colpodia colpodia</i>	+++	-	-	O	C	-	-	-	-	-

Note:

RF: relative frequency (A, abundant with RF = 100–81%; C, common with RF = 80–61%; F, frequent with RF = 60–41%; O, occasional with RF = 40–21%; R, rare with RF = 20–0%)

RA: relative abundance (+++with RA >11%, ++ with RA = 6–10%, + with RA = 5–1%)

PRM: Premonsoon; MON:monsoon; POM:postmonsoon; WIN: winter; - :absent

3.3 Diversity indices

The result of the various indices such as diversity (Shannon-Wiener H'), richness (Margalef D), evenness (Pielou J') of both lakes varies significantly. The H' ranged from 2.231 (post-monsoon) to 3.315(winter) with mean value of 2.588±0.09 in Khalsi lake and 1.88 (winter) to 2.81 (post monsoon) with mean value 2.426±0.12 in Akaipur lake. The species richness (D) value oscillates from 0.79 (winter) to 0.9425 (monsoon) with mean value of 0.86±0.06 in Khalsi lake where as in Akaipur lake ranged between 0.72 (winter) to 0.957 (post-monsoon) with mean value of 0.870±0.11. Pielou evenness (J') was recorded lowest 0.61 (winter) and highest 0.87 (pre-monsoon) with an average value of 0.71±0.06 in Khalsi lake. In Akaipur lake J' value varies from 0.68 (winter) to 0.80 (pre-monsoon) with mean value of 0.74±0.05.

3.3 Degree of eutrophication (TSI)

Trophic status was calculated based on three water parameters- transparency (sechhi disk depth), total phosphorus, total chlorophyll a and two taxon based rotifer and crustaceans. TSI results show that TSI (Chla) varies significantly 33.57 (premonsoon of 1st year) – 53.48 (premonsoon of 2nd year) of study. The value indicated based on presence of chlorophyll a Khalsi lake moving towards higher mesotrophic state from oligotrophic state. In Akaipur lake TSI (Chla) oscillate from 37.14 (premonsoon of 1st year) -54.4 (monsoon of 1st year), indicated similar to Khalsi lake. The value of TSI (SD) varies from 53.03 (post monsoon of 1st year) to 70.51 (premonsoon of 2nd year) in Khalsi lake, while in Akaipur lake varies from 63.09 (postmonsoon of 1st year) -82.51 (premonsoon of 2nd year). The TSI calculated based on total phosphorus present in lake TSI (TP) ranged from 52.18 (premonsoon of 1st year) to 75.43 (post monsoon of 2nd year) (Fig. 4a and b). The mTSI insignificantly varied from 47.28±10.28 to 62.53±13.14 in Khalsi and 51±16.23 to 62.91±15.06 in Akaipur. The mTSI values indicated that both the lakes are inclined towards moderately eutrophication (Table 3).

Table 3
 Numeric scale of trophic status index (TSI) based on Chl-a, SD, TSI_{ROT} and TSI_{CR} following Tang et al. (2019), Ejsmont-Karabin & Karabin (2013) and Ejsmont-Karabin (2012)

Sl. No.	TSI	mTSI _{ROT}	Ecological status
1	0-20	<35	oligotrophic
2	20-30	35-40	low mesotrophic
3	30-40	40-45	high mesotrophic
4	40-50	45-50	low meso-eutrophic
5	50-55	50-55	high meso-eutrophic
6	55-60	55-60	slight eutrophic
7	60-70	60-65	moderately eutrophic
8.	>70	>65	hyper eutrophic

The mTSI_{ROT} values were varied 56.41±2.38 to 62.70±6.70 and 58.73±2.10 to 61.80±6.87 in Khalsi and Akaipur lakes, respectively (Fig. 4a&b). The calculated mTSI_{ROT} values indicated both the lakes were to be transition stage of slightly eutrophic to moderately eutrophic condition. The mROT_{CR} value was varied 49.26±3.44 to 62.32±6.08 and 52.63±5.68 to 67.38±2.38 in Khalsi and Akaipur lakes, respectively (Fig. 4a&b). The variation mROT_{CR} in Akaipur lake was ranged greater varies from meso-eutrophic to hyper eutrophic condition. Single peak value in mROT_{CR} was observed during monsoon of 2014-2015.

Analyses of Pearson's correlations among taxonomic diversity indices D, J, H', and trophic status indices mTSI_{ROT} and mTSI_{CR} with environmental parameters were given in the Table 4. The mTSI_{ROT} of both lakes were found to exhibit a significantly positively correlation with PO₄⁻P and Chl a and significantly negatively correlated with N:P and DO concentration. The mTSI_{CR} were also significantly negatively with N:P and positively with PO₄⁻P and Chl a correlated in both lakes. This indices were also negatively significantly correlated with Temp and DO in Khalsi lake and insignificant in Akaipur lake. The Shannon Wiener (H') is significantly positively correlated with DO concentration in both lakes but negatively with PO₄⁻P and Chl a concentration. Pielou's evenness (J) of both the lakes were highly significantly negatively correlated with water depth and positively with EC. The significance of Margalef index (D) of both lakes were highly variable.

