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RESEARCH ARTICLE

Macrozoobenthic assemblages in relation to environments of the Yangtze-isolated lakes

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Abstract Eutrophication can shift lakes from a clear, macrophyte-dominated state to a turbid, algae-dominated state, and different habitat condition supports different fauna. Macrozoobenthos are good indicators of water environment, and studies on macrozoobenthic assemblage characteristics can help us to know which state a lake is in, thus provide the basis for its eutrophication control. In this study, a systematic investigation on macrozoobenthos was conducted in 17 Yangtze-isolated lakes to explore the macroecological laws of macrozoobenthic assemblages. Detrended correspondence analysis (DCA) revealed that variance of benthic assemblage structure occurred in two types of lakes. In macrophytic lakes, altogether 51 taxa of macrozoobenthos were identified. The average density and biomass of total macrozoobenthos were 2231 individuals$\cdot$m^{-2} and 1.69 g dry weight$\cdot$m^{-2}, respectively. Macrozoobenthic assemblage was characterized by dominance of scrapers (i.e. gastropods). In algal lakes, altogether 20 taxa of macrozoobenthos were identified. The average density and biomass of total macrozoobenthos were 2814 individuals$\cdot$m^{-2} and 1.38 g dry weight$\cdot$m^{-2}, respectively. Macrozoobenthic assemblage was characterized by dominance of collector-gatherers (i.e. oligochaetes). Wet biomass of submersed macrophytes (B_{Mac}) and phytoplankton chlorophyll *a* concentration (*Chl a*) were demonstrated as the key factor structuring macrozoobenthic assemblages in macrophytic and algal lakes, respectively.

Keywords macrozoobenthos, assemblage characteristics, environment analyses, macrophytic lake, algal lake

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1 Introduction

Eutrophication has been considered as a major threat to floodplain lakes [1]. One of the most serious problems caused by eutrophication is the shift from a clear, macrophyte-dominated state to a turbid, algae-dominated state [2,3]. Macrozoobenthos are considered as good indicators of changes in water environment due to their confinement to the bottom and limited abilities of movement [4,5]. Therefore, a better understanding of macrozoobenthic assemblages can help us to know which state a lake is approximately in, thus provide the basic data for studies on its eutrophication control.

In the Yangtze basin of China, floodplain lakes are numerous, with a total area over 16600 km^2. Historically, most lakes were connected freely with the main river course of the Yangtze, where floods occur periodically. To prevent villages and cultivated lands along lakeshore from being flooded, embankments and sluice gates were constructed during the 1950s–1970s and eventually isolated most of the lakes from the river. These river-isolated lakes have been facing the threat of eutrophication, and lake ecosystems may exist in two typically stable states, i.e. macrophyte-dominated state and algae-dominated state. Previous research was concentrated in description of macrozoobenthic assemblage characteristics [6,7], and relationship between assemblage structure and environments [8–10]. However, these studies were carried out in a single lake or in a few lakes, i.e. at a low level of study scale. To explore the macroecological laws of macrozoobenthic assemblages, it is necessary to carry out the field survey at a large-scale level.

In this study, 17 river-isolated lakes along the mid-lower reaches of the Yangtze River were surveyed. Our purposes are: 1) to describe the overall characteristics of macrozoobenthic assemblages in the Yangtze-isolated lakes; 2) to analyze the potential environmental factors influencing macrozoobenthic assemblages.

2 Study area and method

All the 17 river-isolated lakes are situated in the mid-lower Yangtze basin, belonging in the monsoon region of East Asia subtropical zone, among which eight macrophytic lakes were characterized by dense macrophytes, with a wet biomass range of 506.6–6488.3 $g \cdot m^{-2}$, and nine algal lakes were characterized by high phytoplankton chlorophyll *a* concentration, with a concentration range of 36.8–113.3 $mg \cdot m^{-3}$. The distribution of studied lakes is shown in Fig. 1. The basic morphometric and main environmental parameters of the studied lakes are given in Table 1.

