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Responses of Zooplankton Community to Environmental Factors and Phytoplankton Biomass in Lake Nansihu, China

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Authors' Contributions
HZ and WT were responsible for research design. WT drafted the main text and prepared the figures. WT, JZ, LZ, MM and HH were involved in field investigations and sampling.

Key words
Environmental factors, Phytoplankton biomass, Zooplankton community, Seasonal variation, Canonical correspondence analysis.

ABSTRACT

Seasonal variations of zooplankton community structure and their relationships with both environmental factors and phytoplankton biomass are investigated in Lake Nansihu. A total of 76 zooplankton species were identified in the lake, including 17 protozoa, 36 rotifera, 12 cladocera and 11 copepods species, respectively. Zooplankton species richness changed slightly in the four seasons but varied a lot in different positions. Protozoa was absolutely dominated in zooplankton abundance and its mean value ranged from 2710.2 ind./L in winter to 4259.5 ind./L in spring. Annual average biomasses of protozoa, rotifera, cladocera and copepods were 0.13 mg/L, 0.11 mg/L, 0.63 mg/L and 0.34 mg/L, respectively. The lowest values of zooplankton species richness, abundance and biomass appeared at the site which provides the maximum concentrations of nutrients. Zooplankton communities were more correlated to phytoplankton community biomass than environmental factors. Results of canonical correspondence analysis (CCA) revealed that water temperature, Secchi disk depth (SD), total phosphorus and phytoplankton biomass were the most significant factors that influenced zooplankton. Strong correlations between SD and *Brachionus leydigi*, Chrysophyta and *Diaphanosoma leuchtenbergianum*, Cryptophyta and *Theopilium*, *Ascomorpha ovalis*, *Hexarthra mira* were observed during the CCA. These zooplankton species may be used as indicators of relevant variables. Results in this research are very useful in guaranteeing ecological security in Lake Nansihu.

INTRODUCTION

Zooplankton is the intermediate link in aquatic food webs and it plays pivotal roles in maintaining the productivity and stabilization of aquatic ecosystems (Ware and Thomson, 2005; Svensen *et al*., 2011; Mozetič *et al*., 2012; Lacerot *et al*., 2013). Recently, more and more lakes face eutrophication caused by human activities and as a result, algae blooms or species extinction is common (Anderson *et al*., 2002; Heisler *et al*., 2008). Zooplankton is the main predator on phytoplankton and it is sensitively influenced by the fluctuations of environmental factors (Carter and Schindler, 2012; Shurin *et al*., 2012; Yang *et al*., 2012; Mozetič *et al*., 2012; Beaugrand *et al*., 2013; Eisner *et al*., 2014). Sustaining appropriate biomass of zooplankton community in changeable environments is essential to support a healthy and productive aquatic ecosystem (Jeppesen *et al*., 2011; Lacerot *et al*., 2013).

The physical and chemical variables of water, biomass of phytoplankton and the density of planktivorous fish are the main factors that influence zooplankton community (Yang *et al*., 2012; Carter and Schindler, 2012; Mozetič *et al*., 2012; Lacerot *et al*., 2013). Physicochemical conditions such as water temperature (WT) and dissolved oxygen (DO) of an aquatic ecosystem are affecting zooplankton communities through their growth rates, reproduction and metabolic rates (Mahar *et al*., 2008; Jeppesen *et al*., 2011; Carter and Schindler, 2012; Shurin *et al*., 2012; Olson and Daly, 2013). Besides, factors such as WT and nutrients can also impact zooplankton community indirectly through influencing phytoplankton biomass (Saba *et al*., 2011; Özen *et al*., 2013). Predator-prey interaction between phytoplankton and zooplankton is a widely analyzed topic in ecology (Grover, 2002; Prowe *et al*., 2012; Ye *et al*., 2013). Top-down control of zooplankton can determine the composition of phytoplankton assemblage (Vardi *et*

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al., 2002). Predation can be responsible for the breakdown of bacterioplankton blooms and the temporal changes in phytoplankton structure in a mesotrophic lake (Hennes and Simon, 1995). The intensity of predator-prey interaction between phytoplankton and zooplankton is greatly influenced by the trophic states of a lake (Carney and Elser, 1990; Elser and Goldman, 1991). In oligotrophic lakes, zooplankton is dominated by small-sized individuals whose predation ability is weak due to low food density (Carney and Elser, 1990; Elser and Goldman, 1991). In mesotrophic lakes, zooplankton is dominated by the efficient grazer *Daphnia* (Carney and Elser, 1990; Elser and Goldman, 1991; Hennes and Simon, 1995). In eutrophic lakes, phytoplankton is dominated by cyanobacteria, which is grazing-resistant species, and the growth of zooplankton is limited (Carney and Elser, 1990; Elser and Goldman, 1991). R-P-Z (Resource- Phytoplankton- Zooplankton) model can simply represent the relationships among the three trophic groups in aquatic ecosystems (Grover, 2002; Prowe *et al*., 2012; Ye *et al*., 2013). However, situations are more complicated in field lakes since both phytoplankton and zooplankton are complex in taxonomic composition and each of the group has its own ecophysiological traits (Litchman and Klausmeier, 2008; Schwaderer *et al*., 2011; Ciros-Pérez *et al*., 2015).

Lake Nansihu is an important water delivery channel and storage lake of the great South-to-North Water Diversion Project in China. The lake was in a healthy state in the early 1980s (Shu *et al*., 2012). Mean concentrations of total nitrogen (TN) and total phosphorus (TP) were 0.825 mg/L and 0.018 mg/L, respectively (Shu *et al*., 2012). There were 116 phytoplankton genera and 249 zooplankton species in the lake in the early 1980s (Zhang *et al*., 2007; Gong *et al*., 2010). The next few decades have seen the rapid industrial and economic developments in this area. A large amount of internal pollution from aquaculture and external untreated domestic wastewater, industrial wastewaters, and agricultural runoff were flowing into the lake (Zhang *et al*., 2007). Mean TN and TP concentrations reached 3.7 mg/L and 0.15 mg/L, respectively in 2000 (Shu *et al*., 2012). The lake had only 36 phytoplankton species and 28 zooplankton species in 2002 (Gong *et al*., 2010). It was thus classified as eutrophic and ecological fragile region. Situations were getting better since the construction of the great South-to-North Water Diversion Project in 2002. A series of measures for environmental managements and ecological restoration in the lake were taken by the government. Annual average concentrations of TN and TP were 1.01 mg/L and 0.09 mg/L in 2010 (Wu *et al*., 2012). There were 86 phytoplankton species and 52 zooplankton species in 2007 (Gong *et al*., 2010). The lake is now in a recovering state and the main risk in the lake is algae bloom. Due to the key roles of zooplankton community in water ecosystems, analyzing the responses of zooplankton community to the environmental factors and phytoplankton biomass is important in guaranteeing water quality and ecological security in the lake.

In this study, physicochemical values or concentrations of WT, DO, pH, Secchi disk depth (SD), TN, TP, ammonia nitrogen (NH_4^+-N), as well as the composition and structure of both phytoplankton and zooplankton communities were measured in Lake Nansihu. Seasonal shifts in zooplankton community structure at taxonomic, abundance and biomass were also recorded. The influence of environmental factors and phytoplankton biomass on zooplankton community was analyzed through linear Pearson correlation and canonical correspondence analysis (CCA). The purpose of this research is to find the main factors that influence zooplankton in the lake.