Table 4

The Pearson correlations between taxonomic indices (Margalef index (D), Pielou's evenness (J), Shannon Wiener (H')), mTSl_{ROT}, mTSl_{CR} and environmental factors. (* P<0.05 and ** P<0.01)

	Khalsi Oxbow Lake					Akaipur Oxbow Lake				
	mTSl _{ROT}	mTSl _{CR}	D	J	H	mTSl _{ROT}	mTSl _{CR}	D	J	H
Depth (cm)	0.053	-0.162	-.663**	-.896**	-0.245	0.222	0.086	-0.115	-.354*	-0.2
SD (cm)	-0.021	0.221	0.005	-0.23	0.022	0.161	0.001	-0.337	-.604**	-.427*
Temp (°C)	-0.221	-.599**	.388*	-.382*	0.186	0.004	-0.301	0.001	-.544**	-0.2
pH	0.291	0.049	.622**	-0.11	.759**	-0.024	-0.069	0.051	-0.2	0.02
EC (µS/cm)	-0.137	-0.294	-.440*	.590**	-0.301	0.282	0.22	-0.281	-0.1	-0.2
DO (mg/L)	-.471*	-.532**	.684**	-.534**	.365*	-0.057	0.103	0.295	.531**	.379*
Alk (mg/L)	0.136	0.039	-0.246	.578**	0.022	-0.094	0.394*	-0.262	0.25	-0.1
Hard (mg/L)	0.071	0.27	-0.302	.641**	0.079	0	0.620**	-0.244	.446*	-0.1
NO ₃ ⁻ N(mg/L)	0.326	-0.207	-0.013	0.21	0.284	-.405*	-0.415*	.366*	0.03	.388*
PO ₄ ⁻ P (mg/L)	0.275*	.613**	-0.101	-0.06	-0.028	.495**	.0424*	-0.339	-.464*	-.448*
N:P	-0.193	-.456*	-0.126	0.15	-0.09	-.462*	-.577**	0.292	0.04	0.32
Chl a (µg/L)	.656**	.468*	0.002	0.29	0.226	.573**	.414*	-.434*	-.479**	-.485**

CCA was carried out to identify the important environmental factors influencing the zooplankton abundance in Khalsi and Akhaipur lake. The first axis of the CCA (CCA1) explained 23% of the total variation of the model and 15% of the variability was explained by the second component. The first two component CCA indicated that the environmental parameters including phosphate, Secchi disk depth (transparency), alkalinity, hardness, electrical conductivity, chlorophyll a and water depth are the important parameters influencing the zooplankton abundance in Khalsi lake. On the other hand nitrate, temperature, pH, N:P and DO are the important parameters influencing the zooplankton abundance in Akhaipur lake. CCA also indicated that the assemblage pattern of zooplankton in Akhaipur lake was distinct from Khalsi lake (Fig. 5).

4. Discussion

The ecological state of water quality is highly variable in shallow lakes which are disconnected from river, exclusively depend on physico-water quality parameters. The studied both oxbow lakes were significantly different based on electrical conductivity, phosphorus concentration, DO, pH, alkalinity and hardness. Differences in hydrological parameters may be attributed to riverine connectivity of lakes (Amoros and Bornette 2002) and other climatological factors (Sarkar et al. 2020). Seasonal fluctuation of water depth was significant different due to rainfall of the region and latitudinal connectivity of river channel. Water temperature is one of the influencing factors of chemical and biological process of ecosystem (Cremona et al. 2021), fluctuations in temperature were related to regional climatic conditions and air temperature. The pH value in both the lakes were recorded towards alkaline side with limited fluctuation indicating optimum level BIS (2003) for productivity. The pH is a vital component for biochemical function of aquatic ecosystem (Jena et al. 2013). Slightly higher pH value in Akhaipur lake is influenced by oscillation of metabolic activity of aquatic organism, and photosynthetic activity (Saha et al.

2021). The coverage of macrophytes in lakes also attributed to diurnal fluctuation in pH value (Rameshkumar et al. 2019). Comparatively lower pH value in Khalsi might be due to decomposition of macrophyte which is in corollary to the study of Tang et al. (2019). Bala and Mukherjee (2010) observed similar finding in Nadia wetlands of West Bengal. Dissolved oxygen (DO) is one of the health indicators of aquatic ecosystem. DO of both lakes were well within acceptable range (above 5mg/L) for ecological wellbeing. Although DO fluctuation is varying everyday depends on temperature and mixing of nutrient due to influx of runoff from surroundings (Ouhmidou et al. 2015). DO concentration in both the lakes was lowest in monsoon and highest in winter season. Heavy rain during monsoon season, may bring lots of organic matter such as plant leaves, grasses and other organic matters into the lakes, these can cause lots of microbial activity to decompose the vegetation and accelerate the use of oxygen (Mandal et al. 2012).

Chl a is one of the most important components to assess overall algal biomass of lakes and classifying to their trophic level (Gregor and Maršalek 2004). Chl a was comparatively very high in pre-monsoon (PRM) in both the lakes due to decreased water depth of lakes and increasing light penetration. Das Sarkar et al. (2021) studied precisely environmental factors influencing in Chl a concentration and reported, water temperature, total alkalinity, electrical conductivity and pH were key factor to influencing Chl a concentration in Gangetic wetlands. The concentration of Chl a in premonsoon season was higher due to favourable environmental factors. Annual average Chl a was higher in 2015-16, may be due higher influx of organic nutrient in the lakes. Enclosure culture (Pen) is encircling of fixed area depends on water depth and slope for nursery rearing and supplementary feed is permitted in these pen. Enclosure culture (pen culture) practice in initiated during 2015-16 in both the lakes might have produced higher PO_4^{3-}P , which can lead to increasing eutrophication, similarly observed in Baiyangdian lake by Wang et al. (2013). Although, nutrient concentration (NO_3^{-}N and PO_4^{3-}P) was increased from 2014-15 to 2015-16 in both the lakes, however, a slight higher increased deviation was reported in Akaipur as compared to the Khalsi. The enhanced organic nutrients particularly, NO_3^{-}N and PO_4^{3-}P due to unscientific pen culture practices in Akaipur in relation to the total water spread area of the lake as compared to the Khalsi during 2015-2016 that was coinciding the results of (Beveridge 1984). The highest concentration of NO_3^{-}N during monsoon (June to September) in the present study may be also due to the allochthonous organic input and the decomposition of the aquatic macrophytes and jute retting (Ghosh and Biswas 2018). Nutrient (NO_3^{-}N and PO_4^{3-}P) concentration was expected reason for accelerating particularly, during second year of studies, indicating transition from high mesotrophic to slight eutrophic. N:P value have decreased significantly in 2015-16 in both the lakes might be both nutrients NO_3^{-}N and PO_4^{3-}P have equally contributed towards eutrophication. Tang et al. (2019) suggested N as to be only limiting factor in Baiyangdian lake and McCarthy et al. (2007) P as limiting factor in Taihu lake, China for eutrophication. The deviation of the result in our study in contrast to this study might be due to the fact that supply of both nitrogen and phosphorus from atmosphere deposition, non-point source as agriculture runoff is potentially a significant source of increasing nutrients loads in lakes.