Field investigations were conducted in April and September 2004. Water depth (Z) and Secchi depth (Z_{SD}) were measured with a sounding lead and a Secchi Disc, respectively. Water samples were taken near the surface and at the bottom, combined for laboratory analyses. Total nitrogen (TN) was analyzed by the alkaline potassium persulfate digestion-UV spectrophotometric method. Total phosphorus (TP) was analyzed by the ammonium molybdate method. Phytoplankton chlorophyll *a* concentration ($Chl\,a$) was measured after acetone extractions by reading absorbance at 665 and 750 nm using spectrophotometer (Unico UV-2000, Shanghai, China). All of the above methods are described in detail in Huang [11]. Macrophytes were sampled with a scythe (1/5 m^2), 2–4 times at each site, then cleaned, removed superfluous water and weighed for wet weight (B_{Mac}).

Quantitative samples of macrozoobenthos were taken with a weighted Petersen grab (1/16 m^2) and then sieved with a 420-μm sieve. In the same habitat adjacent to benthic sampling site, submersed macrophytes were sampled by scythes. After scything, plants were gathered with a handnet (mesh size = 420 μm) and put into plastic bags. In the laboratory, epiphytic animals were picked up from the rinsed samples. Both epiphytic and benthic animals were preserved in 10% formalin. Wet weight of animals was determined with an electronic balance after being blotted, and then dry weight (mollusks without shells) was calculated according to the ratios of dry-wet weight and tissue-shell weight reported in previous studies [12,13]. All taxa were assigned to functional feeding groups (shredders, collector-gathers, collector-filterers, scrapers, and predators) according to relevant materials [14,15]. When a taxon had several possible feeding activities, its functional designations were equally