METHODS

Study area

Lake Nansihu (116°34′E~117°21′E, 34°27′N~35°20′N) is located in the north of Huai River Basin and it is the second largest freshwater lake in North China (Fig. 1). The lake has an area of 1266 km^2 and a mean water depth of 1.5 m. The capacity of the lake is about 6.37×10^9 m^3 with 54 rivers draining radially into it. Lake Nansihu is categorized as a shallow, open and plain grassland lake and it is part of the Beijing-Hangzhou Grand Canal. In summer, the water in the lake flows into Huaihe River from north to south (Gong *et al*., 2010). The climate of the lake is warm temperate monsoon with an annual average temperature of 13.7°C. The annual average rainfall of the lake is 550 mm to 720 mm and about 60% of the precipitation is in summer.

Sampling and measurements

Twelve sample sites were set according to the distribution of the lake (Fig. 1). Field investigations were conducted in July 2012, April, September and November 2013 to represent situations in different seasons.

Measurements and sampling were all carried out between 8:00 AM and 11:00 AM along the same route. WT (°C), TDS (us/cm), pH and DO (mg/L) were measured in situ using YSI in the lake. The values of SD were measured by Secchi disk. Water quality samples were taken with Tygon tube water sampler from the 12 sites. The samples were then kept in acid-cleaned glass bottles and stored at 4°C before analyses. TN (mg/L) was measured by potassium persulfate digestion-UV spectrophotometry method, NH_4^+-N (mg/L) was determined by Nessler's reagent spectrophotometry method and TP (mg/L) was determined by Mo-Sb Anti-spectrophotometry method.

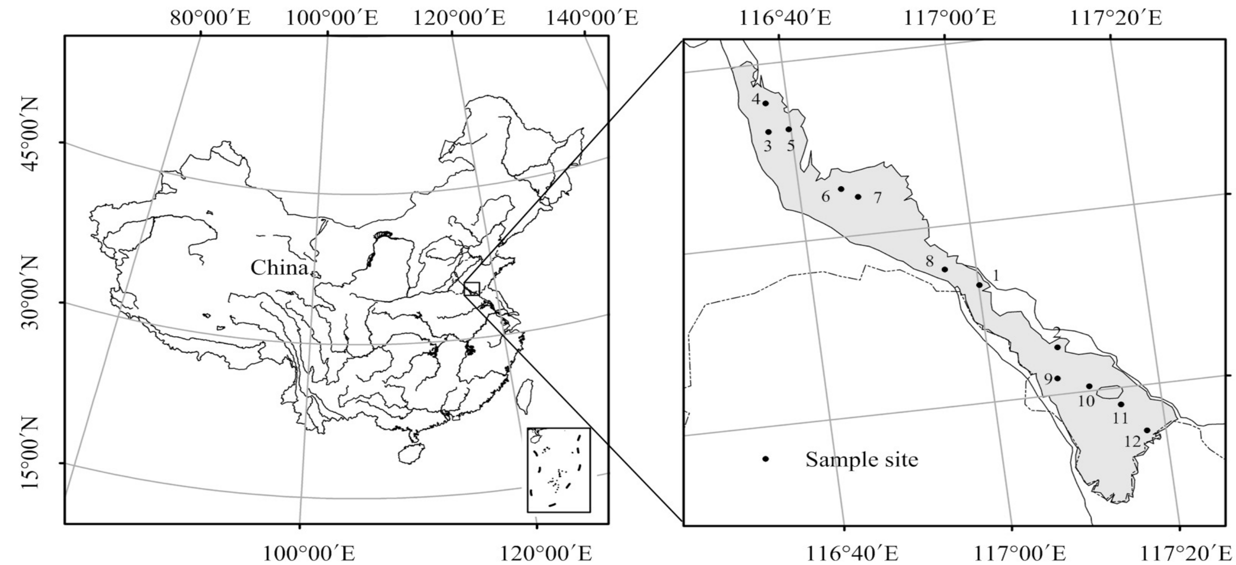

Fig. 1. Location of Lake Nansihu and sample sites in the lake. The figure was made by ArcGIS version 10.0.

Phytoplankton samples were taken 1 L under the water surface in each sample site, then preserved with acidified Lugol's solution for 24 h and condensed to 30 mL. 0.1 mL of the condensed sample was taken on phytoplankton counting box to identify the species and count the cells of each species. The biomass of phytoplankton species was calculated by the cell volume of each species (Sun *et al*., 1999).

Zooplankton samples were taken using a 64µm mesh size net with a diameter of 12 cm. The samples were preserved in a formaldehyde solution (4%) buffered with calcium carbonate before analyses. The species were identified using specialised method (Lansac-Tôha *et al*., 2009). For quantitative research, 1 L mixed water was collected in 0.5 m and 1.0 m under the water surface and samples were preserved with acidified Lugol's solution for 24 h. The samples were condensed to 50 mL. 0.1 mL of the condensed sample was used to count the individuals of protozoa and 1 mL was used to count the number of rotifera, cladocera and copepods under microscope. Zooplankton biomass was estimated from biovolume by comparing the body shape with approximate geometric shapes.

Statistical analysis

The correlation coefficients between zooplankton community and environmental factors or phytoplankton biomass were calculated by linear Pearson correlation. The influence of different factors on zooplankton is analyzed using CCA. The environmental matrix in CCA was consisted of environmental factors and biomasses of different phytoplankton communities. The species matrix was formed at two different scales: (1) the densities and biomasses of different zooplankton communities, (2) the densities of different zooplankton species. In the second case, species is selected when its frequency appeared is higher than 30%. All the variables are transformed by $\log_{10}(x+1)$ except for pH. The calculation of CCA is conducted through Canoco for Windows 4.5 and the figures are drawn through Canodraw for Windows.

RESULTS

Seasonal variations of environmental factors and phytoplankton biomass

In spring, WT ranged from 15.5± to 18.6°C in the 12 sites and its mean value was 17.47°C (Fig. 2). In summer, mean WT was significantly higher than that in other seasons ($p<0.01$) and its value was 32.07±0.78°C (mean ± SD, Fig. 2). Mean WT reached 26.8°C in autumn and it was much higher than that in spring. The standard deviations of WT in the four seasons were low. There was no significant difference among the mean concentrations of DO in spring, summer and autumn ($p>0.05$). Their values were 8.13, 8.76 and 7.85 mg/L, respectively. Mean DO concentration reached its maximum value in winter and it was significantly higher than that in other seasons ($p<0.05$).

