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Influence of environmental factors on zooplankton assemblages in Bosten Lake, a large oligosaline lake in arid northwestern China

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ABSTRACT: Water salinization in semi-arid and arid regions is threatening freshwater or oligosaline ecosystems. Anthropogenic processes enrich nutrients of aquatic systems causing significant environmental effects. Bosten Lake in Xinjiang Province, China is an interesting ecosystem featuring a salinity gradient from fresh to subsaline, as well as a nutrition gradient from oligotrophic to mesotrophic. In the present study, we focused on the effects of salinity and nutrients in Bosten Lake by investigating the zooplankton assemblages and environmental factors from different sampling times. A total of 74 zooplankton taxa were found, consisting of 34 rotifers, 26 protists, 10 cladocerans, and 4 copepods. Although no significant differences were found among different sampling sites, zooplankton species richness, diversity, and evenness showed significant differences between sampling times, with August samples showing highest values along with water temperature and total nitrogen. Principal component analysis and representational difference analysis results showed that zooplankton abundance is correlated with water temperature and nitrogen, but showed no significant relationship with water mineralization or conductivity. The subsaline-tolerating zooplankton species in Bosten Lake made their community insensitive to salinity. The decrease of total nitrogen concentration in Bosten Lake probably implied a primary productivity increase, which subsequently caused the zooplankton diversity to increase in August.

KEYWORDS: semiarid, salinization, nutrient enrichment, abundance, biomass, primary productivity

INTRODUCTION

Waters in semi-arid and arid regions (i.e., drylands with annual mean rainfall between 25 and 500 mm) are threatened by rising salinities owing to natural, and more generically, anthropogenic processes[1]. Environmental impacts of salinization include decrease of species diversity and abundance[2], change in the natural character of aquatic ecosystems, i.e., enhancement of clarification rate[3], change in the relative proportions of cations and anions[4], anoxia of bottom water[5], elevated levels of sulphate, dissolved iron and, nitrate[6], and reduction of water productivity[7]. The extent of impact of rising salinities in these waters depends upon both the range of increase in salinity and their original (natural) salinity. For the former, different salinity thresholds have even been defined along salinity gradients[8]. For example, the threshold salinity level functionally delimiting freshwater from brackish lake communities has been suggested to occur at 2 psu (practical salinity units)[9]. And the greatest impacts may occur when original salinities are low[1], for the more limited halotolerance of the freshwater biota than the biota of salt lakes. Hence freshwater or oligosaline ecosystems may be much more sensitive to salinity variations, and small increases may make big difference.

Another common impact of anthropogenic processes altering aquatic systems is nutrient enrichment[10]. It has been recognized since the 1970's that anthropogenic nutrient loading can lead to undesired algal blooms, fish death, and loss of zooplankton diversity[11]. Aquatic habitats also experience natural nutrient pulses during spring run-off turnover and rainstorms[12]. Thus nutrient pulses tend to be a major environmental factor influencing aquatic communities. Lakes that have different levels of primary productivity are characterized by different zooplankton assemblages[13]. Species composition is expected to change in response to increasing nutrient levels

Table 1 Different areas in Bosten Lake and their characteristics.

Area	Location	Characteristics
I	Huangshuigou	69% industry and agricultural wastewater are discharged into Bosten Lake through this area. The water is extensive in recent lake sediments and serious in water organic contamination.
II	Heishuiwan	Located between Dahekou and Huangshuigou. The water is rich in aquatic vascular plants.
III	Dahekou	The only freshwater entering area in Bosten Lake. The water is rich in aquatic vascular plants, intense in water exchange, high in sediment concentration, and low in salinity.
IV	Dacaohu	Average water quality. Rich in sediment concentration. Water is exchanged through wind and evaporation.
V	Lake centre	High in salinity, weak in water exchange and rich in aquatic vascular plants. Water is exchanged through wind and evaporation.

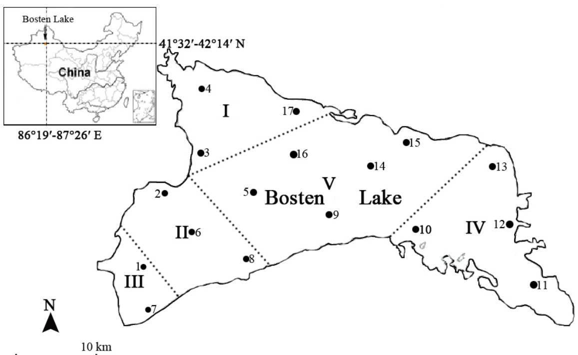

Fig. 1 Sampling sites in Bosten Lake: I Huangshuigou (3, 4, 17), II Heishuiwan (2, 6, 8), III Dahekou (1, 7), IV Dacaohu (10, 11, 12, 13), V the lake centre (5, 9, 14, 15, 16).

and productivity [13], and the diversity will also change when the initial system level was relatively low [14]. In naturally nutrient-poor habitats, increased nutrient inputs would be expected to produce an increase in species diversity – although experiments often show a reduction in diversity following experimental enrichment, possibly owing to dispersal limitation at the timescale over which the experiments are conducted [15].