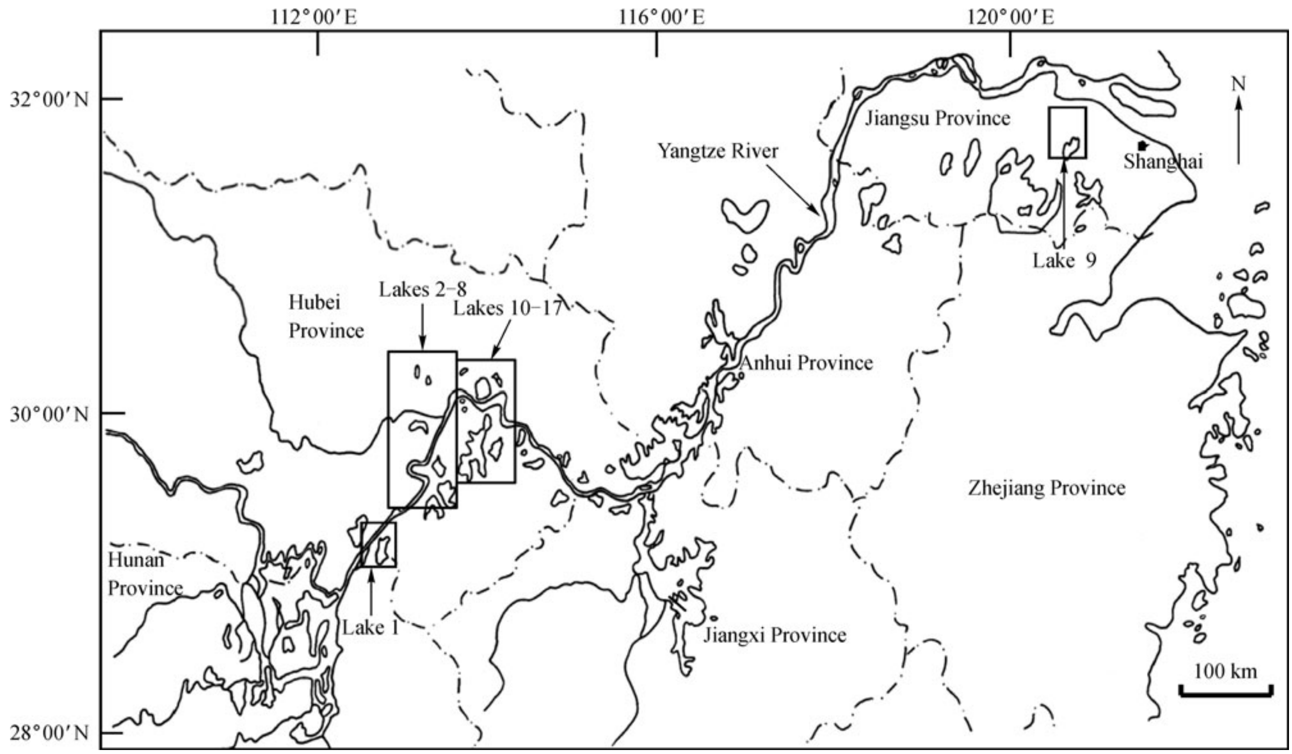

Fig. 1 Distribution of studied lakes along the Yangtze River. Lakes 1–8 are situated in the suburban regions, and these macrophytic lakes are as follows: HHL, Honghu Lake (Lake 1, 8 sites); LHL, Luhu Lake (Lake 2, 8 sites); NBZL, Nanbeizui Lake (Lake 3, 6 sites); NSL, Niushan Lake (Lake 4, 7 sites); QDL, Qiaodun Lake (Lake 5, 4 sites); TJDL, Taojiada Lake (Lake 6, 3 sites); XSHL, Xiaosihai Lake (Lake 7, 10 sites); ZDL, Zhangdu Lake (Lake 8, 6 sites). Lakes 9–17 are situated in the urban regions, and these algal lakes are as follows: GHL, Gehu Lake (Lake 9, 7 sites); HXL, Hongxing Lake (Lake 10, 4 sites); LYL, Longyang Lake (Lake 11, 6 sites); MSL, Moshui Lake (Lake 12, 5 sites); NHL, Nanhu Lake (Lake 13, 7 sites); NTZL, Nantaizi Lake (Lake 14, 6 sites); QLL, Qingling Lake (Lake 15, 3 sites); SJL, Sanjiao Lake (Lake 16, 3 sites); SLQL, Sanliqi Lake (Lake 17, 4 sites)

Table 1 Basic morphometric and main environmental parameters of the studied lakes

type of lakes	code	A/km^2	D_L	D_V	DR	Z/m	Z_{SD}/m	TN/ (mg·m^{-3})	TP/ (mg·m^{-3})	$Chl\ a$/ (mg·m^{-3})	B_{Mac}/ (g·m^{-2})
macrophytic lakes	HHL	355.0	1.54	1.75	8.12	1.3	0.9	918	40	5.0	795.0
	LHL	29.8	5.21	2.20	1.82	1.5	0.9	641	31	3.1	506.6
	NBZL	66.7	6.40	1.96	1.78	2.5	1.6	770	16	3.1	762.4
	NSL	38.0	4.80	2.10	1.23	2.2	2.2	804	33	2.2	586.1
	QDL	8.0	1.95	1.91	0.86	2.7	2.0	536	48	3.8	6488.3
	TJDL	3.0	2.53	1.88	0.72	1.5	1.2	633	46	3.4	1471.9
	XSHL	1.5	3.63	2.62	0.57	2.0	0.9	700	19	3.1	1123.4
	ZDL	35.2	1.22	1.57	2.58	1.7	1.1	717	56	4.5	1226.1
algal lakes	GHL	146.5	1.18	1.88	6.37	1.2	0.4	3197	218	47.7	0
	HXL	0.5	2.12	2.90	0.24	2.8	0.5	7882	384	57.6	0
	LYL	1.8	2.00	2.40	0.67	1.7	0.4	8171	1017	113.3	0
	MSL	3.0	2.00	2.40	0.67	2.2	0.4	6848	1050	103.6	0
	NHL	7.9	2.17	2.00	1.12	2.5	0.4	8259	346	79.9	0
	NTZL	7.9	2.17	2.00	1.87	1.5	0.3	13690	760	96.0	0
	QLL	2.0	1.81	2.60	0.94	1.3	0.4	1638	293	83.2	0
	SJL	2.0	1.80	2.50	0.50	1.8	0.5	6073	205	50.2	0
	SLQL	2.7	2.10	2.71	0.78	1.9	0.5	7096	306	36.8	0

Note: The table shares the same lake codes with Fig. 1. A, area; D_L, development of lake shoreline, which is calculated as the ratio of shoreline length to lake circumference; D_V, development of lake volume, which is calculated as the ratio of Z_{Mean} to Z_{Maxi}; DR, dynamical ratio of lake, which is calculated as the ratio of square root of lake area to mean water depth; Z, water depth; Z_{SD}, Secchi depth; TN, total nitrogen concentration of water; TP, total phosphorus concentration of water; $Chl\ a$, phytoplankton chlorophyll a concentration; B_{Mac}, wet biomass of submersed macrophytes

proportioned. The Jaccard similarity coefficient (S_J) was used to compare macrozoobenthic assemblages between the lakes:

$$S_J = c/(a+b-c), \tag{1}$$

where, a is the number of species in assemblage A, b is the number of species in assemblage B, and c is the number of species co-existing in both assemblages.

