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Effects of sediment dredging on water quality and zooplankton community structure in a shallow of eutrophic lake

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Abstract

Effects of suction dredging on water quality and zooplankton community structure in a shallow of eutrophic lake, were evaluated. The results showed that a decreasing trend for levels of phosphorus, organic matter, total suspended solids, Chlorophyll *a* and Secchi transparency in the water column was found, while levels of water depth, electrical conductivity, total dissolved solids and NO_3^--N concentration increased markedly post-dredging. The effects of dredging on dissolved oxygen, pH value and temperature were almost negligible. The zooplankton community structure responded rapidly to the environmental changes caused mainly by dredging. As a result, the abundance of rotifers decreased, while the density of zooplanktonic crustaceans increased markedly. The representative taxa were *Brachionus angularis*, *B. budapestinensis*, *B. diversicornis*, *Synchaeta* spp. and *Neodiaptomus schmackeri*. A distinct relationship between zooplankton taxa composition and their environment, unraveled by a redundancy analysis, indicating that the measured environment contributed to the variations in the zooplankton community structure to some extent. The first four synthetic environmental variables explained 51.7% of the taxonomic structure. Therefore, with the reduction of internal nutrient load and a shift in dominance by less eutrophic species, it inferred that dredging might be one of effective measures for environmental improvements of such lakes.

Key words: zooplankton community structure; redundancy analysis; internal nutrient load

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Introduction

Lake eutrophication becomes a serious issue in many places in the world, especially in developing countries. Eutrophication constitutes a serious threat to many European lakes and many approaches have been used during the past 20–30 years to improve lake water quality (Søndergaard et al., 2007). Jin (2003) reported the state and trend of eutrophication of lakes in China, and concluded that lakes throughout the country were commonly undergoing the process of eutrophication: most of urban lakes were facing hyper-eutrophication, and many lakes of medium size were of eutrophic state, some even approaching to a hyper-eutrophic level.

Active main approaches employed in lake restoration include nutrient load reduction and bio-manipulation projects (Søndergaard et al., 2007). Among the different restoration techniques, sediment dredging, commonly used in coastal and estuarine habitats, is a large-scale anthropogenic disturbance agent that can profoundly affect water quality, and has been widely used to treat hyper-eutrophic lakes in China. With respect to dredging, both positive and negative effects have been reported (Lohrer and Wetz, 2003; Spencer et al., 2006; Zhong and Fan, 2007). However, the effectiveness of dredging is still suspectable, and the debate on the role of dredging at an ecosystem level remains open.

Literature on effectiveness and environmental impacts of sediment dredging were extensively documented. But most of the previous studies related to effects of dredging on water quality, release of nutrients and heavy metals, benthos, algal-periphyton, bacteria, larval zooplankton, birds and aquatic plants (Brookes, 1987; DeCoursey and Vernberg, 1975; Howarth et al., 1982; Lewis et al., 2001; Lohrer and Wetz, 2003; Nayar et al., 2004; Spencer et al., 2006). Information on the effects of dredging on zooplankton community structure is rare but also inconsistent (Wang et al., 2005; Li et al., 2007; Wu et al., 2008).

In aquatic ecosystems, changes in species composition of small, rapidly reproducing organisms have been considered among the earliest and most sensitive ecosystem responses to anthropogenic stress (Schindler, 1987). People wish to know how human activities influence the fascinating diversity of these biological communities. Yet, this very diversity creates problems for statistical analysis of ecological observations: it implies a large number of

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species and a large inherent variability. A set of community samples and associated environmental measurements (e.g., water chemistry variables) typically yields an enormous amount of noisy data, which is difficult to interpret. Multivariate methods provide a means to structure the data by separating systematic variation from noise (Gauch, 1982).

In this study, physicochemical and biological characteristics of a shallow of eutrophic lake were surveyed over a period of two years including pre- and post-dredging. RDA (redundancy analysis) was used to elucidate the association between zooplankton taxa composition and their environment. Finally, the effects of dredging on water quality and zooplankton community structure were assessed.