The Bosten Lake basin is located in the southern arid region of Xinjiang, China, and its main functions are water resources control, irrigation, and preservation of natural habitat [16]. Bosten Lake was the largest inland freshwater lake in China before the 1960 s. In the past 50 years, however, owing to both natural and anthropogenic processes [17], it has evolved from a freshwater to an oligosaline lake, and becomes a mesotrophic lake, sometimes, reaching the light eutrophic state [18]. Bosten Lake represents an interesting ecosystem featuring a complex hydrology and an intra-system salinity gradient, as well as a nutrition gradient from oligotrophic to mesotrophic [19]. In the present study, we focused on the saline and nutrient effect in Bosten Lake to compare zooplankton assemblage and environmental factors for different sampling times. The objectives of this study were (1) to determine the zooplankton assemblage in this oligosaline lake; (2) to survey the environmental factors in Bosten Lake; and (3) to evaluate the influence of environmental factors on zooplankton communities.

MATERIALS AND METHODS

Study sites

Bosten Lake (E 86° 19′–87° 26′ and N 41° 32′–42° 14′) is the largest lake in Xinjiang, China, covering an area of 998 km^2. It has an average depth more than 8 m, and gets deeper towards the east [20]. According to different characteristics between areas, Bosten Lake can be divided into 5 areas [21] (Table 1). In the present study, we selected 17 sites to represent its five different areas (Fig. 1).

Environmental factors

The samples were collected in June, August and October in 2010. At the stations, depth-integrated samples were collected. Samples for physicochemical analyses were preserved in cold and dark conditions. Water temperature (°C), water depth (m), pH, dissolved oxygen (DO), water transparency, total dissolved solids (TDS), and conductivity were measured in situ using the YSI-6600-V2 Sonde water quality monitoring system (YSI Incorporated, USA). The concentration of the suspended matter (mg/l) was determined by measuring the dry weight of the residue after filtration through a Whatman GF/C membrane. Nutrients, including ammonium (NH_4-N), nitrate (NO_3-N), total nitrogen (TN), orthophosphate (PO_4-P) and total phosphorus (TP) concentrations were analysed by standard colorimetric techniques and were expressed as mg/l. Sub samples for quantification of chlorophyll *a*, were filtered using Whatman GF/C filters (1.2 µm pore size and 25 mm-diameter) and pigment extraction was performed with 90% acetone [22]. The concentrations were determined by the spectrophotometry based on the absorbance at 750 and 663 nm.

Table 2 Limnological characteristics of Bosten Lake.

	June					August					October				
	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
Water temp. (°C)	21.5	21.7	22.0	21.3	21.2	24.0	24.0	24.0	24.0	24.0	15.0	15.0	15.0	15.0	15.0
Water depth (m)	3.1	5.5	10.8	3.8	6.6	3.6	5.5	10.7	4.8	7.3	3.2	5.0	8.9	4.6	6.7
Transparency (cm)	180.0	346.7	490.0	240.0	296.0	150.0	213.0	230.0	163.0	258.0	160.0	303.0	300.0	265.0	268.0
pH	8.66	8.73	8.69	8.68	8.66	8.45	8.55	8.67	8.63	8.63	8.78	8.78	8.77	8.77	8.76
DO (mg/l)	6.3	7.0	6.7	6.6	6.7	7.2	6.9	7.6	7.6	7.4	7.4	7.1	6.8	6.9	7.0
BOD_5 (mg/l)	1.7	1.6	1.7	1.9	1.7	1.9	2.0	1.8	2.0	2.1	0	0	0	0	0
COD (mg/l)	2.6	2.1	2.5	2.4	2.4	2.7	2.8	2.5	2.6	2.8	2.3	2.5	2.3	2.3	2.0
Permanganate value	5.8	6.1	6.3	5.7	5.7	6.2	6.2	5.4	6.1	5.4	5.0	5.5	5.4	5.9	4.9
TDS (mg/l)	1705	1577	1580	1477	1385	1475	1613	1450	1415	1370	1450	1497	1420	1518	1424
Conductivity (µS/cm)	258	185	183	174	157	263	246	182	177	174	229	222	215	228	211
Chlorophyll *a* (µg/l)	2.63	1.30	1.41	2.04	1.62	3.11	2.49	2.39	2.02	2.37	3.75	2.25	2.94	3.08	3.34
Nitrate (mg/l)	0.38	0.39	0.40	0.38	0.42	0.25	0.27	0.24	0.24	0.29	0.28	0.26	0.28	0.28	0.30
NH_4-N (mg/l)	0.14	0.13	0.13	0.15	0.13	0.17	0.17	0.17	0.19	0.18	0.34	0.29	0.19	0.26	0.21
TN (mg/l)	1.20	0.96	0.95	1.00	0.98	0.82	0.91	0.86	0.88	0.81	1.02	1.03	1.04	0.98	0.96
TP (mg/l)	0.005	0.013	0.003	0.026	0.026	0.003	0.007	0.002	0.007	0.012	0	0	0	0	0
Fluoride (mg/l)	0.529	0.516	0.482	0.462	0.439	0.486	0.579	0.533	0.476	0.433	0.550	0.530	0.497	0.541	0.499
Chloride (mg/l)	211.5	196.7	191.7	181.8	167.1	310.0	343.0	301.0	294.0	287.0	441.0	443.0	407.0	454.0	405.0
Sulphate (mg/l)	364	333	324	310	285	545	596	516	507	496	688	691	638	710	636

