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Composition and structure of benthic macroinvertebrate community in two reservoirs in Hubei province, China: Response to eutrophication

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ABSTRACT

Water quality and benthic macroinvertebrate samples were collected from two reservoirs in central China from November 2006 to August 2007. Twenty-nine benthic macroinvertebrate taxa were identified, including 10 oligochaetes, 15 aquatic insects and four molluscs. Some of the most common taxa were *Aulodrilus pluriseta*, *Limnodrilus hoffmeisteri*, *Cryptochironomus* sp., *Polypedilum* sp. and *Tokunagayusurika akamusi*. Average densities of the macroinvertebrates were similar in both reservoirs (about 300 ind.m^{-2}), whereas there was a large difference in biomass with 430.7 mg.m^{-2} in Daoguanhe reservoir and 1294.3 mg.m^{-2} in Jinshahe. Density and biomass of the benthic macroinvertebrates varied over time in both reservoirs with the highest values in November of 2006. Density and biomass also varied spatially. Water temperature, depth, sediment composition and nutrients were correlated with the density of benthic organisms. The biological quality of reservoirs was evaluated with the Shannon diversity, Margalef richness and Goodnight–Whitley indices. Both chemical and biological analyses indicated that Jinshahe reservoir is slightly polluted and still in good ecological conditions, while Daoguanhe reservoir is more heavily polluted, with macroinvertebrate community typical of polluted waters. Studying the condition of the benthic macroinvertebrate communities yielded important information about the health of the reservoirs and the stress factors that influence environmental conditions.

Keywords: Macroinvertebrates; Spatial patterns; Water quality assessment; Artificial lakes; Diptera Chironomidae; Oligochaeta

1. Introduction

Monitoring the concentration of critical chemical constituents is an important part of assessing the health of aquatic systems. However, quantifying certain target chemical constituents is, by itself, not sufficient to thoroughly evaluate water quality since some chemical stressors may be unknown or at concentrations below the detection level of the analytical methods being used. Evaluating the condition of biological communities, or bioassessment, provides a direct means of empirically quantifying the health of an aquatic system and accounts for unknown stressors and periodic pollution events [1]. The condition of the benthic macroinvertebrate community can be a reliable gauge of long-term environmental change. Acute release events leading to elevated concen-

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trations of organic pollutants, such as phenols or pesticides, can be monitored through prompt measurements of physical and chemical conditions. However, such short-term assessments will not account for persistent, recalcitrant pollutants that are sequestered in sediments, thus providing a long-term source of contamination. Bioassessment, however, can be an effective way to better understand the condition of a water body that is under the influence of a host of physical and/or chemical stressors.

Being an important component of aquatic ecosystems, benthic macroinvertebrates also provide a trophic link between detritus, meiobenthos and fishes [2]. Their grazing activities influence decomposition rates [3], energy flow [4] and bacterial activity [5]. Additionally benthic macroinvertebrates have many features that make them ideal subjects for a comprehensive study of water quality in different aquatic environments, including rivers [6], lakes [7], reservoirs [8] and marine systems [9]. Several species have a rather long life cycle, minimal mobility and variable sensitivities to different habitats. In addition, macrobenthos are generally easy to collect and identify, both through physical appearance as well as the type of habitat from which they are obtained. For example, Tubifex can survive in an anoxic environment for 40–120 days, and is the dominant species in waters with heavy organic contamination [10]. However, *Compeloma decisum* can only reproduce in clean, well-oxygenated water. While many juvenile insect species eventually emerge as terrestrial adults, most species spend all or the majority of their lives in the water, thus allowing water quality to influence growth, reproduction and distribution [11,12].

In this study we examined the composition and structure of benthic macroinvertebrate assemblages in two reservoirs and their relationships to some physical and chemical parameters in order to verify their effects on the fauna and evaluate the ecological quality of the reservoirs determined by their respective watersheds.

2. Materials and methods

2.1. Site description

The two studied reservoirs, Jinshahe and Daoguanhe, are located in Hubei province, central China, and are tributaries of the Yangtze River (Fig. 1). Daoguanhe reservoir (35°52′N, 114°59′ E) was built in 1968, with a surface area of 108.84 km^2, a total volume of 6.37×107 m^3 and depths ranging from 1.9 to 21.0 m. Reservoir sediment consists primarily of silt and clay. Daoguanhe reservoir was constructed for flood control and irrigation, but also contributes to aquaculture and tourism. Jinshahe reservoir (31°18′N, 114°34′E) covers 108 km^2 and has a mean depth of 12.53 m. Bottom sediments in Jinshahe are comprised mainly of fine sand (medium grain size = 0.12 mm, with a weak or poor selection and negative asymmetry of –0.27) and mud. Submerged aquatic macrophytes are abundant where there is adequate light penetration. The reservoir is primarily used for irrigation and fish culture.