The pattern of zooplankton community structure and abundance are very important for the maintenance of the ecological health of the aquatic ecosystem. Zooplanktons are considered to be the ecological indicators of aquatic environment (Neto et al. 2014). Rotifers respond quickly to aquatic environmental changes due to their short life cycle and are therefore used as indicators of overall health or condition (Carriack and Schelskek 1977). Three common species *Filinia longispina*, *Brachionus fulcatus*, *Keratella cochlearis* of rotifer was recorded throughout the study period. Sharma et al. (1992) noted *Filinia longispina* is as eurytopic alkaline species. Two commonly occurring species *Brachionus fulcatus*, *Keratella cochlearis* are of the genus *Brachionus* and *Keratella*, considered as cosmopolitans and eurytopic species (Branco et al. 2002; Kumari et al., 2017) due its broader ecological value, thermal tolerance and geographical distribution (Bennett et al., 2019). Rotifer species *Filinia longispina*, *Brachionus rubens*, *B. fulcatus*, *B. forficula*, *Keratella cochlearis*, *K. tropica*, *Bosmina longirostris* and *Polyarthra vulgaris* were present in both the lakes with varying degree of abundance. *Keratella cochlearis* and *K. tropica* have been recorded from many freshwater bodies such as ponds to reservoir (Doukhandji and Arab 2017). The seven species of rotifers of both lakes have wide range of pollution tolerance (Sládeček 1983; Sharma et al. 1992, Branco et al. 2002; Kumari et al. 2017). Genus *Keratella* and *Brachionus* is considered as indication of eutrophic state of the lake due to their close association with nutrient rich surrounding environment, have been confirmed by many authors

(Branco et al. 2002; Kumari et al. 2017; Doukhandji and Arab, 2017; Smaoune et al. 2020). Genus *Polyarthra* was less abundant in both the lakes due to high nutrient availability, less tolerance and other environmental factors. García-Chicote et al. (2018) was reported as indicator of mesotrophic state, while other available reports say the occurrence of *Polyarthra* in both oligotrophic and eutrophic lakes (Obertegger et al. 2008; Obertegger et al. 2014; Karpowicz et al. 2020). In the present study, in winter (higher $PO_4^{3-}P$), *Polyarthra* were absent, therefore this genus is indicator of oligotrophic to mesotrophic state. Genus *Trichocerca* was recorded only in post monsoon and winter, when nutrient concentration was higher. Castro et al. (2005) was also reported the genus from eutrophic environment and agreed with our finding. Genus *Bosmina* was relatively abundant in throughout the seasons except in monsoon. In monsoon season, generally flow of water is higher compare to other seasons and Cladocerans usually prefer lentic water (littoral zone with macrophytes) than lotic water (Maia-Barbosa et al. 2008; Jeong et al (2015), therefore the genera was absent in both lakes in monsoon. Only cladocerans *Ceriodaphnia cornuta*, *Moina branchiate* and *M. micrura* were recorded during monsoon seasons in Khalsi because of their preference towards clear water and macrophyte dominant reasons. Mergeay et al (2006) have also found similar result and confirm their association in macrophyte dominated reasons in shallow Kenyan lakes of southern Kenya. More abundance of copepods in monsoon and post-monsoon indicated well mixing of nutrients and favorable temperature. Yin et al. (2018) also reported higher abundance of copepod in mesotrophic lake. Copepod adult have greater preference towards higher nutrient rich environment than naupli. Mathews et al. (2018) have reported that favorable temperature range 25-28°C for copepod growth and reproduction copepod. In this context monsoon and post-monsoon season is most favorable season for higher abundance of copepods. Ostracod communities have close association with aquatic macrophytes (Matsuda et al. 2015) and higher ecological tolerance (Kiss 2007). *Centropyxis*, *Diffulgia* and *Arcella* were dominant in Khalsi but *Centropyxis* in Akaipur, throughout the study period, all these protozoans are having wide range of tolerance of nutrients, found in oligotrophic to eutrophic conditions (Madoni 2011).

Measuring zooplankton Species diversity is one of the most important characteristics of aquatic ecosystem to maintain stability as means of coping with any environmental changes. We have compared the value of various indices between two lakes. We have found that lowest diversity indices H' and D from Akaipur during winter. Diversity have been decreased due to unscientific enclosure culture practice and lack of connectivity with main river channel that might have corroborated factors such abiotic factor, natural predation by copepod and cladoceran, competition for food and increasing eutrophication (Marcus 2004; Perbiche-Neves et al. 2016; Arcifa et al. 2020).