* Characteristics were shown as average values for Huangshuigou (I), Heishuiwan (II), Dahekou (III), Dacaohu (IV), and the lake centre (V).

Zooplankton

Zooplankton sampling procedures were conducted in parallel to physicochemical analyses with our typical lab method[23]. Samples for qualitative analysis were collected by filtering pooled water through a No. 25 plankton net. Samples for quantitative analysis were fixed in 4% formalin, settled for 24 h, and finally concentrated to 30 ml. Zooplankton identification was performed under an Axioplan 2 imaging microscope (Zeiss, Jena, Germany). Zooplankton was presented in terms of abundance (ind/l) and biomass (µg/l). The level of community structure was assessed according to the diversity index (H')[24], Simpson index (D)[25], and Pielou's evenness index (J')[26]. These indexes were calculated from the annual average density of zooplankton:

$$H' = -\sum_{i=1}^{S} \frac{n_i}{n} \log_2\left(\frac{n_i}{n}\right),$$

where n_i is the average density of the ith species, n is the average density of the entire community, and S is the total number of species.

$$1 - D = \sum (N_i/N)^2$$

where N_i is the density of the ith species and N is the number of species.

$$J' = \frac{H'}{\ln S}.$$

Statistical analysis

Statistical significance between samples was determined by LSD (least significant difference) t test and SNK (Student-Newman-Keuls) q test performed using SPSS 16.0 for Windows. It was also used to compare physicochemical variables between all the stations and between the seasons. The species composition (0/1) matrix was used to perform the unweighted pair-group method using arithmetic averages (UPGMA) clustering with XLSTAT-Pro 2006 (Addinsoft, NY, USA). The relationships between zooplankton assemblages and environmental variable features were explored by principal component analysis (PCA) ordination using CANOCO 4.5 and representational difference analysis (RDA) following Ref. 27.

RESULTS

Environmental parameters

Physicochemical characterization of Bosten Lake was summarized in Table 2. The total dissolved solids reached a high level of 2020 mg/l in June, and the water conductivity could reach up to 372 µS/cm in August, indicating a slight salinization in this lake. Sulphate and chloride were the main ions in this lake, constituting 34% and 21% of the total dissolved solids, respectively. From the nutrient analysis of Bosten Lake, the concentration of total phosphorus was low, especially in October when it was below the detection limit (marked 0 mg/l). The concentration of total nitrogen reached its highest value in June (1.45 mg/l).

Water depths were ranged from greater than 10 m in the central site to approximately 1 m at the shallowest site of western Bosten Lake. Different sampling sites displayed roughly the same transparencies corresponding to no significant differences of physicochemical parameters ($p > 0.05$). The difference in the chlorophyll *a* concentrations between the sampling sites was also negligible ($p > 0.05$).

A significant variation of water temperature was observed between different sampling times (ANOVA, $F = 588$, d.f. $= 50$, $p < 0.001$), ranging from 11.8 °C in October to 24 °C in August (Table 2). Dissolved oxygen also changed significantly, from lowest in June to highest in August. Ammonium nitrogen concentrations reached the highest values in October and dropped to the lowest values in June. pH values were significantly higher in October. However, the concentrations of nitrate and chlorophyll *a* were significantly lower in June. Furthermore, the total nitrogen concentrations in August were significantly lower. The mineralization and conductivity values from sampling times were significantly different (Kruskal Wallis test: d.f. $= 2$, $p < 0.05$, $p < 0.01$, respectively).