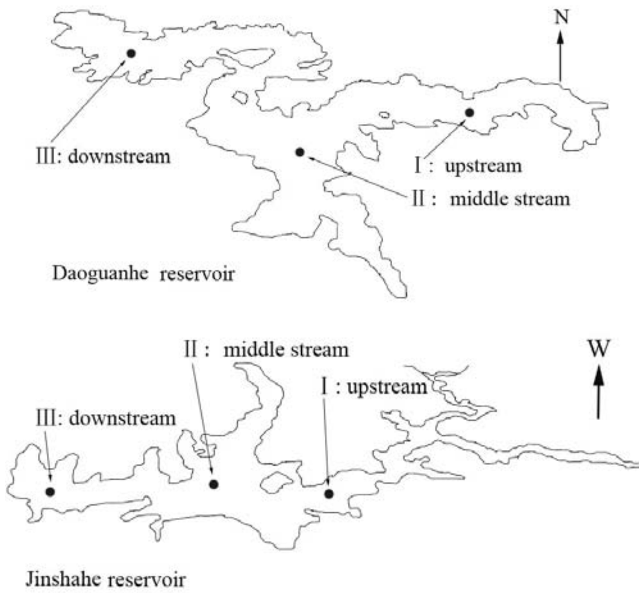

Fig. 1. Map of Daoguanhe and Jinshahe reservoirs. The locations of the sampling stations are indicated.

The two reservoirs are located in the middle reaches of the Yangtze River, in the northern subtropical region. Direct thermal stratification occurs in the summer, with full circulation in spring and autumn, and the possibility of inverse thermal stratification in the winter.

2.2. Sampling and analysis

Samples for physico-chemical and biological analyses were collected seasonally from November 2006 to August 2007 at three open water locations in each reservoir: upstream, middle stream and downstream (Fig. 1). Distinct samples were collected from three vertical locations in the water column at each station: surface, middle and bottom. Dissolved oxygen (DO), water temperature (WT) and pH were measured with a portable Sension^{TM} 156 Multiparameter Meter (Hach Co., Loveland, CO, USA). Secchi depth (SD) and water depth (WH) were determined using a secchi disk and vertical detector, respectively. Ammonia, as the ammonium ion (NH_4^+-N), nitrate (NO_3^--N), nitrite (NO_2^--N), total nitrogen (TN) and total phosphorus (TP) were analyzed in our laboratory within 24 h of preservation with sulfuric acid (to pH 2.0), following standard methods [13,14]. For macrofauna, three to five replicate samples per station were taken randomly using a van Veen grab (0.1 m^2), penetrating about 15 cm into the sediment. Samples were sieved through a 500 µm net and preserved with buffered 4% formalin. Most animals were identified to species although some were identified only to genus. Enumeration was completed using a stereo dissecting microscope (40× magnification). Biomass was determined as wet weight of each species after blotting for two minutes on filter paper. Mollusks were weighed with shells. Density and biomass are reported on a per m^2 basis. Condition of the macrobenthic community was assessed using Shannon's diversity index [15,16], Margalef index [17], and Goodnight–Whitley index (%) [18]. The degree of organic pollution (eutrophication) in each reservoir was determined using DO, TN, TP concentrations and SD values [19].

To assess the relationship between abiotic parameters and biological metrics, correlation analyses were completed using data from upstream, middle stream and downstream of each reservoir with season, depth, TN, TP, NH_4^+-N, NO_3^--N, and benthic macroinvertebrate as multivariables [20].

3. Results

3.1. Physical and chemical data

Water temperature changed seasonally, reaching the highest and lowest values in August and February, respectively (Table 1). Some water parameters in the two reservoirs showed similar seasonal trends. At both reservoirs, for example, pH was notably higher in autumn than in the other seasons. NO_3^--N was highest in the spring while NH_4^+-N and TN reached their peaks during winter. Maximum depth occurred in summer due to higher precipitation and inflow from tributaries. Dissolved oxygen concentrations showed substantial temporal fluctuation in Daoguanhe reservoir, with higher concentrations in summer and autumn (> 8.0 mg.L^{-1}) and lower concentrations in winter and spring (< 6.0 mg.L^{-1}). DO in Jinshahe reservoir, on the other hand, was much more stable, with concentrations around 9.0 mg.L^{-1} in all seasons. Conversely, the transparency of the water, as measured by SD, was more consistent over the four sampling periods in Daoguanhe reservoir than in Jinshahe, but was two to four times higher in the latter. NH_4^+-N, NO_3^--N, NO_2^--N, TN and TP were all higher in Daoguanhe than in Jinshahe.

3.2. Benthic macroinvertebrate assemblage

Twenty-nine taxa were identified during this study (Tables 2 and 3). Ten taxa (37.5% of the total abundance) were oligochaetes, 15 (53.6%) were aquatic insects and four (10.7%) were molluscs. There were distinct differences in species composition depending upon the location of the sampling stations. Aquatic insects were usually found in the shallow water near the shoreline, especially in the presence of aquatic macrophytes (primarily grass). The density of insects decreased significantly below 10 m. Molluscs favoured relatively clean water with muddy and sandy sediment. Oligochaeta displayed a wide distribution and were collected at all the stations.