STATISTICA 6.0 was used for Unequal N HSD test after one-way ANOVA. CANOCO 4.5 was used for detrended correspondence analysis (DCA) and canonical correspondence analysis (CCA) [16]. To reduce heterogeneity of variances, the macrozoobenthic densities were lg ($x + 1$) transformed.

3 Results

3.1 Classified groups of the studied lakes

Limnological parameters of the studied lakes are given in Table 2. One-way ANOVA revealed that environmental variance existed between two types of lakes. According to the standard suggested by Nürnberg for fixed boundary classification of lake system [17], the macrophytic lakes were in mesotrophic-eutrophic state, and the algal lakes were in hypereutrophic state. Fig. 2 shows the DCA ordination diagram of sampling lakes. It is demonstrated that two types were distinguishable, ordinated by the first axis. This phenomenon revealed that variance of benthic assemblage structure occurred in two types of lakes. Therefore, assemblage characteristics of macrozoobenthos should be separately described.

3.2 Assemblage characteristics of macrozoobenthos

Macrozoobenthic taxa in 17 river-isolated lakes of the Yangtze basin are given in Appendix 1. Altogether 57 taxa of macrozoobenthos belonging to 17 families and 49 genera were identified. The Jaccard coefficient between macrophytic lakes and algal lakes was only 0.30, which indicated that the similarity of macrozoobenthos between the two types of lakes was low.

Figures 3 and 4 give the densities and biomass of each taxonomic group and each functional feeding group of macrozoobenthos in macrophytic and algal lakes, respectively. Table 3 gives the densities, biomass and percentage of dominant taxa. In macrophytic lakes, altogether 51 taxa of macrozoobenthos belonging to 16 families and 45 genera were identified. The average density and biomass of total macrozoobenthos were 2231 individuals·m^{-2} and 1.69 g dry weight·m^{-2}, respectively. Scraper mollusks were predominant group, being 93.6% of the total in density, 85.2% in biomass. The dominant taxa were *Parafossarulus striatulus*, *Hippeutis cantori*, *Alocinma longicornis*, *Radix* sp., *Bellamya* sp. and *Branchiura sowerbyi*.

Table 2 Limnological parameters of the studied lakes, with probability levels (p) determined by Unequal N HSD test after one-way ANOVA

parameters	value	macrophytic lakes	algal lakes	p
A/km^2	mean±SE	67.2±41.8	19.4±15.9	0.295
	min–max	1.5–355.0	0.5–146.5	
D_L	mean±SE	3.41±0.67	1.93±0.10	0.040
	min–max	1.22–6.40	1.18–2.17	
D_V	mean±SE	2.00±0.11	2.38±0.12	0.040
	min–max	1.57–2.62	1.88–2.90	
DR	mean±SE	2.21±0.88	1.39±0.63	0.463
	min–max	0.57–8.12	0.24–6.37	
Z/m	mean±SE	1.9±0.2	1.9±0.2	0.853
	min–max	1.3–2.7	1.2–2.8	
Z_{SD}/m	mean±SE	1.9±0.3	0.4±0.0	0.002
	min–max	0.9–2.2	0.3–0.5	
TN/(mg·m^{-3})	mean±SE	715±41	6983±1134	<0.001
	min–max	536–918	1638–13690	
TP/(mg·m^{-3})	mean±SE	36±5	509±113	0.002
	min–max	16–56	205–1050	
$Chl\,a$/(mg·m^{-3})	mean±SE	3.5±0.3	70.2±9.1	<0.001
	min–max	2.2–5.0	36.8–113.3	
B_{Mac}/(g·m^{-2})	mean±SE	1620.0±705.2	0.0±0.0	0.031
	min–max	506.6–6488.3	0.0–0.0	