1 Materials and methods

1.1 Study site

Lake Yuehu (30°33′N, 114°15′E) is a small lake with area of 61 ha, located in central Wuhan, China (Fig. 1). Deep sediment covered more than 50% of the whole area. The surface sediment pre-dredging was characterized by follows: the percentage of silt plus clay was 80%, organic matter was 124 g/kg, total nitrogen (TN) was 4.7 g/kg and total phosphorus (TP) was 2.7 g/kg (Chen et al., 2007). The lake without tributaries is adjacent to the estuary of Han River to the Yangtze River. There was no water exchange between the lake and the river except flood was pumped to the river in wet seasons. The major source of water was rainfall. At present, the lake is only subjected to recreation and ecotourism.

In recent years, Lake Yuehu has developed to a hyper-eutrophic state with heavy algal bloom (mainly cyanobacteria) in spring and summer. Function of the aquatic ecosystem has degraded seriously and considerable funding has gone to finding solutions for the restoration of the lake. Among the various solutions, fish cleanup was executed in March 2004. Since then, no fish stocking was proceeded. Aquatic macrophyte re-establishment was proceeded during the year of 2004–2005. Suction dredging was started in June 2006, and finished in October 2006. Dredging depth was about 1.0 m on average for the whole lake. No other restoration measures were carried out during the period of the survey, which provided a possibility to compare the differences between pre- and post-dredging.

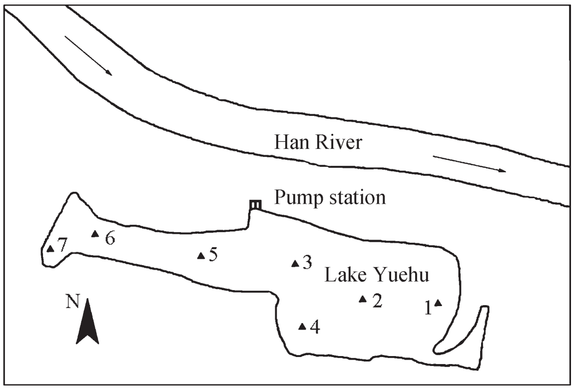

Fig. 1 Distribution of sampling site (1–7) in Lake Yuehu, Wuhan, China.

1.2 Methods

Samples were collected monthly from July 2005 to June 2006 and from Jan to Dec 2007. No sample was taken during the process of dredging. The sampling sites in the lake are shown in Fig. 1. Samples for chemical analysis were obtained from mixed water collected at four depths from bottom to surface of the lake using a modified 5-l Patalas sampler. Samples for Chl-*a* (chlorophyll *a*) analysis were collected from the upper 20–40 cm stratum, fixed *in situ* with 1% magnesium carbonate and preserved at 4°C. Chl-*a* was determined spectrophotometrically after filtration on Whatman GF/C glass filters and 24-hr extraction with 90% acetone. TN, NO_2^--N, NO_3^--N, TP, IP (inorganic phosphorus) and TSS (total suspended solids) were analyzed according to the standard methods (State EPA of China, 2002). COD_{Cr} (chemical oxygen demand) was measured using a DR/2400 Portable Spectrophotometer (Hach Company, USA). TOC (total organic carbon) was determined by multi N/C 1000 (Analytik Jena, Germany). DO (dissolved oxygen), TDS (total dissolved solids), EC (electrical conductivity), pH and temperature were determined *in situ* with an Orion 5-Star Portable pH/ORP/DO/Conductivity Multimeter (Thermo Fisher Scientific Company, USA). Water depth and SD (Secchi transparency) were measured using Secchi disk.

Crustacean samples were collected by sieving 10 L of mixed water through a 64-μm plankton net and preserved in 4% formalin solution. Another liter of the water was fixed in Lugol's solution for rotifer quantification. In the laboratory, crustacean samples were counted completely using a dissecting microscope at 40× magnification. Rotifer samples were placed in a glass column, and after more than 24 hr of sedimentation, the supernatant was carefully removed and the residue was collected, concentrated to 30 mL and preserved in 4% formalin solution. After mixing completely, 1 mL sub-sample was placed in a count-frame, counted using an inverted microscope at 160× magnification. Zooplankton were identified to the genus/species level with reference to Chiang and Du (1979), Shen (1979), Wang (1961), Zhang and Huang (1991) and Jersabek et al. (2003), and were sorted into main groups with a minimum individual contribution more than 0.4% of total zooplankton density when calculating. Averages of the biotic and abiotic data sets on each sampling occasion were prepared for further analysis.