Most of the sites in the lake showed weak alkaline and pH value in summer was significantly higher than that in winter ($p<0.05$). However, there was no statistically significant difference among the pH values in other seasons

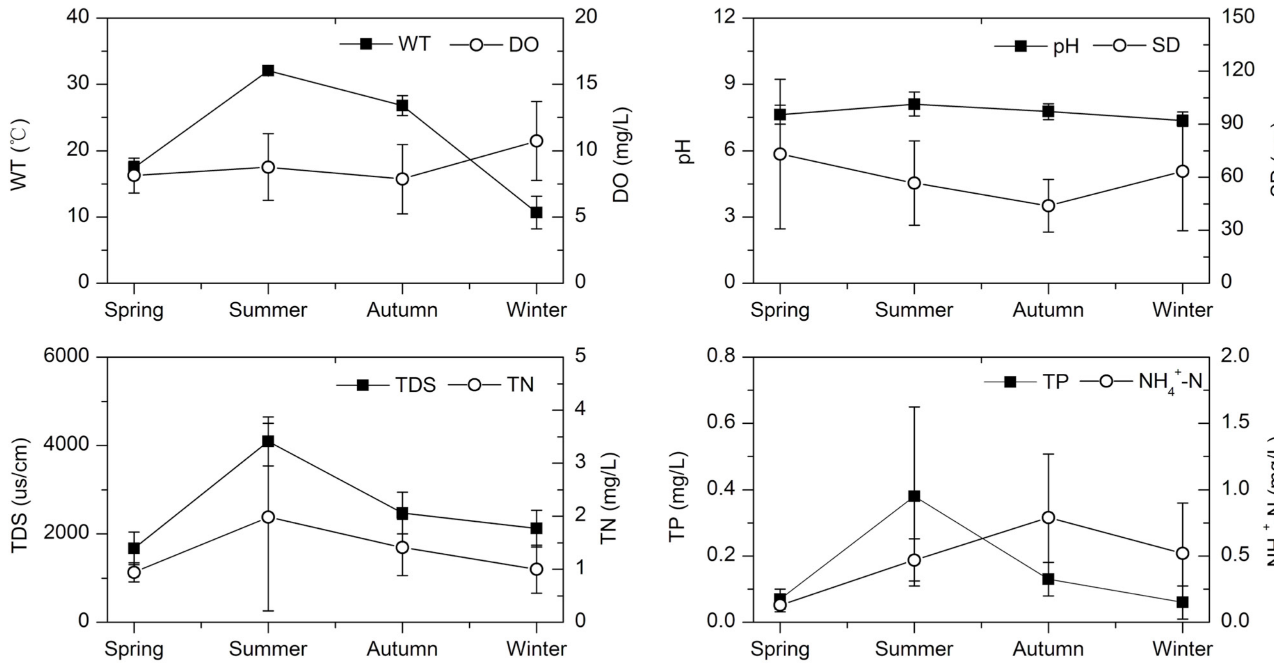

Fig. 2. Mean values of environmental factors of Lake Nansihu in different seasons.

(p>0.05). Average values of SD in the four seasons were 73.1, 56.8, 43.8 and 63.4 cm, respectively and there was no apparent difference among them (p>0.05). Values of SD in most of the sites were lower than 1 m during the sampling time. There were apparent seasonal variations in TDS (Fig. 2). Mean TDS in summer was 4090.4 µs/cm, which was higher than that in other seasons (p<0.01).

Nutrient concentrations in the lake were enriched and there were apparent seasonal differences. In spring, TN ranged from 0.63 mg/L to 1.23 mg/L, with an average of 0.94 mg/L and a standard deviation of 0.18 in the 12 sample sites (Fig. 2). TN reached its highest value in summer with an average value of 1.98 ± 1.77 mg/L. Mean concentration of TN was significantly higher than that in spring (p<0.01). The maximum value of TN appeared at Site 8 (Fig. 1) and its value reached 5.96 mg/L. In autumn and winter, mean TN concentrations reached 1.41 ± 0.53 mg/L and 1.00 ± 0.45 mg/L, respectively (Fig. 2). TP concentration varied from 0.04 mg/L to 0.14 mg/L in spring and its mean value was 0.07 mg/L. In summer, TP pollution was serious and its mean value reached 0.38 ± 0.27 mg/L (Fig. 2). The maximum value of TP also appeared at Site 8 (Fig. 1) and its value was 0.89 mg/L. Mean concentration of NH_4^+-N in spring was lower than that in autumn (p<0.01) and winter (p<0.05). NH_4^+-N reached its maximum value in autumn with an average of 0.79 mg/L (Fig. 2). There was no significant difference between the mean concentrations of NH_4^+-N in summer and winter.

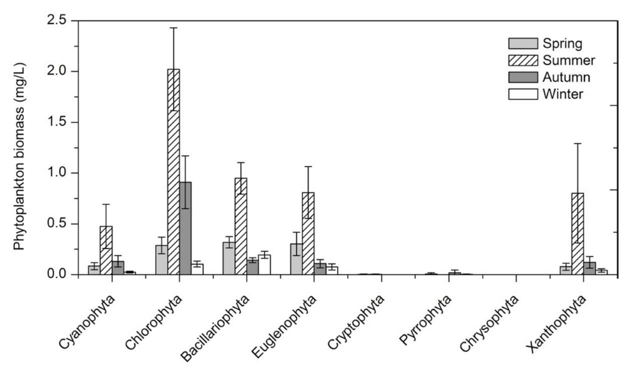

Fig. 3. Mean biomasses of phytoplankton communities in different seasons.

Phytoplankton biomass was dominated by Cyanophyta, Chlorophyta, Bacillariophyta and Euglenophyta (Fig. 3). Mean biomasses of these four groups in spring were 0.08 ± 0.04 mg/L, 0.29 ± 0.08 mg/L, 0.32±0.06 mg/L and 0.30 ± 0.12 mg/L, respectively. In summer, phytoplankton biomass reached its maximum value, with an average of 5.06 mg/L. Chlorophyta was the dominant community and its biomass ranged between 1.50 mg/L and 2.83 mg/L. Mean biomasses of Cyanophyta, Bacillariophyta, Euglenophyta and

Xanthophyta were 0.47 mg/L, 0.95 mg/L, 0.81 mg/L and 0.80 mg/L, respectively (Fig. 3). In autumn, the biomass of Chlorophyta was still high and its value was 0.91 ± 0.41 mg/L (Fig. 3). It was significantly greater than that of other communities ($p<0.01$). In winter, phytoplankton biomass was dominated by Bacillariophyta and its mean value was 0.19 mg/L. There were substantial seasonal changes in the dominant phytoplankton communities, from Cyanophyta, Chlorophyta and Bacillariophyta in spring, Chlorophyta in summer and autumn to Bacillariophyta in winter (Fig. 3).

Seasonal variations of zooplankton community

A total of 76 zooplankton species were identified in the lake, including 17 protozoa species, 36 rotifera species, 12 cladocera species and 11 copepods species, respectively. Zooplankton species richness in the four seasons was nearly in the same level. However, there were apparent differences in species richness among the 12 sites. The minimum number of zooplankton species was 15 and it appeared at Site 8 (Fig. 1), where the concentrations of TN and TP both reached the maximum values. The largest value of zooplankton species richness was 55 and it appeared at Site 9 (Fig. 1), where the values of environmental factors were in medium levels.