The $mTSl_{ROT}$ and $mTSl_{CR}$ values were determined annually for both the lakes but spatial as well as temporal difference was insignificant. Rotifer community among the zooplankton shows quick response to the environmental changes, is considered as highly suitable for assessing degree of eutrophication, have been confirmed by many authors (Jekatierynczuk-Rudczyk et al. 2014; Dembowska et al. 2015; Ejsmont-Karabin et al. 2016; Wen et al. 2017; Smaoune et al. 2020) (Table 5). In this study trophic state index was assessed based on rotifer and crustacean groups. The $mTSl_{ROT}$ and $mTSl_{CR}$ found positively significantly relationship with phosphorus concentration ($PO_4^{3-}P$) in both the lakes. Similar finding was reported by Xiong et al. (2016) from two subtropical lakes. Although, there are cumulative effect of many abiotic factors in changing the trophic dynamics of ecosystem $PO_4^{3-}P$ and Chl *a* showed significantly positive relationship towards eutrophication.

Table 5

The overview of selected trophic status indices methods used in various parts of world for the assessment ecological status of lakes

Country	Aquatic ecosystem type	Frequency of sampling	Period of sampling	Taxon- and trait-based trophic indices	Reference
North Eastern Poland	41 dimictic and 33 polymictic lakes	Once a year, during the summer stagnation period	1976- 2005	Rotifer based Trophic status indices (TSI _{ROT})	EJSMONT-KARABIN, 2012
Poland	12 lakes within Suwałki Landscape Park	Once	23–31 July 2009	TSI _{SD} , TSI _{Chl} , TSI _{TP} Rotifer trophic state indices (TSI _{ROT}) Crustacea trophic state index (TSI _{CRU})	Jekatierynczuk-Rudczyk et al., 2014
Eastern Poland	Jeziorak, a postglacial lake	Summer	2011-12	TSI _{ROT} TSI _{TP+SD+Chla}	Dembowska et al., 2015
India	OSMANSAGAR RESERVOIR	Monthly	December 2010 to November 2012	Based on presence of specific indicator rotifer species	Karuthapandi et al., 2015
Poland	Suwalki Landscape Park : Typical deep channel lakes, moraine lakes and shallow polymictic lakes.	Once a year	July/August 1983–1985, 2009, 2012 and 2015	Rotifer trophic state indices (TSI _{ROT})	Ejsmont-Karabin et al., 2016
China	2 Shallow lakes	Twice a month	July 2012 to June 2013	Comprehensive trophic state index (TSI) based on Chl a, SD (Secchi disk), TN (total nitrogen) and TP (total phosphorous) Tait-based indices: rotifer community Guild ratio	Wen et al., 2017
Algeria	Three reservoirs: SidiYacoub, Bakhadda, HammamBoughrara		December 2015 to November 2017	Carlson index and TSI _{ROT}	Smaoune et al., 2020
China	Han river downstream (HD), Reservoir (RE) and Tidal creek (TC)	Seasonal	July 2015, November 2015, January 2016 and May 2016	Rotifer abundance and the rotifer trophic state	Liang et al., 2019

The composition and diversity of zooplankton species with higher trophic state have well explained by combination of environmental parameters with Pearson's correlations and CCA analysis. García-Chicote et al. (2018) explained the dominance of some of the species in ecological stressful environment. Our result also shows dominance of genus *Brachionus* influenced by NO₃⁻N rich environment also supported by favourable temp and pH. According to Branco et al. 2002; Kumari et al. 2017 dominance of genus *Brachionus* is a considerably good indicator of eutrophication of the lakes.

Present study also reveals the fluctuation in species composition with high level of eutrophication and agreed by Obertegger and Manca (2011). The density of rotifers much more prevalent in both the lakes

5. Conclusion

Based on the scientific evidences, rotifers proved their strong sensitivity of nutrient load in freshwater ecosystem. The present investigation advocate the suitability of rotifers based TSIs which is first of its kind, integrating with physico-chemical mTSIs to assume and validate biological indices to suggest an indicator species for determination of water quality and ecosystem health of the lakes. The mTSI_{CR} and TSI based combination of environmental factors have revalidated our finding to assess degree of eutrophication of oxbow lakes. The study highlights the importance of understanding riverine connectivity of lakes and short term impact of enclosure culture on degree of eutrophication of lakes. The present investigation could further help us to understand the phenological mechanisms of water quality and rotifer abundance for scientific management. Nutrient concentration PO₄⁻P, temperature, Chl a, EC, Hard, Alk and SD was found to be most significant influencing factor in both lakes. Based on the finding following points can be concluded.

- Khalsi, a partially open wetland has more sinking capacity as compared to Akaipur (closed wetland) that that left a marginal scope for continue enclosure culture practices on long term basis and suggested a holistic investigation on impact assessment.
- Khalsi has more fish production potential and essential water quality parameters for open water fisheries in optimal range emphasizing upon the scientific management and ecosystem based approach for sustainable fish production to the riparian communities.
- Akaipur is required immediate intervention in terms of restricted irrational culture practices and to cutoff point source of organic load as per the sinking capacity of the wetland.
- Akaipur might be succeeding toward super eutrophication if same practices continue for long term without considering scientific management.
- Present study is first of its kind to validate the physico-chemical and biotic factors with rotifer and crustacean based indices thus advocating that rotifers can be considered as excellent indicator organism for ecological assessment, water quality monitoring and assessment of degree of eutrophication for better policy decisions.
- Thus, addressing the issues related to the eco-hydrological alteration taking place in the closed and semi-closed lakes for fisheries enhancement and carry forward ecosystem services in sustainable manner for wellbeing of the riparian community.