Zooplankton assemblage

A total of 74 zooplankton species were found in Bosten Lake, consisting of 34 rotifer, 26 protist, 10 cladoceran, and 4 copepod species (Table 3). Most of them were widespread species, while many uncommon species, discovered mostly between submerged vegetation, were also found, e.g., *Cephalodella* sp., *Dissotrocha aculeata*, *Lecane leontina*, *L. ohioensis*, *Monostyla furcata*, *M. ornate*, *Mytilina ventralis*, and *Schizocerca diversicornis*. In addition, a brackish or marine water species—*Brachionus plicatilis*—was detected in our analysis.

Species were also varied with sampling times. *Bosmina longirostris* and *Microcyclops* sp. were common species in all samples. *Ceriodaphnia quadrangula*, Ciliate sp., *Daphnia hyalina*, *Diaphanosoma leuchtenbergianum*, *Halteria grandinella*, *Harpacticoida* sp., *Keratella cochlearis*, *Polyphemus pediculus* and *Strobilidium gyrans* were common species in June samples. *Brachionus angularis*, *Ceriodaphnia quadrangula*, *Collotheca* sp., *Euglypha* sp., *Filinia longiseta*, *K. cochlearis*, *Pedalia mira*, *Polyarthra trigla* and *Trichocerca pusilla* were common August species. While *Ciliate* sp., *Daphnia hyalina*, *Diaphanosoma leuchtenbergianum*, *Halteria grandinella*, *Tintinnidium fluviatile* and *Vorticella* sp. were common species found in October.

Zooplankton abundance in Bosten Lake were ranged from 0–810 ind/l and the average abundance was low, only 6 ind/l. The total zooplankton abundance in June samples was 7692 ind/l, with protozoa, nauplius, copepods, cladocerans, and rotifers constituting 70%, 14%, 9%, 4%, and 4%, respectively. In August samples, however, rotifers took the major part of zooplankton abundance (3065 ind/l), reaching 60%, and followed by nauplius (14%), cladocerans (12%), protozoa (10%), and copepods (4%). In October samples protozoa took the major part of zooplankton abundance of 7403 ind/l, reaching 65%, followed by cladocerans (34%) and rotifers (1%). Copepods and nauplius were rare samples in October. The zooplankton biomass in Bosten Lake were ranged from 0.27–7.80 mg/l with the average of 0.87, 0.68, 3.32 mg/l in June, August and October, respectively.

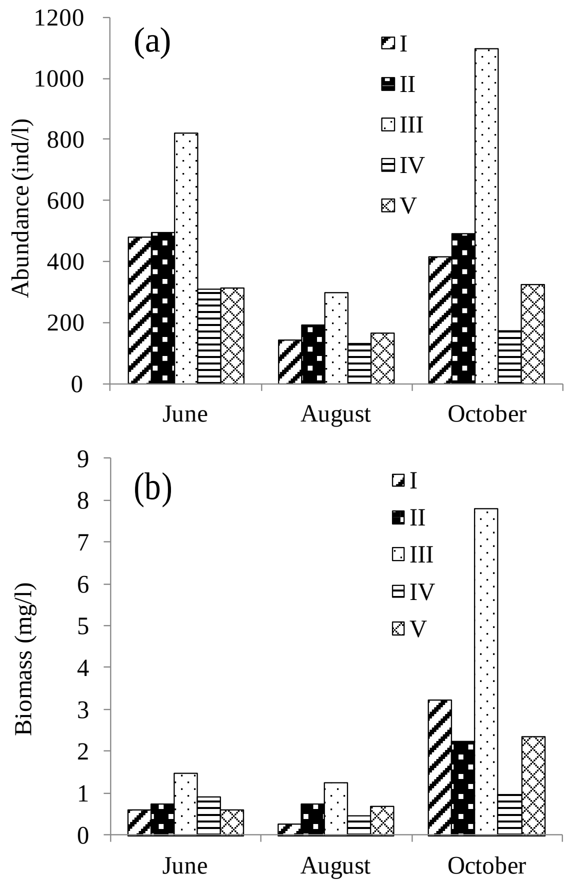

Fig. 2 Zooplankton total abundance and biomass at different sampling times: (a) total abundance and (b) biomass. I indicates samples in Huangshuigou, II in Heishuiwan, III in Dahekou, IV in Dacaohu, and V in the lake centre.