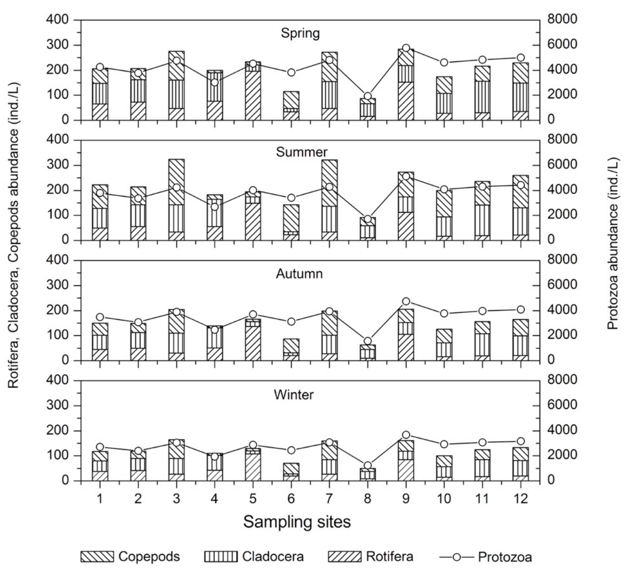

Fig. 4. Zooplankton community abundance of different sample sites in different seasons.

In spring, protozoa abundance ranged from 3021 ind./L to 5781 ind./L in the 12 sites (Fig. 4). The lowest abundance appeared at Site 8 where zooplankton species richness was the lowest and nutrients were the most enriched. Site 9 has the maximum value of protozoa abundance. It also has the maximum species richness and medium level of nutrients in the 12 sites. Abundance of Rotifera ranged between 16 ind./L and 196 ind./L (Fig. 4). Cladocera abundance varied from 13 ind./L to 126 ind./L in the 12 sites and that of copepods ranged between 10 ind./L and 117 ind./L (Fig. 4). Mean abundance of cladocera was considerably higher than that of rotifera and copepods (Fig. 4). In summer, protozoa abundance ranged from 1710 ind./L to 5135 ind./L in the 12 sites (Fig. 4). The minimum and maximum values also appeared at Site 8 and 9, respectively (Fig. 4). Mean abundance of rotifera and cladocera was lower than that in spring. In autumn and winter, all community abundance was apparently lower than that in spring and summer (Fig. 4). Mean abundance of protozoa, rotifera, cladocera and copepods was 3845 ind./L, 44 ind./L, 57 ind./L and 49 ind./L, respectively in autumn. In winter, zooplankton abundance reached its minimum value and mean values of the four groups were 2710 ind./L, 37 ind./L, 44 ind./L and 39 ind./L, respectively.

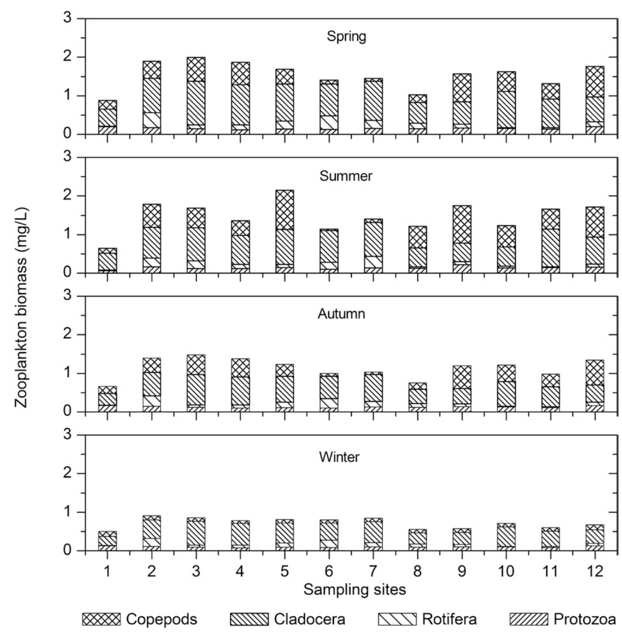

Fig. 5. Zooplankton community biomass of different sample sites in different seasons.

In spring, autumn and winter, zooplankton biomass was dominated by cladocera while in summer both cladocera and copepods were the dominant communities (Fig. 5). Mean biomasses of protozoa, rotifera, cladocera and copepods were 0.15 mg/L, 0.15 mg/L, 0.81 mg/L and 0.42 mg/L, respectively. Zooplankton community composition varied a lot in the 12 sites (Fig. 5). In summer, mean biomasses of protozoa, rotifera and cladocera were a little lower than that in spring and there values were 0.14 mg/L, 0.11 mg/L and 0.72 mg/L. Mean biomass of copepods was higher than that in spring and its value was 0.51 mg/L. The biomass of rotifera was low and negligible in some sites (Fig. 5). In autumn and winter, zooplankton biomass was smaller than that in spring and summer (Fig. 5). Mean biomasses of protozoa, rotifera, cladocera and copepods in autumn were 0.13 mg/L, 0.11 mg/L, 0.56 mg/L and 0.34 mg/L, respectively. In winter, zooplankton biomass was the lowest and mean values of the four groups were 0.10 mg/L, 0.08 mg/L, 0.44 mg/L and 0.10 mg/L, respectively. Mean cladocera biomass were accounting for 52.9%, 48.4%, 49.5% and 61.2% of the total zooplankton biomass in the four seasons.

Correlations between zooplankton community and environmental factors or phytoplankton

The linear Pearson correlations between environmental factors and zooplankton community were listed in Table I. From Table I, we can conclude that the abundance of copepods was significantly correlated with WT ($p<0.01$), TDS ($p<0.05$) and TP ($p<0.01$). Both WT ($p<0.01$) and TN ($p<0.01$) were highly correlated with the biomass of copepods ($p<0.01$). Besides, a positive relationship between the biomass of protozoa and TN was observed ($p<0.05$). The correlation coefficients among other variables were not significant ($p>0.05$) (Table I).

Significant positive correlations between the abundance of protozoa and the biomasses of both Euglenophyta ($p<0.05$) and Cryptophyta ($p<0.05$) were observed. However, the biomass of protozoa was only statistically correlated with Cryptophyta ($p<0.01$). Both the abundance and biomass of Rotifera were not correlated with the phytoplankton communities ($p>0.05$) as shown in Table II. There was a positive correlation between cladocera abundance and Euglenophyta biomass ($p<0.01$). Cladocera biomass was highly correlated with Bacillariophyta ($p<0.05$), Euglenophyta ($p<0.01$), Chrysophyta ($p<0.05$) and Xanthophyta ($p<0.05$). Both the biomass and abundance of copepods were significantly correlated with most of the phytoplankton communities (Table II).

Table I.- Correlation coefficients between environmental factors and zooplankton community.

Variables		WT	DO	pH	SD	TDS	TN	TP	NH_4^+-N
Abundance	Protozoa	0.25	-0.13	0.10	0.01	-0.09	-0.01	0.06	-0.11
	Rotifera	0.04	-0.21	0.04	0.23	-0.09	0.08	-0.13	-0.02
	Cladocera	0.22	0.02	0.22	-0.05	0.11	-0.03	0.20	-0.24
	Copepods	0.39**	0.07	0.23	-0.13	0.32*	-0.02	0.39**	-0.10
Biomass	Protozoa	0.27	-0.24	0.23	-0.01	0.03	0.33*	0.03	-0.22
	Rotifera	0.06	-0.11	0.17	0.24	0.01	-0.21	-0.16	-0.14
	Cladocera	0.25	-0.12	0.18	0.18	0.07	-0.21	-0.03	-0.21
	Copepods	0.44**	-0.22	0.28	0.09	0.22	0.38**	0.20	-0.03

* Denotes $p<0.05$, ** denotes $p<0.01$.