Declarations

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Competing interests

The authors declare no competing interests.

Disclaimer

The statements made herein are solely the responsibility of the authors

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Figures

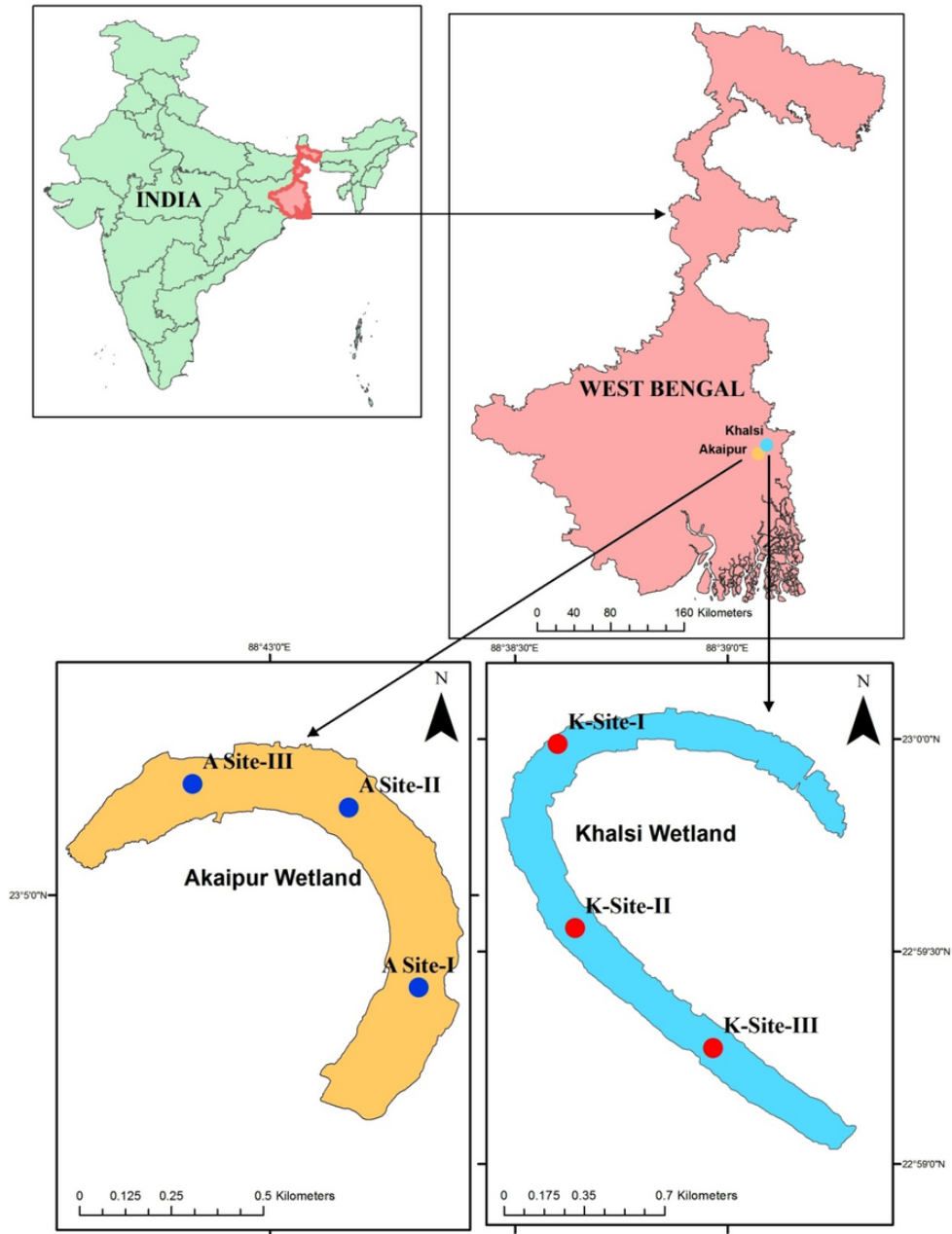


Figure 1