Note: the meanings of limnological parameters are presented in Table 1

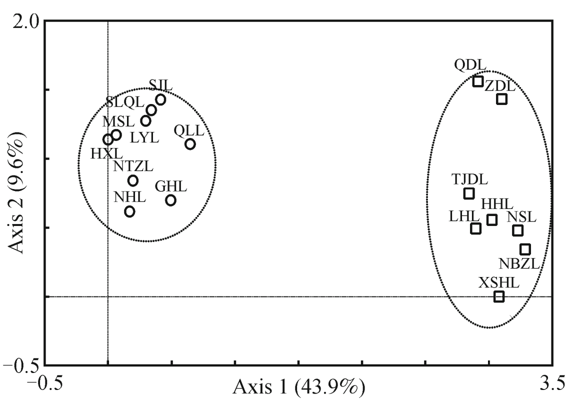

Fig. 2 Ordination diagram of sampling lakes by detrended correspondence analysis (DCA) based on abundance of macrozoobenthos.□, macrophytic lakes; ○, algal lakes. The meanings of abbreviative letter of sampling lakes are presented in Fig. 1

In algal lakes, altogether 20 taxa of macrozoobenthos belonging to 8 families and 18 genera were identified. The average density and biomass of total macrozoobenthos were 2814 individuals·m^{-2} and 1.38 g dry weight·m^{-2}, respectively. Oligochaetes were predominant group, being 79.6% of the total in density, 56.5% in biomass. With regard to functional groups, collector-gatherers were predominant, being 90.8% in density, 75.4% in biomass. The dominant taxa were *Limnodrilus hoffmeisteri*, *Tanypus* sp., *Bellamya* sp. and *Branchiura sowerbyi*.

3.3 Environmental factors influencing macrozoobenthic assemblages

Analyses of forward selection and Monte Carlo permutation test revealed that the important environmental factors influencing abundance and distribution of macrozoobenthos in macrophytic lakes were wet biomass of submersed macrophytes (B_{Mac}), water depth (Z), Secchi depth (Z_{SD}) and development of lake volume (D_V). In Fig. 5(a), Axes 1 and 2 accounted for 60.8% information of species-environment relations, and both axes were significant at $p < 0.05$ (Monte Carlo permutation test). The factors strongly correlated with the first axis were B_{Mac} and Z. The second axis was predominantly correlated with Z and Z_{SD}.

Analyses of forward selection and Monte Carlo permutation test revealed that the important environmental factors influencing abundance and distribution of macrozoobenthos in algal lakes were phytoplankton chlorophyll *a* concentration ($Chl\,a$), water depth (Z), development of lake volume (D_V), total nitrogen concentration of water (TN) and Secchi depth (Z_{SD}). In Fig. 5(b), Axes 1 and 2 accounted for 69.4% information of species-environment relations, and both axes were significant at $p < 0.05$

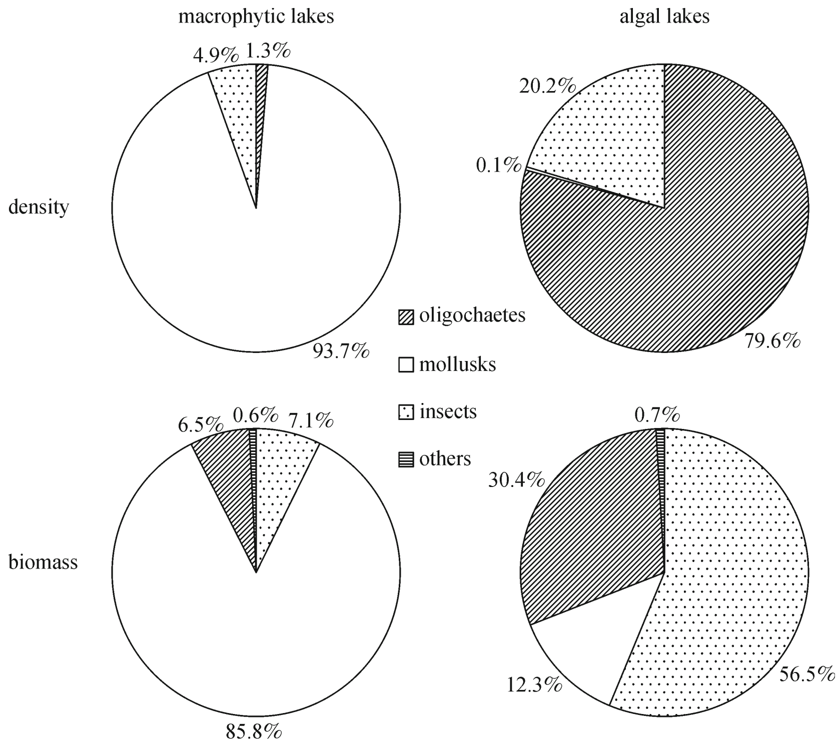

Fig. 3 Density (D, individuals·m^{-2}) and biomass (B, g dry weight·m^{-2}) (mollusks without shells) of each taxonomic group of macrozoobenthos in macrophytic and algal lakes of the Yangtze basin