Table II.- Correlation coefficients between phytoplankton biomass and zooplankton community. Cyan: Cyanophyta, Chlo: Chlorophyta, Baci: Bacillariophyta, Eugl: Euglenophyta, Cryp: Cryptophyta, Pyrr: Pyrrophyta, Chry: Chrysophyta, Xant: Xanthophyta.

Variables		Cyan	Chlor	Baci	Eugl	Cryp	Pyrr	Chry	Xant
Abundance	Protozoa	-0.05	0.10	0.28	0.30*	0.49*	0.06	-0.09	0.14
	Rotifera	0.00	0.04	0.16	0.16	0.01	0.04	0.55	0.06
	Cladocera	0.12	0.18	0.27	0.38**	0.31	0.14	-0.41	0.22
	Copepods	0.29*	0.36*	0.45**	0.50**	0.50*	-0.22	-0.59	0.50**
Biomass	Protozoa	0.13	0.23	0.26	0.24	0.74**	-0.16	-0.14	0.14
	Rotifera	0.01	-0.06	0.04	0.21	0.04	-0.22	0.73	0.21
	Cladocera	0.15	0.11	0.35*	0.45**	-0.12	-0.13	0.87*	0.35*
	Copepods	0.37*	0.48**	0.49**	0.40**	0.64**	0.03	0.19	0.28

* Denotes $p<0.05$, ** denotes $p<0.01$.

Table III.- Eigenvalues for CCA axis and species environment correlation.

		AX1	AX2	AX3	AX4	Total inertia
Community	Eigenvalues	0.005	0.003	0.002	0.001	0.025
	Species-environment correlations	0.707	0.729	0.641	0.471	
Species	Eigenvalues	0.076	0.040	0.020	0.019	0.515
	Species-environment correlations	0.780	0.744	0.617	0.598	

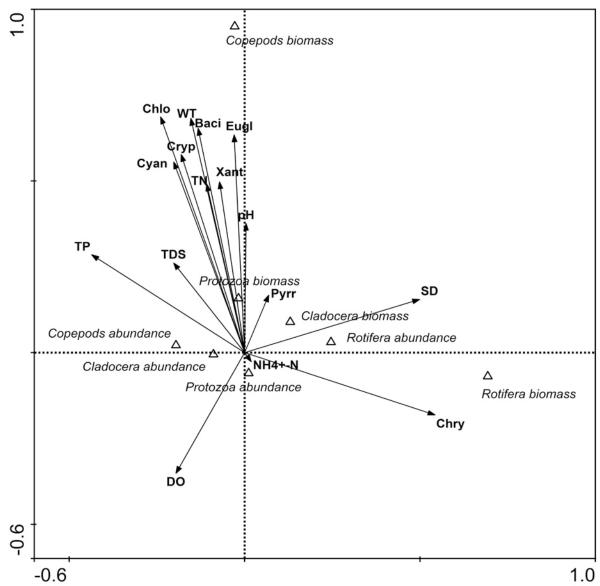

Fig. 6. CCA biplot of environmental factors, phytoplankton and zooplankton communities.

The influence of environmental factors and phytoplankton on zooplankton community

The influence of environmental factors and phytoplankton biomass on zooplankton community are shown in Table III and Figure 6. Results revealed that the first two environmental factors axes were vertical with each other. The correlation coefficient between the first two species axes was 0.06 and they were nearly perpendicular with each other. Thus the results of CCA were credible. The eigenvalues of the first two axes were 0.005 and 0.003 (Table III). The correlation coefficients between the first two environmental axes and species axis were 0.707 and 0.729, indicating a close relationship between environmental factors, phytoplankton and zooplankton community.

Species axis 1 was positively correlated with SD and Chrysophyta biomass but negatively correlated with TP (Fig. 6). Species axis 2 was positively related to WT, TN and the biomasses of Cyanophyta, Chlorophyta, Bacillariophyta, Euglenophyta, Cryptophyta, and Xanthophyta (Fig. 6). From Figure 6, we can conclude that the abundance and biomass of protozoa were distributed near the original point. Protozoa biomass was influenced by many phytoplankton communities, but its abundance was only slightly influenced (Fig. 6). Both the abundance and biomass of rotifera were in the positive direction of the first axis and they were strongly influenced by SD and Chrysophyta biomass (Fig. 6). Cladocera abundance was distributed in the negative direction of the first axis and it was mainly influenced by DO and TP (Fig. 6). However, its biomass was influenced by SD and Pyrrophyta (Fig. 6). There was a strong correlation between the biomass of copepods and many factors such as WT, TN and phytoplankton communities (Fig. 6). Unexpectedly, copepods abundance was slightly influenced by the environmental factors and phytoplankton.

Zooplankton species which were chosen in the CCA are listed in Table IV. Among all these species, *Z1-Z11* are belonging to protozoa and species *Z12-Z28* to rotifera. Nine cladocera species are selected and coded from *Z29* to *Z37*. Species *Z38* to *Z43* belong to copepods. The first two environmental factors axes were vertical with each other and the first two species axes were nearly perpendicular. Eigenvalues of the first two axes were 0.076 and 0.040 respectively. The correlation coefficients between the first two environmental axes and species axis were 0.780 and 0.744. Thus the results of CCA were credible and thereas a close relationship between environmental factors, phytoplankton and zooplankton species.

Species axis 1 was positively correlated with Cyanophyta but negatively correlated with Cryptophyta and Chrysophyta (Fig. 7). There was significantly positive correlation between species axis 2 and SD (Fig. 7). Zooplankton species can be generally divided into three groups according to their distribution in the biplot. Group 1 was mainly distributed in the positive direction of axis 1 and consisted of Protozoa species *Z3*, *Z5*, *Z6*, *Z11*, Rotifera species *Z14*, *Z16*, *Z26*, Cladocera species *Z30*, *Z31*, *Z34*, *Z36*, *Z37* and copepod species *Z39*, *Z40*, *Z42*, *Z43*. Their distribution in the lake was mainly influenced by Cyanophyta biomass, DO, TP and TDS (Fig. 7). Group 2 was mainly distributed in the second quadrant and most

Table IV.- Codes of zooplankton species for CCA.