The Khalsi and Akaipur oxbow lakes and their sampling locations

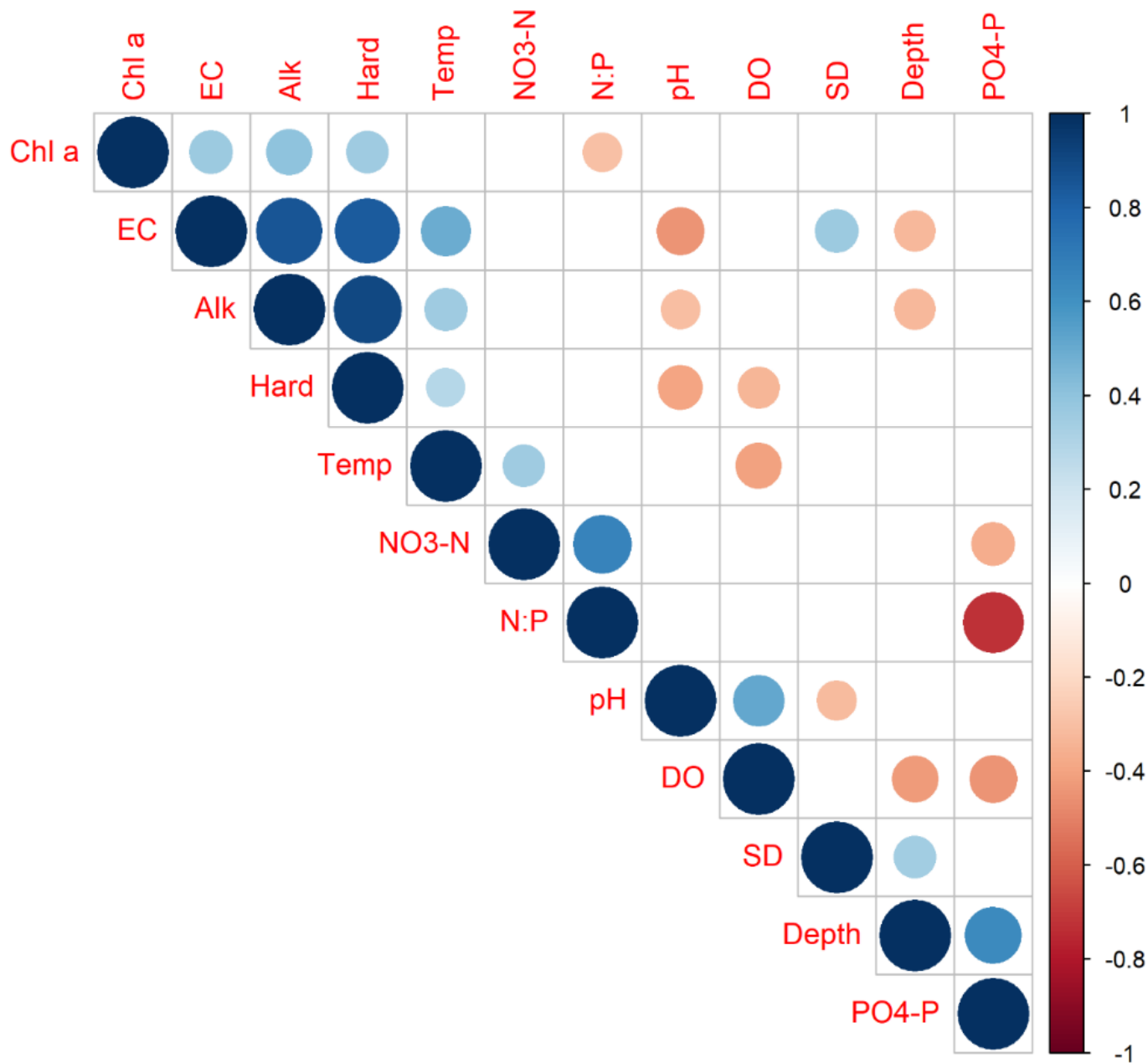


Figure 2

Correlogram of environmental variables of lakes

Note: Chl a= Chlorophyll a; EC= electrical conductance; Alk= alkalinity; Hard=hardness; Temp= water temperature; NO₃-N= nitrate nitrogen; N/P=nitrate/phosphate; DO= dissolved oxygen; SD=Scechi depth;PO₄-P= phosphate phosphorus;