1.3 Data analysis

Data were analyzed for normal distribution with Shapiro-Wilks tests. Independent *t*-tests and Mann-Whitney *U*-tests were applied to the environmental and biological data sets. Levene's tests were used for testing the equality of variances among independent *t*-tests; these analyses were completed using the statistical program SPSS 13.0 for windows. To evaluate the association between zooplankton taxa composition and their environment, we opted for a linear model of ordination instead of unimodal since preliminary DCA (detrended correspondence analysis) showed a short gradient length on the biological data (SD < 2) (ter Braak and Šmilauer, 2002). In principle, environmental variables are displayed by their weights in an ordination diagram. With correlated environmental variables, these weights are often difficult to interpret (ter Braak, 1986). There is a real danger of over-interpretation, especially when the number of environmental variables is of the same order of magnitude as the sample size (ter Braak and Verdonschot, 1995). In this study, there were 16 measured environmental variables (Table 1) and 24 samples (after averaging the data sets on each sampling occasion). To abstain from multicollinearity among the environmental variables, PCA (principal component analysis) was used to reduce the number of environmental variables and the first few components of this analysis were treated as the new environmental variables in RDA. The biological data in RDA were $\log(x+1)$-transformed so as to downweight large values. To guard against interpretation of spurious axes, the statistical significance of the first and all the ordination axes was tested by Monte Carlo permutation test (499 unrestricted permutations). DCA and RDA were performed by the computer program Canoco 4.5 for Windows, while PCA and later Pearson's correlation analysis were also completed using the SPSS 13.0 for Windows.

2 Results

2.1 Water quality characteristic

Physicochemical characteristics of water quality pre- and post-dredging are summarized in Table 1. Differences between the two stages were detected by independent *t*-tests and Mann-Whitney *U*-tests. The latter was used due to non-normal distribution. Finally, significant differences ($P < 0.05$, $n = 24$) were detected in chemical indices of NO_3^--N, TP, Chl-*a* and TDS, and in physical indices of EC, SD and water depth. In more detail, levels of TP, Chl-*a* and SD declined significantly, while those of NO_3^--N, TDS, EC and water depth increased significantly post-dredging.

Table 1 Physicochemical characteristics of water quality in Lake Yuehu

Parameter	July 2005–June 2006	Jan. –Dec. 2007
TN (mg/L)	2.99 ± 0.63	2.95 ± 1.92
NO_2^--N (mg/L)	0.071 ± 0.059	0.061 ± 0.043
NO_3^--N (mg/L)	0.120 ± 0.109	0.172 ± 0.069*
TP (mg/L)	0.431 ± 0.236	0.254 ± 0.084*
IP (mg/L)	0.133 ± 0.125	0.077 ± 0.058
COD_{Cr} (mg/L)	49.1 ± 18.6	36.8 ± 8.2
TOC (mg/L)	20.6 ± 5.9	16.6 ± 5.4
TSS (mg/L)	33.0 ± 11.4	25.4 ± 10.9
Chl-*a* (μg/L)	99.1 ± 62.1	30.3 ± 19.9**
Temperature (°C)	18.5 ± 8.7	19.8 ± 8.7
pH	8.34 ± 0.63	8.45 ± 0.38
EC (μS/cm)	396.6 ± 33.9	487.2 ± 58.9**
TDS (mg/L)	193.5 ± 17.4	238.7 ± 29.0**
DO (mg/L)	9.88 ± 3.72	9.73 ± 2.97
SD (cm)	37.9 ± 10.1	22.0 ± 7.5**
Depth (cm)	84.0 ± 18.3	133.4 ± 8.3**

Data are expressed as mean ± standard deviation. *$P < 0.05$; **$P < 0.01$

2.2 Zooplankton community structure

A total of 84 taxa, including 63 taxa for Rotifera, 15 taxa for Cladocera and 6 taxa for Copepoda, was recorded in Lake Yuehu (Table 2). The rotifer community during the period of pre-dredging was numerically dominated by *B. angularis*, *Keratella* spp., *Polyarthra dolichoptera* and *Trichocerca* spp., but it was replaced by *Keratella* spp., followed by *P. dolichoptera* and *B. angularis* post-dredging. Mann-Whitney *U*-tests revealed that the densities of *B. angularis*, *B. budapestinensis*, *B. diversicornis* and *Synchaeta* spp. significantly declined post-dredging ($P < 0.05$, $n = 24$). The density of *Pompholyx sulcata* also increased apparently compared to pre-dredging (Table 3).