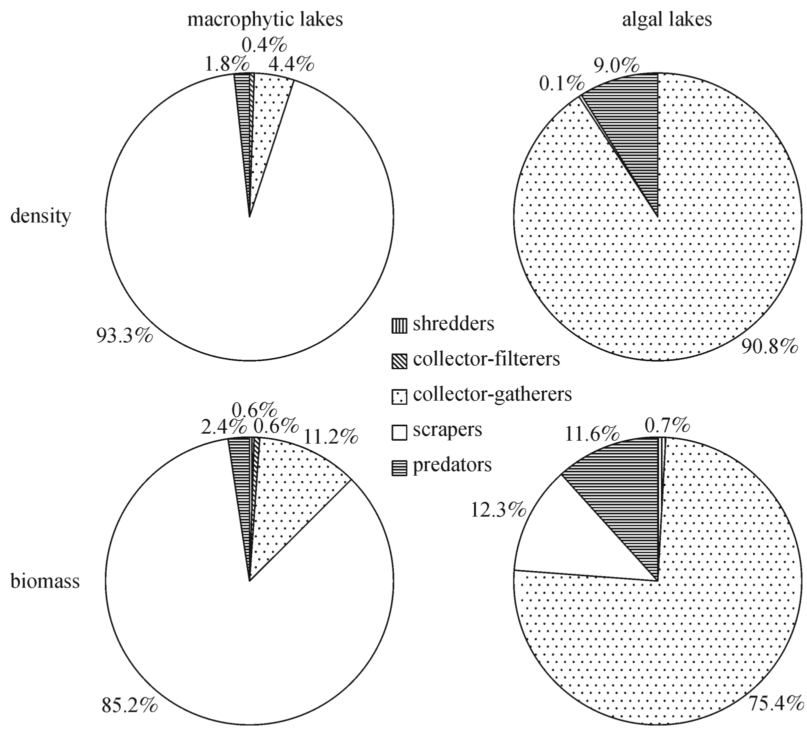

Fig. 4 Density (D, individuals·m^{-2}), biomass (B, g dry weight·m^{-2}) (mollusks without shells) of each functional feeding group of macrozoobenthos in macrophytic and algal lakes of the Yangtze basin

Table 3 Density (D, individuals·m^{-2}), biomass (B, g dry weight·m^{-2}) (mollusks without shells) and percentage of dominant taxa in macrophytic and algal lakes of the Yangtze basin

taxa	density in macrophytic lakes		biomass in macrophytic lakes		density in algal lakes		biomass in algal lakes	
	D	%	*B*	%	*D*	%	*B*	%
Oligochaeta								
Limnodrilus hoffmeisteri	0	0.0	0.00	0.0	2049	72.8	0.66	47.8
Branchiura sowerbyi	20	0.9	0.10	5.9	25	0.9	0.09	6.5
subtotal	20	0.9	0.10	5.9	2074	73.7	0.75	54.3
Gastropoda								
Bellamya sp.	9	0.4	0.10	5.9	4	0.1	0.17	12.3
Parafossarulus striatulus	996	44.6	0.79	46.7	0	0.0	0.00	0.0
Alocinma longicornis	229	10.3	0.23	13.6	0	0.0	0.00	0.0
Radix sp.	195	8.7	0.14	8.3	0	0.0	0.00	0.0
Hippeutis cantori	665	29.8	0.13	7.7	0	0.0	0.00	0.0
subtotal	2094	93.8	1.39	82.2	4	0.1	0.17	12.3
Insecta								
Tanypus sp.	5	0.2	0.003	0.2	480	17.1	0.30	21.7
subtotal	5	0.2	0.003	0.2	480	17.1	0.30	21.7
total	2119	94.9	1.49	88.3	2558	90.9	1.22	88.3

Note: the taxon whose relative density or relative biomass exceeds 5% of the total is considered as a dominant taxon

(Monte Carlo permutation test). The factors strongly correlated with the first axis were *Chl a*, D_V and Z. The second axis was predominantly correlated with Z and D_V.