The protozoan species abundance was much higher than other zooplankton species in Bosten Lake, with *Strobilidium gyrans* reaching 194 ind/l in Octo-

Table 3 List of zooplankton species present in different sampling times.

	June					August					October				
	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
Protozoa															
Actinophrys sol Ehrenberg					+										
Arcella vulgaris Ehrenberg	+									+					
Askenasia volvox Eichwald			++								+				
Centropyxis aculeate Ehrenberg			+					+							
Centropyxis ecornis Ehrenberg					+										
Centropyxis platystoma Penard	+			++		+		+							
Ciliate sp.*	+	+	+	+	+	+	++	++	+		+	+	+++	++	+++++
Coleps hirtus Nitzsch		+	+	++											
Cyclidium glaucoma Müller														+++	
Cyphoderia ampulla Müller								+							
Cyrtolophosis sp.									+						
Difflugia globulosa Dujardin								++		++	+		+		
Difflugia oblonga Ehrenberg						+	+++	+	++			+	+	+	
Euglypha sp.						+	+	+	++	+++					
Euplotes sp.														+	+
Halteria grandinella Müller	++	+	++	+++	+++					+	+	++	+++	++++	++++
Hemiophrys sp.				+											
Histriculus similis Quennerstedt		+	+												
Lacrymaria sp.									+						
Prorodon sp.							+	+							
Strobilidium gyrans Stokes	+	++	+++	+	++									+++	+
Tintinnidium fluviatile Stein								+		+	+	+	++	+	++
Tintinnopsis wangi Nie		+											+	++	+
Trachelophyllum sp.											+			++	+
Urosoma sp.							+	+							+++
Vorticella sp.	+	+									++	+	++	+	+++
Rotifer															
Anuraeopsis fissa Gosse	+	+		+	+		+	++	+	+++	+		++		++
Ascomorpha saltans Bartsch										+++					
Asplanchna priodonta Gosse	+		+			+		++	+	+				+	+
Bdelloidea sp.*	+	+		+			++		++	+					
Brachionus angularis Gosse	+	+		++		+	++	+++	++	+++					
Brachionus calyciflorus Pallas									+	+					
Brachionus plicatilis Müller								+		+					
Brachionus quadridentatus Hermann				+					+						
Brachionus urceolaris Müller	+	++		+++	++++		+++	+++	++++	+++++	+				
Cephalodella sp.									+	+			+		
Collotheca sp.				++	+	++	+++	+++	++++	+++++			++		
Dissotrocha aculeata Ehrenberg				++	+		+		+			+		+	
Euchlanis dilatata Ehrenberg									+	+					
F. longiseta Ehrenberg				+		++	+++	+++	++++	++++		++	++		
K. cochlearis Gosse	++	+	+++	++	+++	+	+	+++	+++	++	+		+++		+
K. quadrata Müller	++	++		++++	+++				+	+		+			
K. valga Ehrenberg		+			+	++	++	+++		+++					
Lecane leontina Turner									+						
Lecane luna Müller			+	++		+									
Lecane ohiensis Herrick									+						
Lepadella ehrenbergii Perty								+							
Monostyla bulla Gosse						+			+++	+					
Monostyla furcata Murray										+			+		+
Monostyla lunaris Ehrenberg										+					
Monostyla ornata Harring & Myers										+					
Monostyla pyriformis Daday					+										
Mytilina ventralis Ehrenberg										+					
Pedalia mira Hudson		+				++	+++	+++	+++	+++++	+				
Polyarthra trigla Ehrenberg	+			+		++	+++	+++	++++	+++++			++		+
Rotifer sp.				+		+	++	+		+			+		
Schizocerca diversicornis Daday										+					
Testudinella patina Hermann				++											
Trichocerca pusilla Jennings		+				+	+	+++	++	++++			+		
Trichotria tetractis Ehrenberg					+				+						
Cladocera															
Alona costata Sars	+													+	
Alona quadrangularis Müller	+						+			+		+	+	+	
Bosmina longirostris Müller	++	++	+	++++	++	++	+	+++	++++	+++++	++	++	+++	++++	+++++
Ceriodaphnia quadrangula Müller	++	+++	++	++	++++	+	+	++	++	+++	+	+	+		
Chydorus ovalis Kurz	+	+	++	+++					+	+		+	+	++	
Daphnia hyalina Leydig	++	++	+++	++	+++		++	++	++	+++	++	+	+++	++++	+++++
Diaphanosoma leuchtenbergianum	+	+	+++	+++	++		++	+++	++++	++++	+	+	+++	++	++++
Graptoleberis testudinaria Fischer													+		
Leptodora kindti Focke	+	+	+					+				+		++	+
Polyphemus pediculus Linnaèus	+	++	++	+	++++	+		+			+				+
Copepoda															
Eucyclops macruroides Lilljeborg			+		+										
Harpacticoida sp.*	+	+	+	++	+	+				+					
Macrocyclops sp.		+		++	++				+				+	+	++
Microcyclops sp.	++	+++	+++	++++	+++++	+++	+++	+++	+++++	++++++	+	+	+++	++++	++++

The number of '+' indicates frequency of species occurrences.