The richest cladoceran was *Bosmina longirostris*, followed by *Diaphanosoma leuchtenbergianum* and *Moina micrura* pre-dredging. Nevertheless, it changed to *D. leuchtenbergianum*, followed by *B. longirostris* and *M. micrura* post-dredging. No statistical difference among the three cladocerans was detected between the two stages. Nauplii and copepodites were the richest taxa among the copepods. The density of *N. schmackeri* increased significantly post-dredging (Mann-Whitney *U*-test, $P < 0.05$, $n = 24$) and that of *Thermocyclops taihokuensis* also increased obviously (Table 3).

2.3 Relationships between zooplankton and their environment

In PCA, varimax was selected to carry out a rotation, which could minimize the number of factors with maximum loadings and thus make it easier to explain each of the potential components. In this analysis, we kept the default (eigenvalues over 1) to extract principal components. Finally, six components were extracted and explained 86.098% of the cumulative variance (Table 4). Factor loadings for all variables are presented in Table 5. Factor scores were concurrently calculated by the method of regression and saved as new variables for the later RDA analysis. According to the factor loadings shown in Table 5, component 1 was affected mainly by IP, Chl-*a* and TP, component 2 by EC, TDS and TN, component 3 by pH, DO, COD_{Cr} and TSS, component 4 by SD, depth and temperature, component 5 by NO_3^-–N and TOC, and component 6 by NO_2^-–N.

With the submission of the first four synthetic gradients to RDA, the first two eigenvalues explained 48.3% of the cumulative variance of species data. Also, the species-environment correlations of axis 1 (0.917) and axis 2 (0.857) were high. The first four environmental variables explained 51.7% of the total variance in species data. The Monte Carlo permutation test was significant on the first axis (*F*-ratio = 9.758, *P*-value = 0.002) and on all axes (*F*-ratio = 5.089, *P*-value = 0.002) (Table 6).

In Fig. 2a, the upper quadrant was completely confined to the distribution of rotifers and the lower one mainly to the distribution of zooplanktonic crustaceans. Similarly, in Fig. 2b, the upper quadrant was restricted largely to the distribution of samples taken pre-dredging, while the lower one mainly to the distribution of samples taken