4 Discussion

The intensive human activity makes river-isolated lakes face the threat of eutrophication. Lake ecosystems may exist in two typically stable states, i.e. macrophyte-dominated state and algae-dominated state. Macrozoobenthos are considered as good indicators of changes in water environment due to their confinement to the bottom and limited abilities of movement. Macrozoobenthos showed different responses to different habitat conditions. Many obvious differences of macrozoobenthic assemblage structure were revealed between macrophytic lakes and algal lakes. First, macrophytic lakes supported more macrozoobenthic taxa than that of algal lakes. Second, pollutant-sensitive taxa (e.g. EPT: Ephemeroptera, Plecoptera and Trichoptera) occurred in macrophytic lakes, but disappeared in algal lakes. Third, macrophytic lakes were characterized by dominance of gastropods, while algal lakes were characterized by dominance of oligochaetes.

In macrophytic lakes, macrophytes have the key position in the structuring benthic assemblages [18]. They create significant horizontal and vertical heterogeneities that provide a physical template for distinct niches [19,20], and serve as a refuge against predators [21,22]. Therefore, the more complex and diverse fauna were supported in macrophytes-dominated lakes. Furthermore, macrophytes can provide food sources for epiphytic animals [18,23], serve as a site for oviposition [20,24], and provide chances for snails to crawl on the air-water interface (particularly for pulmonates) [25]. Therefore, a large number of epiphytic gastropods were supported by dense macrophytes.

In algal lakes, macrophytes reduced and even disappeared. The reasons of macrophytes reduction are as follows: 1) eutrophication is associated with an increase in phytoplankton, accompanied by decrease of the euphotic depth, thereby inhibiting the growth of submersed macrophytes [26,27]; 2) the bottom of eutrophic waterbody is always a thick layer of fine organic sludge [28], and organic-rich sediment prevents aquatic plants from absorbing nutrients, or injures plants through producing deoxidized ions [29,30]. In algal lakes, intensive decomposition leaded to lack of dissolved oxygen, and only some pollutant-tolerate animals can survive [31,32]. EPT (Ephemeroptera, Plecoptera and Trichoptera) are well-known by their general intolerance of harmful effects of eutrophication [33,34], so they disappeared in algal lakes.

Eutrophication can shift lakes from the clear to the turbid state, and assemblage structure of macrozoobenthos also changed accordingly. Comparisons of macrozoobenthic assemblages in two types of lakes indicated that lake eutrophication was accompanied by decline in diversity, disappearance of pollutant-sensitive taxa and aggregation of pollutant-tolerant taxa. In view of indicative function of macrozoobenthos to water environment, this systematic study on macrozoobenthic assemblages may provide some