* Species of Ciliate, Bdelloidea rotifer, and Harpacticoida.

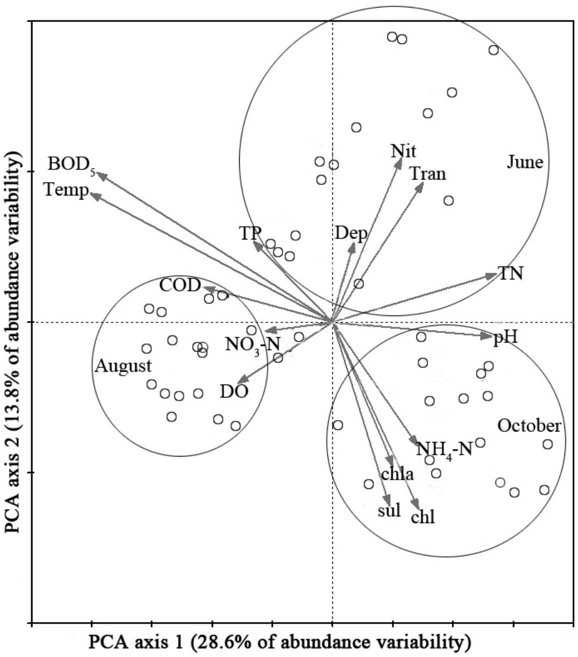

Fig. 3 Principal component analysis (PCA) of the first two axes on the zooplankton abundance data set. (DO): dissolved oxygen, (temp): water temperature, (NO_3-N): nitrate, (chla): chlorophyll *a*, (TN): total nitrogen, (TP): total phosphorus, (NH_4-N): ammonium, (Sus): suspended matter, (Tran): water transparency, (chl): chloride, (Sul): sulphate, (Per): permanganate value, (Dep): water depth. Cycles represents samples in different seasons.

Table 4 Variance (var.) explained by each environmental variable, tested by RDA method.

Variable	Explained var. (%)	Significance[a]	FW[b]
Temperature	21.5	0.01**	X
BOD_5	21.1	0.01**	
TN	9.7	0.01**	
pH	8.9	0.01**	
Chloride	8.5	0.01**	
Transparency	7.3	0.01**	X
Sulphate	7.2	0.01**	
Nitrate	6.9	0.01**	X
COD	6.7	0.01**	
NH_4-N	6.3	0.01**	
Chla	5.7	0.01**	
TP	4.8	0.05*	
Permanganate val.	4.5	0.05*	
DO	4.2	0.05*	
Depth	4	0.05*	

[a,b] Unit, P value; FW, forward selection.
* $p \leqslant 0.05$; ** $p \leqslant 0.01$; X, selected by forward selection.

ber samples. The total zooplankton species abundance in June samples was almost the same as in October samples (Fig. 2a). However, for the increase of crustacean abundance, the biomass reached highest in October samples (Fig. 2b).

The Shannon-Wiener diversity index in Bosten Lake was ranged from 1.11 in October to 2.36 in August. Similarly, the highest Simpson diversity index was detected in August, reaching 0.87. Pielou's evenness index also reached the highest of 0.83 in August and the lowest of 0.54. Through multiple comparisons, the species richness, diversity and evenness in August were significantly higher than in other sampling times (one-way ANOVA, d.f. $= 50$, $p < 0.05$, $F = 11.2$, 13.6, 14.7, respectively), while no differences were found between different sampling sites.

Environment-zooplankton relationships

PCA axes 1 and 2 represent 42% of the total variation in zooplankton community structure. Axis 1, representing the major axis of variation (29%), was positively correlated with pH and total nitrogen (Fig. 3). Axis 1 was negatively correlated with water temperature, BOD_5, COD, and dissolved oxygen. PCA axis 2 was positively correlated with nitrate concentration, water transparency and permanganate values. The second PCA axis was negatively correlated with concentration of ammonium nitrogen, chlorophyll *a*, chlorides, and sulphates.