Table 2 Zooplankton species composition in Lake Yuehu

Rotifera	Rotifera	Rotifera
Anuraeopsis fissa (Gosse, 1851)	*K. tropica* (Apstein, 1907)	*T. pusilla* (Lauterborn, 1898)
Asplanchna brightwellii (Gosse, 1850)	*Lecane bulla* (Gosse, 1851)	*T. rousseleti* (Voigt, 1901)
A. girodi de (Guerne, 1888)	*L. closterocerca* (Schmarda, 1859)	*T. similis* (Wierzejski, 1893)
A. priodonta (Gosse, 1850)	*L. hamata* (Stokes, 1896)	*T. tenuior* (Gosse, 1886)
Ascomorpha sp.	*L. hornemanni* (Ehrenberg, 1834)	*Trichotria* sp.
Brachionus angularis (Gosse, 1851)	*L. luna* (Müller, 1776)	**Cladocera**
B. budapestinensis (Daday, 1885)	*L. lunaris* (Ehrenberg, 1832)	*Alona rectangula* (Sars, 1861)
B. calyciflorus amphiceros (Ehrenberg, 1838)	*L. stenroosi* (Meissner, 1908)	*Bosmina longirostris* (O. F. Müller, 1776)
B. calyciflorus (Pallas, 1766)	*Lepadella* sp.	*Ceriodaphnia cornuta* (G. O. Sars, 1885)
B. capsuliflorus Pallas	*Mytilina compressa*	*Chydorus sphaericus* (O. F. Mueller, 1785)
B. diversicornis (Daday, 1883)	*Notholca acuminata* (Ehrenberg, 1832)	*C. ovalis* (Kurz, 1874)
B. falcatus (Zacharias, 1898)	*Plationus patulus* (Müller, 1786)	*Daphnia pulex* (Leydig, 1860)
B. forficula (Wierzejski, 1891	*Polyarthra dolichoptera* (Idelson, 1925)	*Diaphanosoma leuchtenbergianum* (Fischer, 1854)
B. leydigii (Cohn, 1862)	*Pompholyx sulcata* (Hudson, 1885)	*Disparalona hamata* (Birge, 1879)
B. rubens (Ehrenberg, 1838)	*Proales* sp.	*D. rostrata* (Koch, 1841)
Cephalodella gibba (Ehrenberg, 1832)	*Rhinoglena frontalis*	*Ilyocryptus sordidus* (Liévin, 1848)
Collotheca sp.	*Rotaria neptunia* (Ehrenberg, 1832)	*Leydigia leydigi* (Leydig, 1860)
Colurella uncinata f. deflexa (Ehrenberg, 1834)	*R. rotatoria* (Pallas, 1766)	*Moina micrura* (Kurz, 1874)
Conochilus dossuarius (Hudson, 1875)	*R. tardigrada* (Ehrenberg, 1832)	*Oxyurella tenuicaudis* (G. O. Sars, 1862)
Dicranophorus grandis (Ehrenberg, 1832)	*Scaridium longicaudum* (O. F. Müller, 1786)	*Rhynchotalona falcata* (G. O. Sars, 1861)
Epiphanes sp.	*Synchaeta pectinata* (Ehrenberg, 1832)	*Simocephalus vetulus* (O. F. Müller, 1776)
Euchlanis triquetra (Ehrenberg, 1838)	*S. stylata* (Wierzejski, 1893)	**Copepoda**
Filinia longiseta (Ehrenberg, 1834)	*Testudinella* sp.	*Cyclops vicinus* (Uljanin, 1875)
F. minuta (Smirnov, 1928)	*Trichocerca bicristata* (Gosse, 1887)	*Eucyclops speratus* (Lilljeborg, 1901)
F. terminalis (Plate, 1886)	*T. bidens* (Lucks, 1912)	*Mesocyclops leuckarti* (Claus, 1857)
Gastropus sp.	*T. capucina* (Wierzejski & Zacharias, 1893)	*Thermocyclops taihokuensis* (Harada, 1931)
Hexarthra mira (Hudson, 1871)	*T. cylindrica* (Imhof, 1891)	*Neodiaptomus schmackeri* (Poppe & Richard, 1892)
Keratella cochlearis (Gosse, 1851)	*T. elongata* (Gosse, 1886)	Harpacticoida spp.
K. tecta (Gosse, 1851)	*T. inermis* (Linder, 1904)	

Table 3 Densities of main zooplankton groups in Lake Yuehu during the period of the survey (unit: ind./L)