Code	Latin name	Code	Latin name	Code	Latin name
Z1	*Carchesium*	*Z2*	*Difflugia*	*Z3*	*Amoeba*
Z4	*Theopilium*	*Z5*	*Vorticella*	*Z6*	*Ciliophora*
Z7	*Holomastigotoides*	*Z8*	*Teleogryllus*	*Z9*	*Holophrya*
Z10	*Cercomonas*	*Z11*	*Stentor*	*Z12*	*Asplanchna priodonala*
Z13	*Asplanchna*	*Z14*	*Brachionus calyciflorus*	*Z15*	*Brachionus quadridentatus*
Z16	*Keratella cochlearis*	*Z17*	*Brachionus budapestiensis*	*Z18*	*Brachionus diversicornis*
Z19	*Brachionus forficula*	*Z20*	*Ascomorpha*	*Z21*	*Brachionus leydigi*
Z22	*Ascomorpha ovalis*	*Z23*	*Pompholyx complanata*	*Z24*	*Hexarthra mira*
Z25	*Filinia longiseta*	*Z26*	*Brachionus forcatus*	*Z27*	*Keratella valga*
Z28	*Brachionus angularis*	*Z29*	*Diaphanosoma leuchtenbergianum*	*Z30*	*Diaphanosoma brachyurum*
Z31	*Simocephalus vetulus*	*Z32*	*Moina rectirostris*	*Z33*	*Moina affinis*
Z34	*Bosmina longirostris*	*Z35*	*Daphnia longispina*	*Z36*	*Chydorus sphaericus*
Z37	*Acroperus harpae*	*Z38*	*Cyclops vicinus*	*Z39*	*Eucyclops serrulatus*
Z40	*Mesocyclops leuckarti*	*Z41*	*Sinocalanus tenellus*	*Z42*	*Sinocalanus dorrii*
Z43	*Nauplius*				

of the species were belonging to Rotifera. Protozoa species *Z7*, *Z8*, *Z10* and Cladocera species Z29 were also in group 2. Chrysophyta and SD were the main factors that influenced the zooplankton species in this group (Fig. 7). The remaining species were belonging to Group 3 and mainly distributed in the third quadrant (Fig. 7). Their distribution was primarily influenced by Cryptophyta (Fig. 7).

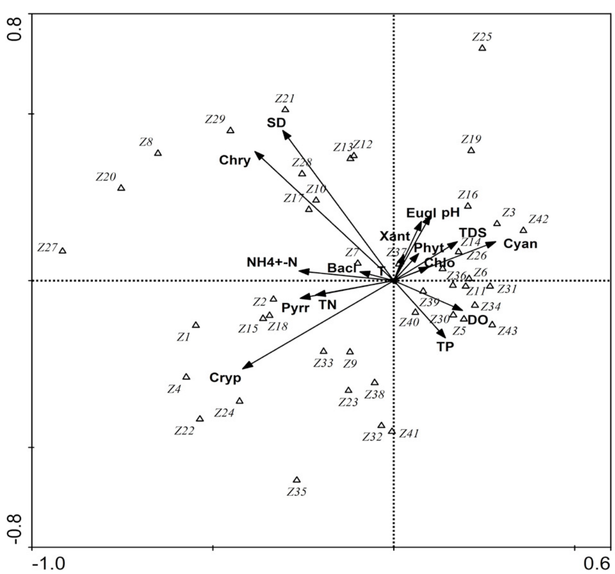

Fig. 7. CCA biplot of environmental factors, phytoplankton and zooplankton species.

We have observed a strong correlation between the values of SD and *B. leydigi* abundance (Fig. 7). It indicated that rotifera species *B. leydigi* could be used as an indicator of water SD. Similar phenomenon was found in the correlation between cladocera species *D. leuchtenbergianum* and Chrysophyta biomass. Protozoa species *Theopilium*, Rotifera species *A. ovalis* and *H. mira* were highly correlated to the biomass of Cryptophyta (Fig. 7). These zooplankton species may be used as indicators of relevant environmental changes.

DISCUSSION

Lake Nansihu is experiencing from pollution to restoration in the past few decades. Annual average concentration of TN ranged from 0.825 mg/L in the early 1980s, 3.70 mg/L in 2000 to 1.01 mg/L in 2010 (Shu *et al*., 2012; Wu *et al*., 2012). In this study, mean TN concentrations were 0.94 mg/L, 1.98 mg/L, 1.41 mg/L and 1.00 mg/L in the four seasons. TN concentration was lower than that in 2000 but still higher than that in 1980s (Shu *et al*., 2012). Mean concentrations of TP were ranging from 0.06 mg/L to 0.38 mg/L seasonally in this research. TP concentrations in spring, autumn and winter were lower than that in 2000, but in summer it was much higher (Shu *et al*., 2012). From the concentrations of TN and TP, we can conclude that water quality is gradually getting better now but situations in summer are still serious. In Lake Nansihu, phytoplankton community was dominated by Cryptophyta and Bacillariophyta in 1983 (Zhang *et al*., 2007). In this research, phytoplankton was dominated by Chlorophyta and Bacillariophyta. These changes in phytoplankton community were mainly due to the degradation of water quality in the lake. Zooplankton species was ranging from 249 species in the early 1980s to 28 species in 2002 (Zhang *et al*., 2007; Gong *et al*., 2010). In this research, there were 76 zooplankton species in 2013. The number of zooplankton was gradually recovering with the changes of water quality in the lake.

Ecologists have observed that zooplankton peaked in spring in many lakes due to environmental warming and nutrients loading (Feuchtmayr *et al*., 2010). In Lake Nansihu, zooplankton peaked in both spring and summer. Environmental conditions were widely variable in the four seasons with mean temperatures ranging from 10.6°C in winter to 32.1°C in summer, as well as higher concentrations of both TN and TP in summer than that in other seasons. The seasonal phytoplankton biomass described in this research also suggested that food availability was low in spring and much higher in summer. Comparing with the result of Feuchtmayr *et al*. (2010), we can conclude that water temperature may be the main reason of zooplankton peak. Ecologists have found that temperature and phytoplankton have great influence on copepods community (Huntley and Lopez, 1992; Turner, 2004; Mahar *et al*., 2007; Apaydın Yağcı, 2014). In this research, copepods community was significantly correlated with WT and the biomasses of Cyanophyta, Chlorophyta, Bacillariophyta, Euglenophyta and Cryptophyta, which is consisting with previous studies (Huntley and Lopez, 1992; Turner, 2004).

Recent studies have revealed that the relative abundance of rotifers was significantly higher in non-polluted region than polluted region (Al-Ghanim, 2012; Patrick *et al*., 2012). Copepods community was more tolerable in polluted water than other communities (Patrick *et al*., 2012). In this research, the minimum values of zooplankton species richness, abundance and biomass appeared at the site which provides the maximum concentrations of nutrients. The relative abundance of both cladocera and copepods in polluted region was higher than that in other sites. Comparing with the results of Patrick *et al*. (2012), we can conclude that large-size zooplankton is more adaptive than other communities in polluted water. Some researchers have revealed that in mesotrophic lakes, zooplankton is dominated by the efficient grazer *Daphnia* and the intensity of predator-prey interaction is the strongest (Carney and Elser, 1990; Elser and Goldman, 1991). In this study, Lake Nansihu was meso-eutrophic and zooplankton biomass was dominated by Cladocera. Thus we can conclude that in both mesotrophic and slight eutrophic lakes, the intensity of predation was strong and zooplankton biomass was dominated by the efficient grazer Cladocera.

The recently proposed transparency regulator hypothesis revealed that SD was the main reason of diel vertical migration of zooplankton (Williamson *et al*., 2011). Besides, some ecologists found that the increasing zooplankton grazing could contribute to improvements in water SD (Auer *et al*., 1990). Results of CCA in this research show that SD has significant influence on zooplankton. Comparing with previous studies, we can conclude that zooplankton and SD can mutually influence each other (Auer *et al*., 1990; Williamson *et al*., 2011). Zooplankton species were widely used as indicator to disturbance and water pollution in aquatic ecosystems (Attayde and Bozelli, 1998; Vandysh, 2004). Apaydın-Yağcı *et al*. (2016) reported that *Hexarthra mira* was highly related to environmental changes according to CCA and it was found where the temperature was high in Lake Eğirdir from Turkey. In this work, strong correlations between *B. leydigi* and SD, Chrysophyta biomass and *D. leuchtenbergianum*, Cryptophyta and *Theopilium*, *A. ovalis*, *H. mira* were observed. These zooplankton species could be used as indicators of relevant environmental changes.