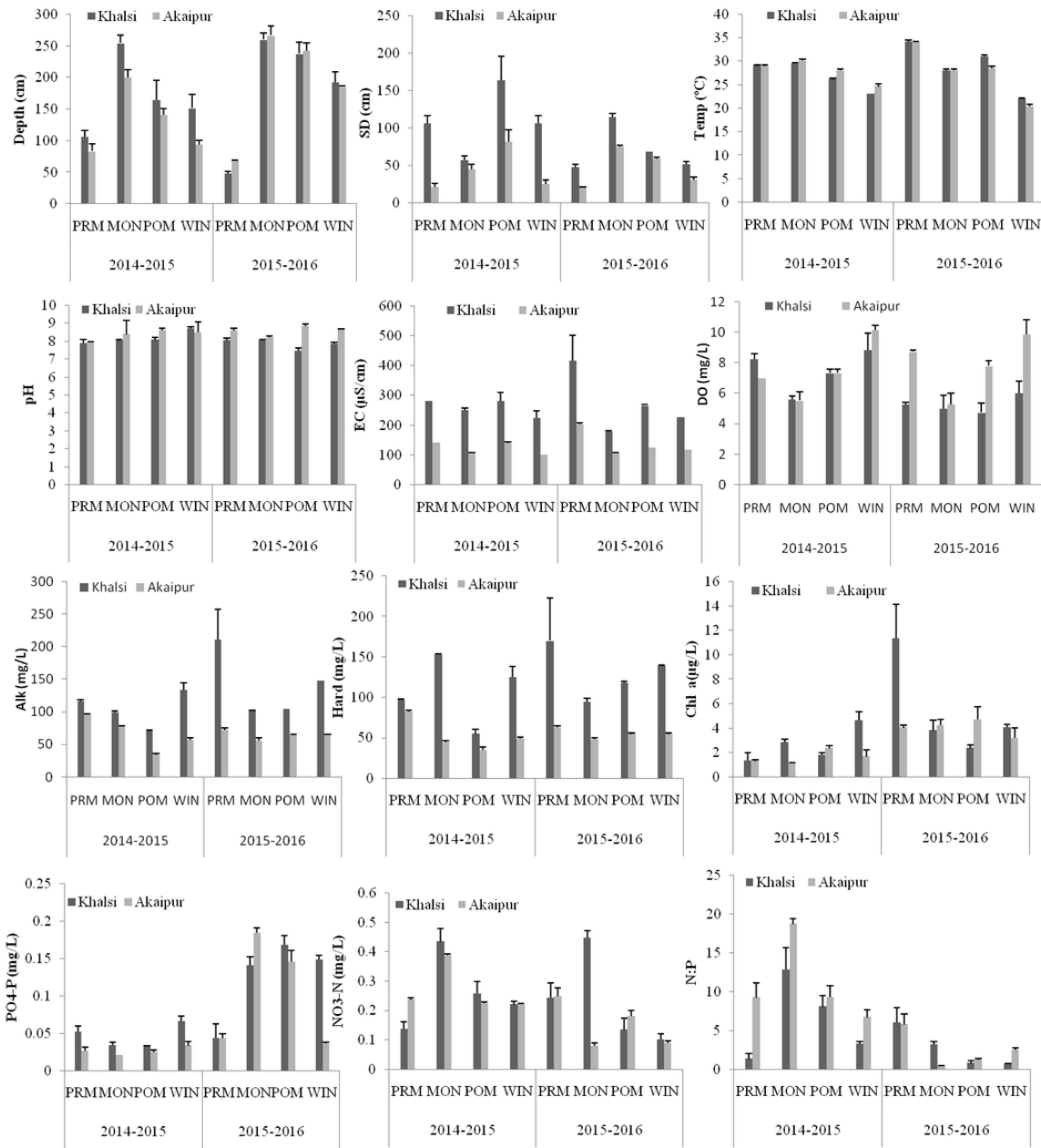


Figure 3

Spatio-temporal variations of environmental parameters *viz.* Depth, Secchi depth (SD), Water temperature (Temp), pH, Electrical conductivity (EC), Dissolved oxygen (DO), Total Alkalinity (Alk), Total Hardness (Hard), Chlorophyll a (Chl a), Phosphate ($PO_4\text{-P}$), Nitrate ($NO_3\text{-N}$), Nitrate: phosphate (N:P),

Note: PRM: Pre-monsoon season; MON: Monsoon season; POM: Post-monsoon season; WIN: Winter season

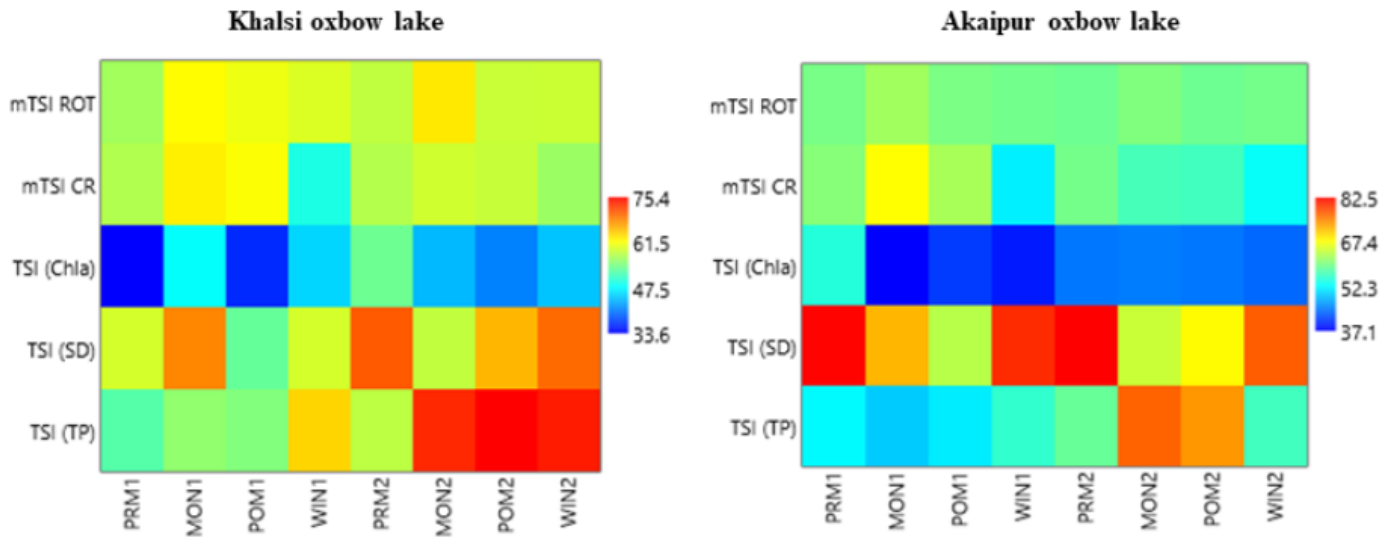


Figure 4

Temporal variation of TSI in seasonally open (Khalsi) and closed (Akaipur) oxbow lakes

Note: 1: 2014-2015; 2: 2015-2016; PRM: Pre-monsoon season; MON: Monsoon season; POM: Post-monsoon season; WIN: Winter season; mTSI ROT: mean trophic status index based on Rotifer; mTSI CR: mean trophic status index based on Crustaceans; TSI (Chl a): trophic status index based on Chlorophyll a; TSI (SD): trophic status index based on sechhi depth; TSI (TP): trophic status index based on total phosphorus