	July 2005–June 2006	Jan 2007–Dec 2007		July 2005–June 2006	Jan 2007–Dec 2007
Rotifera			**Cladocera**		
Anuraeopsis fissa (*Anura.*)	179.0 ± 196.3	163.8 ± 324.5	*Bosmina longirostris* (*Bosmi.*)	35.1 ± 114.4	49.8 ± 53.9
Asplanchna spp. (*Aspla.*)	53.5 ± 122.9	77.4 ± 165.7	*Ceriodaphnia cornuta* (*Cerio.*)	0.1 ± 0.3	3.3 ± 6.6
Brachionus angularis (*B. angu.*)	1379.4 ± 2090.0	606.3 ± 1516.0*	*Chydorus* spp. (*Chydo.*)	2.1 ± 2.2	1.3 ± 3.7
B. budapestinensis (*B. buda.*)	58.1 ± 120.5	0.0 ± 0.0**	*Diaphanosoma leuchtenbergianum* (*Diaph.*)	26.5 ± 55.6	51.2 ± 83.6
B. calyciflorus (*B. caly.*)	273.8 ± 179.3	180.8 ± 165.6	*Moina micrura* (*Moina*)	15.7 ± 37.3	23.8 ± 48.3
B. diversicornis (*B. dive.*)	157.1 ± 384.8	0.0 ± 0.0**	Total cladocerans (*T. clad.*)	80.2 ± 146.3	129.7 ± 178.9
B. forficula (*B. forf.*)	112.1 ± 180.3	209.8 ± 610.0	**Copepoda**		
Filinia spp. (*Filin.*)	881.3 ± 868.6	466.6 ± 722.9	*Cyclops vicinus* (*Cyclo.*)	6.1 ± 9.4	6.4 ± 14.5
Keratella spp. (*Kerat.*)	1319.6 ± 1223.5	2030.0 ± 3782.3	*Mesocyclops leuckarti* (*Mesoc.*)	11.1 ± 25.9	2.6 ± 4.1
Polyarthra dolichoptera (*Polya.*)	1230.8 ± 1185.4	792.8 ± 1032.8	Nauplii+copepodites (Naupl.)	243.6 ± 296.4	329.8 ± 348.9
Pompholyx sulcata (*Pomph.*)	101.9 ± 184.7	422.5 ± 617.1	*Neodiaptomus schmackeri* (*Neodi.*)	0.0 ± 0.0	4.4 ± 5.7*
Synchaeta spp. (*Synch.*)	128.8 ± 168.4	64.2 ± 175.3*	*Thermocyclops taihokuensis* (*Therm.*)	8.1 ± 17.4	32.1 ± 49.3
Trichocerca spp. (*Trich.*)	1194.8 ± 2240.2	382.6 ± 922.6	Total copepods (*T. cope.*)	269.3 ± 332.5	375.5 ± 392.1
Total rotifers (*T. roti.*)	7781.5 ± 5073.5	5884.3 ± 5537.0			

Data are expressed as mean ± standard diviation. *$P < 0.05$; **$P < 0.01$. Taxa abbreviations presented in brackets were used in latter RDA analysis.

post-dredging. Therefore, samples taken pre-dredging were characterized by more rotifers, while samples taken post-dredging were characterized by more crustaceans. According to the centroid principle and distance rule implied in RDA, in Fig. 2a, Factor-1 and Factor-2 were both associated mainly with rotifers, while Factor-4 mainly with crustaceans.

3 Discussion

3.1 Water quality variation

In general, fine-grain sediments contain high concentrations of soluble nitrogen and phosphorus (Fisher et al., 1982; Valiela, 1995). These nutrients are derived from organic matter, which sinks to the sediments, where it is utilized and transformed by benthic organisms. Nutrient elements dissolved in sedimentary pore water will diffuse

Table 4 Total variance

Component	Rotation sums of squared loadings		
	Total	Variance percentage (%)	Cumulative (%)
1	3.176	19.848	19.848
2	2.909	18.179	38.027
3	2.677	16.729	54.755
4	2.500	15.627	70.382
5	1.367	8.546	78.928
6	1.147	7.171	86.098