CONCLUSION

The main risk in Lake Nansihu is the outbreak of algae. Zooplankton community is important in guaranteeing the ecological security and water quality in lake ecosystems. Results in this study showed that zooplankton community is strongly correlated with phytoplankton biomass. In spring, zooplankton biomass reached its maximum value while the biomass of phytoplankton was pretty low. High values of zooplankton biomass may be the reason of the disappearance of phytoplankton spring bloom in Lake Nansihu. Results also showed that WT, SD, nutrients and phytoplankton biomass are the most significant factors that influence zooplankton community. Thus measures should be mainly focused on limiting anthropogenic import of nutrients, increasing SD values, protecting and restoring the habitats of zooplankton species in Lake Nansihu.

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Statement of conflict of interest

There was no conflict of interest in the submission of the manuscript.

REFERENCES

Al-Ghanim, K.A., 2012. Spatio-temporal distribution and composition of zooplankton in Wadi Hanifah Stream Riyadh (Saudi Arabia) and Abu Zabaal Lakes (Egypt). *Pakistan J. Zool.*, **44**: 727-736.

Anderson, D.M., Glibert, P.M. and Burkholder, J.M., 2002. Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. *Estuaries*, **25**: 704-726. https://doi.org/10.1007/BF02804901

Apaydın-Yağcı, M., 2014. Seasonal variations in zooplankton species of Lake Gölhisar, a shallow lake in Burdur, Turkey. *Pakistan J. Zool.*, **46**, 927-932.

Apaydın Yağcı, M., Yağcı, A. and Dölcü, B., 2016. Relationships between the physicochemical parameters and zooplankton in Eğirdir Lake (Turkey). *Iran. J. Fish. Sci.*, **15**: 118-132.

Attayde, J.L. and Bozelli, R.L., 1998. Assessing the indicator properties of zooplankton assemblages to disturbance gradients by canonical correspondence analysis. *Can. J. Fish. aquat. Sci.*, **55**: 1789-1797. https://doi.org/10.1139/f98-033

Auer, M.T., Storey, M.L., Effler, S.W., Auer, N.A. and Sze, P., 1990. Zooplankton impacts on chlorophyll and transparency in Onondaga Lake, New York, USA. *Hydrobiologia*, **200**: 603-617. https://doi.org/10.1007/BF02530377

Beaugrand, G., Mackas, D. and Goberville, E., 2013. Applying the concept of the ecological niche and a macroecological approach to understand how climate influences zooplankton: advantages, assumptions, limitations and requirements. *Prog. Oceanogr.*, **111**: 75-90. https://doi.org/10.1016/j.pocean.2012.11.002

Carney, J.J. and Elser, J.J., 1990. The strength of zooplankton phytoplankton coupling in relation to trophic state. In: *Large lakes* (eds. M.M. Tilzer and C. Serruya), Springer, Berlin, Heidelberg, pp. 616-631. https://doi.org/10.1007/978-3-642-84077-7_33

Carter, J.L. and Schindler, D.E., 2012. Responses of zooplankton populations to four decades of climate warming in lakes of southwestern Alaska. *Ecosystems*, **15**: 1010-1026. https://doi.org/10.1007/s10021-012-9560-0

Ciros-Pérez, J., Ortega-Mayagoitia, E. and Alcocer, J., 2015. The role of ecophysiological and behavioral traits in structuring the zooplankton assemblage in a deep, oligotrophic, tropical lake. *Limnol. Oceanogr.*, **60**: 2158-2172. https://doi.org/10.1002/lno.10157

Eisner, L.B., Napp, J.M., Mier, K.L., Pinchuk, A.I. and Andrews, A.G., 2014. Climate-mediated changes in zooplankton community structure for the eastern Bering Sea. *Deep-Sea Res. Pt. II.*, **109**: 157-171. https://doi.org/10.1016/j.dsr2.2014.03.004

Elser, J.J. and Goldman, C.R., 1991. Zooplankton effects on phytoplankton in lakes of contrasting trophic status. *Limnol. Oceanogr.*, **36**: 64-90. https://doi.org/10.4319/lo.1991.36.1.0064

Feuchtmayr, H., Moss, B., Harvey, I., Moran, R., Hatton, K., Connor, L. and Atkinson, D., 2010. Differential effects of warming and nutrient loading on the timing and size of the spring zooplankton peak: an experimental approach with hypertrophic freshwater mesocosms. *J. Plankt. Res.*, **32**: 1715-1725. https://doi.org/10.1093/plankt/fbq087

Gong, J.X., Duan, D.X., Wang, Z.Z., Du, X.H., Zhang, J.L., Liu, H.C., Chen, J.P. and Sun, D., 2010. Research and analysis on the plankton of Nansi Lake. *J. Yangtze Univ. (Nat. Sci. Edit)*, **7**: 39-42.

Grover, J.P., 2002. Stoichiometry, herbivory and competition for nutrients: simple models based on planktonic ecosystems. *J. theor. Biol.*, **214**: 599-618. https://doi.org/10.1006/jtbi.2001.2488

Heisler, J., Glibert, P.M., Burkholder, J.M., Anderson, D.M., Cochlan, W., Dennison, W.C., Dortch, Q., Gobler, C.J., Heil, C.A., Humphries, E., Lewitus, A., Magnien, R., Marshall, H.G., Sellner, K., Stockwell, D.A., Stoecker, D.K. and Suddleson, M., 2008. Eutrophication and harmful algal blooms: a scientific consensus. *Harmf. Algae*, **8**: 3-13. https://doi.org/10.1016/j.hal.2008.08.006

Hennes, K.P. and Simon, M., 1995. Significance of bacteriophages for controlling bacterioplankton growth in a mesotrophic lake. *Appl. environ. Microb.*, **61**: 333-340.

Huntley, M.E. and Lopez, M.D.G., 1992. Temperature-dependent production of marine copepods: a global synthesis. *Am. Nat.*, **140**: 201-242. https://doi.org/10.1086/285410

Jeppesen, E., Nõges, P., Davidson, T.A., Haberman, J., Nõges, T., Blank, K., Lauridsen, T.L., Søndergaard, M., Sayer, C., Laugaste, R., Johansson, L.S., Bjerring, R. and Amsinck, S.L., 2011. Zooplankton as indicators in lakes: a scientific-based plea for including zooplankton in the ecological quality assessment of lakes according to the European Water Framework Directive (WFD). *Hydrobiologia*, **676**: 279-297. https://doi.org/10.1007/s10750-011-0831-0

Lacerot, G., Kruk, C., Lürling, M. and Scheffer, M., 2013. The role of subtropical zooplankton as grazers of phytoplankton under different predation levels. *Freshw. Biol.*, **58**: 494-503. https://doi.org/10.1111/fwb.12075

Lansac-Tôha, F.A., Bonecker, C.C., Velho, L.F., Simões, N.R., Dias, J.D., Alves, G.M. and Takahashi, E.M., 2009. Biodiversity of zooplankton communities in the Upper Paraná River floodplain: interannual variation from long-term studies. *Braz. J. Biol.*, **69**: 539-549. https://doi.org/10.1590/S1519-69842009000300009

Litchman, E. and Klausmeier, C.A., 2008. Trait-based community ecology of phytoplankton. *Annu. Rev. Ecol. Evol. S.*, **39**: 615-639. https://doi.org/10.1146/annurev.ecolsys.39.110707.173549

Mahar, M.A., Jafri, S.I.H. and Baloch, W.A., 2008. Seasonal variation and species composition of crustacean zooplankton (Order: Cladocera) in Manchhar Lake, Sindh, Pakistan. *Pakistan J. Zool.*, **40**: 65-68.