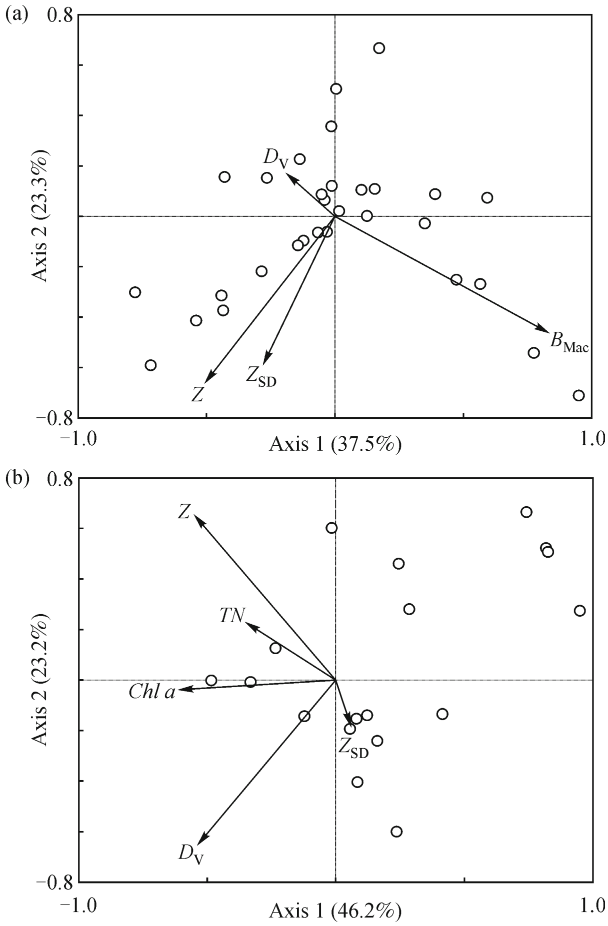

Fig. 5 CCA biplots of species-environments. Major environmental variables influencing abundance and distribution of macrozoobenthos in macrophytic lakes (a) and in algal lakes (b) are presented. Environmental parameters: D_V, development of lake volume; Z, water depth (m); Z_{SD}, Secchi depth (m); TN, total nitrogen concentration of water ($mg \cdot m^{-3}$); *Chl a*, phytoplankton chlorophyll *a* concentration ($mg \cdot m^{-3}$); B_{Mac}, wet biomass of submersed macrophytes ($g \cdot m^{-2}$)

basic data for eutrophication control.

5 Conclusions

Compared with macrozoobenthos in algal lakes, more benthic taxa were supported in macrophytic lakes. Macrozoobenthic assemblages were characterized by dominance of scrapers (i.e. gastropods) and by dominance of collector-gatherers (i.e. oligochaetes) in macrophytic and algal lakes, respectively. Wet biomass of submersed macrophytes (B_{Mac}) and phytoplankton chlorophyll *a* concentration (*Chl a*) were demonstrated as the key factor structuring macrozoobenthic assemblages in macrophytic and algal lakes, respectively.

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Appendix 1 List of macrozoobenthic taxa in 17 river-isolated lakes of the Yangtze basin. + means presence

taxa	macrophytic lakes	algal lakes
Annelida		
Oligochaeta		
Limnodrilus grandisetosus Nomura	+	+
Limnodrilus hoffmeisteri Claparède		+
Limnodrilus sp.	+	+
Ilyodrilus sp.	+	+
Spirosperma nikolskyi (Lastockin *et* Sokolskaya)	+	
Aulodrilus pluriseta (Piguet)	+	+
Branchiura sowerbyi Beddard	+	+
Hirudinea		
Glossiphoniidae	+	+
Mollusca		
Gastropoda		
Cipangopaludina chinensis (Gray)	+	
Bellamya sp.	+	+
Parafossarulus eximius (Frauenfeld)		+
Parafossarulus striatulus (Benson)	+	
Alocinma longicornis (Benson)	+	
Semisulcospira cancellata (Benson)	+	
Radix sp.	+	
Hippeutis cantori (Benson)	+	
Hippeutis umbilicalis (Benson)	+	

(*Continued*)

taxa	macrophytic lakes	algal lakes
Lamellibranchia		
Limnoperna lacustris (Martens)	+	
Unio douglasiae Gray	+	
Acuticosta chinensis (Lea)	+	
Schistodesmus lampreyanus (Baird *et* Adams)	+	
Arconaia lanceolata (Lea)	+	
Hyriopsis cumingii (Lea)	+	
Lancelaria grayana (Lea)	+	
Lamprotula caveata (Heude)	+	
Lamprotula leai (Gray)	+	
Anodonta woodiana woodiana (Lea)	+	
Anodonta arcaeformis (Heude)	+	
Anodonta lucida (Heude)	+	
Anodonta angula Tchang *et al*.	+	
Anodonta arcaeformis flavotincta (Martens)	+	
Cristaria plicata (Leach)	+	
Corbicula fluminea (Müller)	+	
Sphaerium lacustre (Müller)		+
Arthropoda		
Amphipoda	+	+
Trichoptera		
Polycentropodidae	+	
Odonata		
Sinictinogomphus sp.	+	
Plecoptera	+	
Diptera		
Ceratopogonidae	+	+
Chaetocladius sp.	+	
Chironomus sp.	+	+
Cladopelma sp.	+	
Clinotanypus sp.	+	
Coelotanypus sp.	+	
Cryptochironomus sp.	+	
Diplocladius sp.		+
Einfeldia sp.	+	
Glyptotendipes sp.	+	+
Microchironomus sp.	+	+
Orthocladiinae		+
Paracladopelma sp.	+	
Polypedilum sp.	+	
Procladius sp.	+	+
Propsilocerus akamusi (Tokunaga)		+
Stictochironomus sp.	+	
Tanypus sp.	+	+
Tanytarsus sp.	+	
total taxa number	51	20