According to RDA results, zooplankton community variation showed a significant association with water temperature, BOD_5, total nitrogen, and pH (Table 4). Suspended matter, degree of mineralization and conductivity of the water were not related to zooplankton communities. Results of the RDA for the main affecting factors on different zooplankton species are shown in Fig. 4. Temperature, nitrate and transparency could explain 31% of zooplankton abundance variability. Different species were evenly distributed along the axes, indicating a relatively high heterogeneity in Bosten Lake. Nauplius was closely related to water temperature, while *Bosmina longirostris* and *Strobilidium gyrans* were negatively correlated to water temperature. *Halteria grandinella* and *Microcyclops* sp. were significantly correlated to nitrate concentration.

DISCUSSION

Our study in Bosten Lake was carried out in the warm seasons, covering water temperatures from 11.8–24 °C. As a result, some zooplankton species preferring cold water could not be detected in our

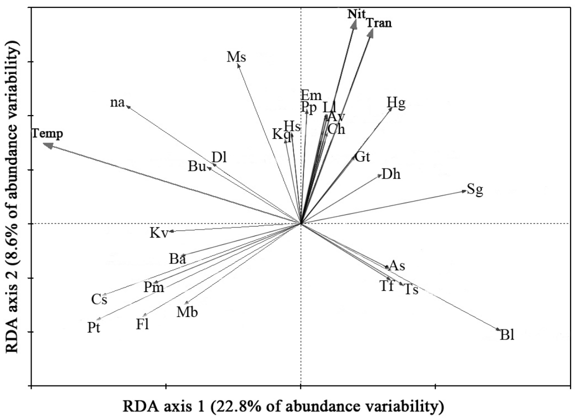

Fig. 4 Redundancy analysis (RDA) biplots of environmental factors and zooplankton abundance. The factors with major effect are depicted as solid arrows, others as thin arrows (only the significantly correlated species are depicted). As, *Actinophrys sol*; Av, *Askenasia volvox*; Ba, *Brachionus angularis*; Bl, *Bosmina longirostris*; Bu, *Brachionus urceolaris*; Ch, *Coleps hirtus*; Cs, *Collotheca* sp.; Dh, *Daphnia hyalina*; Dl, *Diaphanosoma leuchtenbergianum*; Em, *Eucyclops macruroides*; Fl, *F. longiseta*; Gt, *Graptoleberis testudinaria*; Hg, *Halteria grandinella*; Hs, *Harpacticoida* sp.; Kq, *K. quadrata*; Kv, *K. valga*; Ll, *Lecane luna*; Mb, *Monostyla bulla*; Ms, *Microcyclops* sp.; na, nauplius; Pm, *Pedalia mira*; Pp, *Polyphemus pediculus*; Pt, *Polyarthra trigla*; Sg, *Strobilidium gyrans*; Tf, *Tintinnidium fluviatile*; Ts, *Trachelophyllum* sp.

analysis. By comparing with previous zooplankton studies[20,28,29], however, we found mainly *Acanthodiaptomus* and *Daphinia cucullata* developed in cold water in Bosten Lake, and a zooplankton abundance and richness peak appeared in May to November. Thus most of the zooplankton members in Bosten Lake were part of our analysis.

As a large lake in an arid region, Bosten Lake has rich characteristics, embodied in the existence of many uncommon species not detected in other places, such as *Dissotrocha aculeata*, *Lecane leontina*, *L. ohioensis*, *Monostyla furcata*, *M. ornata*, and *Schizocerca diversicornis*, which may due to the abundant of water grasses in Bosten Lake[20]. Meanwhile, owing to the oligosalination (the average salinity detected was 1490 mg/l) in this lake, the zooplankton species diversity and abundance in Bosten Lake were low (with the averaged Shannon-Wiener index and abundance of 1.58 and 388 ind/l, respectively), comparing to reservoirs or even rivers in Xinjiang[30–32]. However, although five different areas could be divided in this lake (Table 1), zooplankton assemblage (e.g., species diversity, abundance, and evenness) did not vary among different sampling sites, corresponding to no significant differences of environmental factors (e.g., physicochemical parameters and chlorophyll *a* concentration).

By comparing zooplankton assemblage with environmental factors, we found zooplankton community varied significantly as physicochemical parameters changed between different sampling times. From June to October, dominant species varied (protozoan species in June and October, rotifers in August). Species diversity was highest in August, and cladocerans also developed in October (Fig. 2). These variations were correlated to environmental factors. Water temperature and dissolved oxygen reached highest values in August (with the average of 24 °C and 7.3 mg/l, respectively), which could cause the zooplankton peak. The pressure release of fish predator may allow cladocerans to improve in October[20]. We also found pH was positively correlated with zooplankton abundance, indicating that the higher pH in October may contribute to the cladoceran increase.