Mahar, M.A., Jafri, S.I.H. and Kazmi, Q.B., 2007. Diversity and seasonal variation of copepod zooplankton in Manchhar lake (Distt: Dadu) Sindh, Pakistan. *Pakistan J. Zool.*, **39**: 347-350.

Mozetič, P., Francé, J., Kogovšek, T., Talaber, I. and Malej, A., 2012. Plankton trends and community changes in a coastal sea (northern Adriatic): bottom-up vs. top-down control in relation to environmental drivers. *Estuar. Coast. Shelf. S.*, **115**: 138-148. https://doi.org/10.1016/j.ecss.2012.02.009

Olson, M.B. and Daly, K.L., 2013. Micro-grazer biomass, composition and distribution across prey resource and dissolved oxygen gradients in the far eastern tropical North Pacific Ocean. *Deep-Sea Res. Pt. I.*, **75**: 28-38. https://doi.org/10.1016/j.dsr.2013.01.001

Özen, A., Šorf, M., Trochine, C., Liboriussen, L., Beklioglu, M., Søndergaard, M., Lauridsen, T.L., Johansson, L.S. and Jeppesen, E., 2013. Long-term effects of warming and nutrients on microbes and other plankton in mesocosms. *Freshw. Biol.*, **58**: 483-493. https://doi.org/10.1111/j.1365-2427.2012.02824.x

Patrick, A.E.S., Kadotgasan, J.M. and Naveendrakumar, G., 2012. Study to detect impacts of pollution on the distribution of zooplankton in the Northern tropical ponds in Sri Lanka. *Arch. appl. Sci. Res.*, **4**: 2552-2556.

Prowe, A.E.F., Pahlow, M., Dutkiewicz, S., Follows, M. and Oschlies, A., 2012. Top-down control of marine phytoplankton diversity in a global ecosystem model. *Progr. Oceanogr.*, **101**: 1-13. https://doi.org/10.1016/j.pocean.2011.11.016

Saba, G.K., Steinberg, D.K., Bronk, D.A. and Place, A.R., 2011. The effects of harmful algal species and food concentration on zooplankton grazer production of dissolved organic matter and inorganic nutrients. *Harmf. Algae*, **10**: 291-303. https://doi.org/10.1016/j.hal.2010.11.003

Schwaderer, A.S., Yoshiyama, K., De Tezanos Pinto, P., Swenson, N.G., Klausmeier, C.A. and Elena, L., 2011. Eco-evolutionary differences in light utilization traits and distributions of freshwater phytoplankton. *Limnol. Oceanogr.*, **56**: 589-598. https://doi.org/10.4319/lo.2011.56.2.0589

Shu, F.Y., Liu, Y.P., Zhao, Y., Wu, Y.P. and Li, A.H., 2012. Spatio-temporal distribution of TN and TP in water and evaluation of eutrophic state of Lake Nansi. *Environ. Sci.*, **33**: 3748-3752.

Shurin, J.B., Clasen, J.L., Greig, H.S., Pavel, K. and Thompson, P.L., 2012. Warming shifts top-down and bottom-up control of pond food web structure and function. *Phil. Trans. R. Soc. B.*, **367**: 3008-3017. https://doi.org/10.1098/rstb.2012.0243

Sun, J., Liu, D.Y. and Qian, S.B., 1999. Study on phytoplankton biomass I. Phytoplankton measurement biomass from cell volume or plasma volume. *Acta Oceanol. Sin.*, **21**: 75-85.

Svensen, C., Seuthe, L., Vasilyeva, Y., Pasternak, A. and Hansen, E., 2011. Zooplankton distribution across Fram Strait in autumn: Are small copepods and protozooplankton important? *Progr. Oceanogr.*, **91**: 534-544. https://doi.org/10.1016/j.pocean.2011.08.001

Turner, J.T., 2004. The importance of small planktonic copepods and their roles in pelagic marine food webs. *Zool. Stud.*, **43**: 255-266.

Vandysh, O.I., 2004. Zooplankton as an indicator of the state of lake ecosystems polluted with mining wastewater in the Kola Peninsula. *Russ. J. Ecol.*, **35**: 110-116. https://doi.org/10.1023/B:RUSE.0000018936.56649.20

Vardi, A., Schatz, D., Beeri, K., Motro, U., Sukenik, A., Levine, A. and Kaplan, A., 2002. Dinoflagellate-cyanobacterium communication may determine the composition of phytoplankton assemblage in a mesotrophic lake. *Curr. Biol.*, **12**: 1767-1772. https://doi.org/10.1016/S0960-9822(02)01217-4

Ware, D.M. and Thomson, R.E., 2005. Bottom-up ecosystem trophic dynamics determine fish production in the Northeast Pacific. *Science*, **308**: 1280-1284. https://doi.org/10.1126/science.1109049

Williamson, C.E., Fischer, J.M., Bollens, S.M., Overholt, E.P. and Breckenridge, J.K., 2011. Toward a more comprehensive theory of zooplankton diel vertical migration: integrating ultraviolet radiation and water transparency into the biotic paradigm. *Limnol. Oceanogr.*, **56**: 1603-1623. https://doi.org/10.4319/lo.2011.56.5.1603

Wu, Z.H., Zhang, K., Jin, L.R., Yang, L.K. and Zhang, J., 2012. Analysis of spatial distribution of water quality and assessment of water quality improvement in Nansi Lake. *Water Resour. Protec.*, **28**: 1-7.

Yang, G.J., Qin, B.Q., Tang, X.M., Gong, Z.J., Zhong, C.N., Zou, H. and Wang, X.D., 2012. Contrasting zooplankton communities of two bays of the large, shallow, eutrophic Lake Taihu, China: Their relationship to environmental factors. *J. Great Lakes Res.*, **2**: 299-308.

Ye, L., Chang, C.Y., García-Comas, C., Gong, G.C. and Hsieh, C.H., 2013. Increasing zooplankton size diversity enhances the strength of top-down control on phytoplankton through diet niche partitioning. *J. Anim. Ecol.*, **82**: 1052-1061. https://doi.org/10.1111/1365-2656.12067

Zhang, Z.L., Xin, L.J. and Liang, C.L., 2007. The analysis of hydrological characteristics and processes of ecosystem in Lake Nansi during the past 50 years. *Geogr. Res.*, **26**: 957-966.