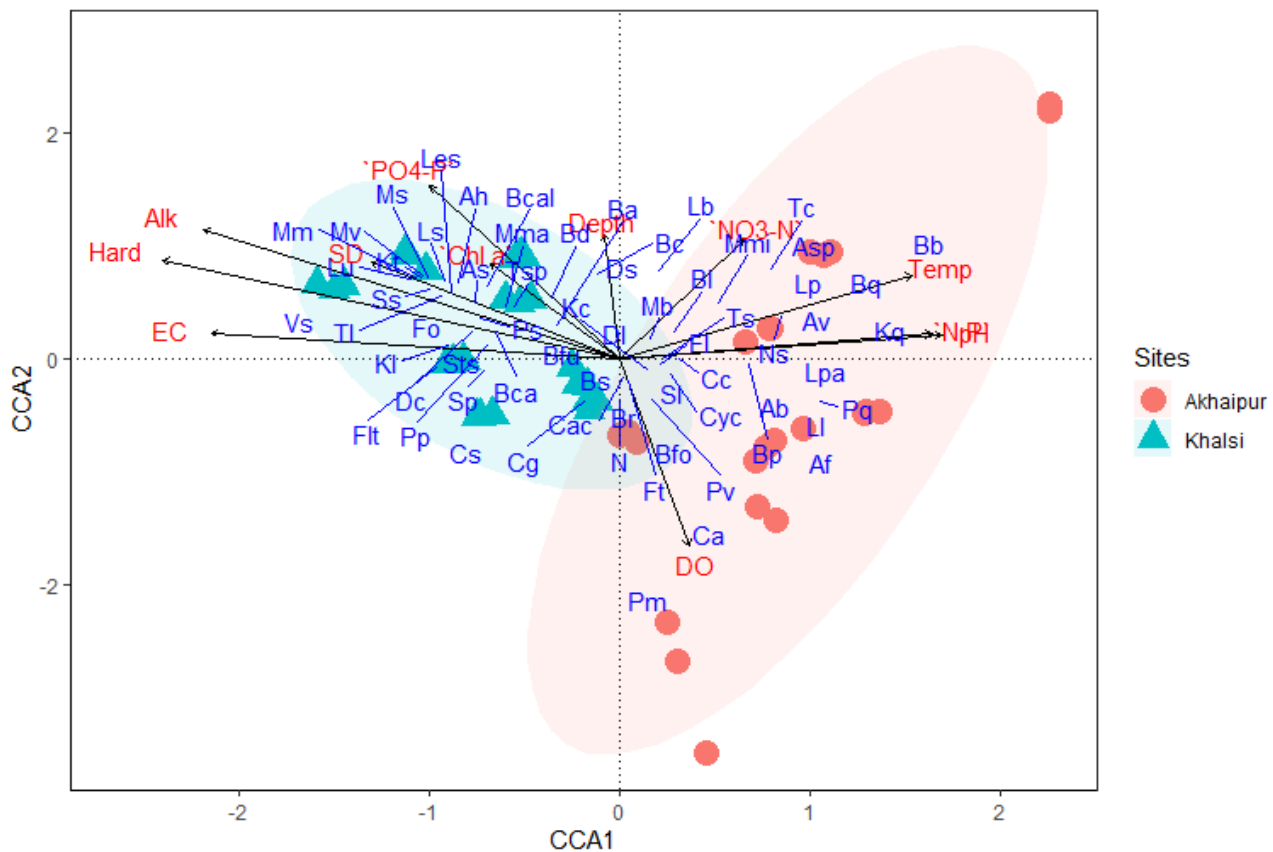


Figure 5

A canonical correspondence analysis (CCA) of zooplankton species and physicochemical parameters. Sl, *Scardium lingicaudum*; Pv, *Polyarthra vulgaris*; Pm, *Polyarthra multiappendiculata*; Ps, *Polyarthra* sp.; Fl, *Filinia longispina*; Ft, *Filinia terminalis*; Flt, *Filinia longiseta*; Fo, *Filinia opoliensis*; Ts, *Trichocerca similis*; Tl, *Trichocerca longiseta*; Tc, *Trichocerca cylindrical*; T, *Trichocera* sp.; Af, *Anuraeopsis fissa*; Pp, *Platyias polycanthus*; Pq, *Platyias quadricornis*; Cg, *Cephalodella gibba*; Br, *Brachionus rubens*; Bfu, *Brachionus fulcatus*; Bfo, *Brachionus forficula*; Bb, *Brachionus budapestiensis*; Bc, *Brachionus Calyciflorous*; Bp, *Brachionus patulus*; Bq, *Brachionus quadridentatus*; Bca, *Brachionus caudatus f. austerogenitus*; Bc, *Brachionus caudatus*; Bd, *Brachionus diversicornis*; Ba, *Brachionus angularis*; Kc, *Keratella cochlearis*; Kq, *Keratella quadrata*; Kl, *Keratella longiseta*; Kt, *Keratella tropica*; Mm, *Mytilina mucronata*; Mv, *Mytilina ventralis*; Ms, *Monostyla* spp.; Lu, *Lecane unguate*; Lb, *Lecane bulla*; Lp, *Lecane ploenensis*; Ll, *Lecane luna*; Lpa, *Lepadella patella*; Ls, *Lepadella* sp.; Ss, *Synchaeta* sp.; Ns, *Notholca* sp.; Ab, *Asplanchna brightwelli*; Ah, *Asplanchna herricki*; Asp, *Asplanchna* sp.; Bl, *Bosmina longirostris*; Bs, *Bosmina* sp.; Cc, *Ceriodaphnia cornuta*; Mb, *Moina brachiata*; Mmi, *Moina micrura*; Mma, *Moinodaphnia macleayi*; Av, *Alona verrucosa*; As, *Alona* sp.; Les, *Leydigia* sp.; Dl, *Daphnia lumhottzi*; Ds, *Daphnia* sp.; Cyc, Cyclopoid copepod; Cac, Calanoid copepod; Cs, *Cypris* sp.; Sts, *Stenocypris* sp.; Sp, *Stylonychia pustulata*; Ca, *Centropyxis aculeate*; Dc, *Diffugia corona*; Vs, *Vorticella* sp.; Coc, *Colpodia colpoda*