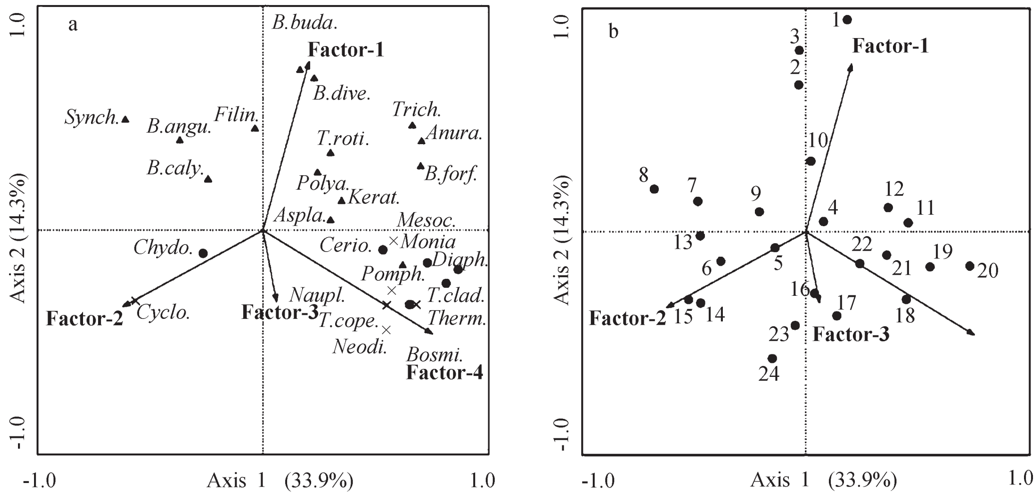

Fig. 2 RDA ordination plots. (a) with species and environmental variables. Up-triangle represented rotifers, circle represented cladocerans and x-mark represented copepods; taxa abbreviations are presented in Table 3. (b) with samples and environmental variables. Numbers of 1–12 represented samples taken monthly from July 2005 to June 2006 and numbers of 13–24 taken monthly from Jan to Dec 2007.

Table 5 Rotated component matrix[a]

Variable	Component					
	1	2	3	4	5	6
IP	**0.887**	–0.129	–0.179	0.034	–0.027	0.062
Chl-*a*	**0.848**	–0.197	0.287	–0.152	–0.157	–0.013
TP	**0.799**	–0.234	–0.240	–0.141	–0.111	–0.102
EC	–0.262	**0.889**	–0.139	0.292	0.083	0.055
TDS	–0.286	**0.882**	–0.127	0.294	0.090	0.046
TN	0.001	**0.716**	0.127	–0.382	–0.046	0.179
pH	–0.221	–0.044	**0.843**	0.196	0.146	0.132
DO	–0.333	0.156	**0.814**	–0.107	–0.239	0.048
COD_{Cr}	0.276	–0.052	**0.787**	–0.077	0.030	–0.230
TSS	0.065	–0.317	**0.666**	–0.070	0.468	–0.193
SD	0.150	–0.021	–0.022	**–0.894**	0.036	0.201
Depth	–0.161	0.350	–0.009	**0.882**	0.054	–0.049
Temperature	0.525	–0.405	–0.016	**0.658**	–0.039	0.232
NO_3^--N	–0.151	0.492	0.100	–0.107	**0.786**	–0.111
TOC	0.544	0.200	0.002	–0.172	**–0.625**	–0.188
NO_2^--N	–0.022	0.145	–0.082	–0.163	–0.020	**0.917**

[a] Rotation converged in eight iterations.
Major factor loadings are highlighted in bold.
Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalization.

Table 6 Summary of the RDA analysis

Axes	1	2
Eigenvalues	0.339	0.143
Species-environment correlations	0.917	0.857
Cumulative percentage variance		
of species data	33.9%	48.3%
of species-environment relation	65.6%	93.3%
Total variance explained	51.7%	
The Monte Carlo permutation test	*F*-ratio	*P*-value
on the first axis	9.758	0.002
on all axes	5.089	0.002

slowly to overlying water. While sediment particles may also bind some nutrients (Nixon et al., 1976; Rosenfeld, 1979), re-suspension of sediments following disturbance generally causes rapid release of nutrients to the water column (Jones and Lee, 1981; Klump and Martens, 1981).

In this study, a decreasing trend for levels of nitrogen, phosphorus, COD_{Cr}, TOC and TSS except NO_3^--N in the water column was found over the period of the survey. This was partly due to the following reasons. First, Lake Yuehu was in a hyper-eutrophic state and its sediment was the main source of various nutrients. Suction dredging reduced the internal nutrient load, and correspondingly decreased the amount of nutrients released to the water column. Simultaneously, dissolved nutrients such as phosphorus could be adsorbed by suspended solids and deposited to the sediment. Second, dredging reduced organic matter load, spoiled benthic and microbial community structure, and depressed extracellular enzymes activities in the sediment. Therefore, the amount of organic matter mineralization decreased post-dredging.