Salinity has long been considered an important influence on the composition and dynamics of aquatic ecosystems[33], and species richness of microfauna was generally negatively correlated with salinity levels in lakes[34]. Nielsen et al[35] found zooplankton species richness and abundance reduced at salinities between 1000 and 5000 mg/l. The average salinity was 1474 mg/l in Bosten Lake during our study, which meant a probable effect of saline on zooplankton community in this lake. Considering no zooplankton research had been conducted before the lake became saline, we compared variations of zooplankton communities together with water mineralization and conductivity. Although both mineralization and conductivity changed significantly during the sampling times, they were not significantly correlated with the first two main PCA axes (Fig. 3). Furthermore, they were not related to zooplankton communities according to the RDA results (Table 4). This may due to the zooplankton community adaptability in this oligosaline lake, with only subsaline tolerant members remaining.

The effects of even small rises in the salinity of fresh waters can be profound because the halotolerance of the freshwater biota is more limited than the biota of salt lakes[1]. The zooplankton in Bosten Lake, however, probably have established a community tolerant to slight salinization variations during the past 50 years. In the present study, most of the detected zooplankton taxa were freshwater species. Nevertheless, many of them have also been detected in saline lakes, for example,

Table 5 Dominant species found in Bosten Lake and examples of their existence in saline environment of previous records. Note that this table does not provide an exhaustive record of what can be found in the published literature.

Dominant species	Environment of the study site	References
Actinophrys sol	saline water	present study
Anuraeopsis fissa	saline water	39
Bosmina longirostris	saline water	40
Brachionus urceolaris	saline lake	37
Coleps hirtus	brackish water	41
Collotheca sp.	saline water	present study
Cyphoderia ampulla	salt mash	42
Daphnia hyalina	saline water	43
Diaphanosoma leuchtenbergianum	saline lake	44
Difflugia oblonga	salt mash	42
Euglypha sp.	saline water	present study
Euplotes sp.	saline water	present study
F. longiseta	saline lake	37
Halteria grandinella	saline lake	45
K. cochlearis	subsaline lake	36
K. quadrata	costal lake	2
Strobilidium gyrans	saline-alkaline pond	46
Microcyclops sp.	saline water	present study
Monostyla furcata	saline water	present study
Pedalia mira	saline water	present study
Polyarthra trigla	saline water	40

Anuraeopsis fissa, *Brachionus angularis*, *Brachionus calyciflorus*, *Brachionus quadridentatus*, *Brachionus urceolaris*, *Brachionus plicatilis*, *Euchlanis dilatata*, *F. longiseta*, *K. cochlearis*, *Lecane luna*, *Lepadella patella*, *Mytilina ventralis*, *Platyias quadricornis*, *Testudinella patina* (the salinity could reach up to 10 g/l)[36,37], which means that many zooplankton taxa in Bosten Lake have a good adaptability to salinization. Furthermore, the negative relationship between microfauna community and salinity levels in lakes may be driven by one particularly diverse or dominant taxonomic group which constitutes a significant proportion of the species in a system[38]. However, most of the dominant species in our study were euryhaline (Table 5), which may consequently determine the subsaline accustomed community in Bosten Lake.

According to RDA results (Table 4), we also found total nitrogen concentration significantly contributed to zooplankton variability in addition to water temperature. In the present study, we detected the lowest total nitrogen concentration in August samples, which may be due to the phytophankton's high reproduction in August in Bosten Lake[47]. Meanwhile, we observed the highest zooplankton diversity in August samples, although their abundances were the lowest. Hence we deduce the increase of nitrogen concentration in Bosten Lake could raise the zooplankton diversity. Empirical evidence suggests that species richness often exhibits a unimodal ("hump-shaped") pattern with increasing primary productivity[48]. Lacustrine species richness is influenced by lake productivity. Pure water in rock pools supports few or no species[49] and the most productive lakes, such as sewage lagoons, also show low species richness[50]. Lakes between these extremes of primary productivity generally have the highest species richness, at least for crustacean zooplankton[51]. The productivity of Bosten Lake was probably below the peak value of its unimodal curve. Thus with the concentration of total nitrogen getting down in August, the primary productivity of Bosten Lake increased, which led to the increase of zooplankton diversity. It is worth mentioning that this increase originate from the macrophyte, as no difference of chlorophyll *a* concentration was found between August and October samples, while dissolved oxygen reached highest in August samples. However, a more intensive analysis on both macrophyte and zooplankton community is needed to fully understand nutrient effects on zooplankton in Bosten Lake.

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