Lewis et al. (2001) determined the impacts of hydraulic dredging on an urbanized estuary, and found that the effects on surface water pH, DO and temperature were negligible, but photosynthetically active radiation was decreased at several stations. A similar trend was found in this study. According to the results, the significant decrease in Chl-*a* content indicated the marked decline in algal biomass. This was probably due to the declined transparency and phosphorus levels. There were significant correlations between Chl-*a* and phosphorus levels in the study (Pearson's correlation, $P < 0.05$, $n = 24$), which indicated phosphorus limitation of primary production in the lake. At the same time, the ratio of TN:TP during the period of either pre- or post-dredging was less than 29 (Table 1), which was a clear indication for the occurrence of dominance by bloom-forming cyanobacteria according to Smith (1983). The simultaneous field data of phytoplankton (Gao et al., unpublished data) also supported the point. The increase in EC was partly due to the increasing NO_3^--N concentration judged from their significant correlation (Pearson's correlation, $P = 0.018$, $n = 24$). The increases in EC and TDS levels might also indicate the re-suspension of particulate metals (e.g., Ca, Mg, Na, K, Ba, Fe, Sr (Zhang, unpublished data)) and their release from the sediment to the aqueous phase (Nayar et al., 2004).

3.2 Community structure variation

Zooplankton community composition associates with trophic status of water body tightly, and the outcome of impacts like nutrient enrichment can be reflected in zooplankton community structure (Conde-Porcuna et al., 2002; Hietala et al., 2004). This can be illustrated by the RDA analysis in the context, which displayed a distinct relationship between zooplankton taxa composition and their environment. The first four synthetic environmental variables explained 51.7% of the taxonomic structure. As stated previously, nutrient as well as organic matter load in the water column declined markedly. The zooplankton community structure responded rapidly to the environmental changes. As a result, the abundance of rotifers decreased, while the density of zooplanktonic crustaceans increased markedly. The representative taxa were *B. angularis*, *B. budapestinensis*, *B. diversicornis*, *Synchaeta* spp. and *N. schmackeri*, implying these species could possibly be considered as target taxa for more intensive monitoring. Normally, a high abundance of *Brachionus* can be considered as a biological indicator of more eutrophic water (Attayde and Bozelli, 1998). Therefore, with the reduction of internal nutrient load via dredging, a shift in dominance towards less eutrophic species occurred.

Rotifers are usually regarded as bio-indicators of water quality (Sládeček, 1983), and their abundance and population characteristics are used as effective indicators of environmental changes (Attayde and Bozelli, 1998). According to the results, Factor-1 and Factor-2 were both mainly associated with rotifers, and Factor-4 mainly with zooplanktonic crustaceans, while PCA showed that Factor-1 was mainly affected by IP, Chl-*a* and TP, Factor-2 by EC, TDS and TN, and Factor-4 by SD, water depth and temperature. It could be concluded that rotifers were much related to nutrients, while zooplanktonic crustaceans were mainly related to physical conditions in the lake. This is consistent with the results from previous studies that rotifers are more sensitive to changes in nutrients than crustaceans (Gannon and Stremberger, 1978).

Submerged macrophytes are of vital importance in maintaining water clarity through sedimentation, competition and allelopathy against phytoplankton or other suspended solids (Hilt and Gross, 2008). A macrophyte community, consisted mainly of *Potamogeton crispus* and *Elodea nuttallii*, was well re-established in Lake Yuehu from January to June 2005, and their biomass peaked in May 2005 and declined thereafter. In this case, dredging destroyed the macrophytes remained, which had not recovered in the next year. The disappearance of macrophytes mostly accounted for the obvious decline in transparency (Sosnowski, 1984), which was an important factor in shaping the crustacean zooplankton community.

In a word, suction dredging had lowered the internal nutrient load and changed the zooplankton community structure, which demonstrated the improved environmental conditions in the lake.

4 Conclusions

After comparing water quality and zooplankton community structure pre- with post-dredging in Lake Yuehu, a decreasing trend for levels of phosphorus, organic matter, TSS and Chl-*a* in the water column was found. With respect to the zooplankton community structure, the abundance of rotifers decreased, while the density of zooplanktonic crustaceans increased markedly. The decreases in densities of *B. angularis*, *B. budapestinensis*, *B. diversicornis* and *Synchaeta* spp., and the increase in density of *N. schmackeri* suggested a decline in trophic state of the lake. Therefore, with the internal nutrient load reduction and the zooplankton community succession towards less eutrophic levels, it was inferred that dredging might be an effective way to improve such eutrophic lakes.

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