3.2.1. Daoguanhe reservoir

Species richness was quite low in Daoguanhe reservoir (Table 2). Of the 10 species found, four were Oligochaeta and six were chironomids. Oligochaeta dominated the macrobenthic collection both in numbers and biomass, with an average density of 205.6 ind.m^{-2} (64.6% of the whole abundance), and an average biomass of 232.9 mg.m^{-2} (53.4% of the whole biomass). Both abundance and biomass of insects recorded in May 2007 and August 2007 were lower than those in November 2006 and February 2007 (Fig. 2). The dominant species in Daoguanhe reservoir were Limnodrilus hoffmeisteri and Tokunagayusurika akamusi, contributing a combined 72.9% of the whole abundance and 69% of the whole biomass, respectively. Other common species were *Branchiura sowerby*, *Tubifex sinicus*, *Procladius* sp., and occasionally abundant taxa were *Branchiodrilus hortensis*, *Polypedilum* sp., *Tanypus* sp., *Proclodius choreus* and *Paratanytarsus* sp.

Table 1
The results of physico-chemical water analysis of Daoguanhe and Jinshahe reservoirs

Index	Daoguanhe reservoir					Jinshahe reservoir				
	Spring	Summer	Autumn	Winter	Average	Spring	Summer	Autumn	Winter	Average
NH_4^+-N, mg.L^{-1}	0.426	0.117	0.434	0.719	0.424	0.100	0.187	0.135	0.736	0.289
NO_3^--N, mg.L^{-1}	0.150	0.059	0.050	0.112	0.093	0.101	0.069	0	0.049	0.055
NO_2^--N, mg.L^{-1}	0.003	0.001	0.004	0.006	0.004	0.004	0.001	0	0.005	0.002
TN, mg.L^{-1}	0.842	0.520	1.031	1.679	1.018	0.196	0.178	0.386	0.808	0.392
TP, mg.L^{-1}	0.111	0.023	0.021	0.013	0.042	0.015	0.017	0.015	0	0.012
DO, mg.L^{-1}	5.953	8.379	8.073	5.700	7.026	9.129	8.769	9.073	8.867	8.994
pH	6.826	6.890	8.070	7.000	6.858	7.618	7.049	7.900	7.000	7.392
WH, M	8.500	14.00	6.73	7.53	9.19	11.87	15.93	10.17	12.17	12.53
WT, °C	20.13	25.91	11.33	7.57	16.24	22.23	23.01	11.93	7.47	16.16
SD, M	1.027	1.433	1.097	1.530	1.272	4.767	2.210	2.167	4.700	3.461

Table 2
Average density (ind.m^{-2}) of benthic macroinvertebrates in Daoguanhe reservoir over four sampling periods (November 2006 – August 2007)

Taxon	2006–11			2007–2			2007–5			2007–8		
	I	II	III	I	II	III	I	II	III	I	II	III
Oligochaeta												
Limnodrilus hoffmeisteri Claparède	144	225	208	80.3	160	277	160	112	144	96.3	80.3	144
Branchiura sowerbyi Beddard	46.7	32.3	16.0	0	16.4	32.3	32.3	32.3	48.7	16.0	32.7	16.4
Tubifex sinicus Chen	32.3	16.7	16.4	48.7	0	0	16.7	32.3	32.3	0	0	32.7
Branchiodrilus hortensis Stephenson	0	32.3	0	0	16.7	16.7	0	16.4	0	0	0	0
Diptera Chironomidae												
Tokunagayusurika akamusi Tokunaga	112	129	48.7	144	129	16.4	96.3	80.7	32.3	80.4	32.3	16.7
Polypedilum sp.	16.4	16.4	0	16.0	0	0	16.0	16.4	16.4	16.0	0	0
Procladius sp.	32.3	16.4	0	14.4	5.30	16.4	16.4	32.3	0	32.3	16.4	0
Tanypus sp.	0	16.0	0	16.0	16.4	0	0	0	0	0	0	0
Procladius choreus Meigen	0	16.7	0	16.0	16.7	0	0	16.0	0	0	16.7	0
Paratanytarsus sp.	0	0	0	0	0	0	0	0	0	16.0	0	0

Note: I: Upstream, II: Middle stream, III: Downstream

The average density of all benthic macroinvertebrates in Daoguanhe reservoir (318.2 ind.m^{-2}) was similar to the average density in Jinshahe reservoir (316.8 ind.m^{-2}), and, in fact, density of organisms in Daoguanhe reservoir in the middle and downstream segments was actually higher than in Jinshahe (Table 4). However, biomass in Jinshahe in all reservoir segments was much higher than in Daoguanhe. The average biomass in Jinshahe (1294.3 mg.m^{-2}) was three times the biomass measured in Daoguanhe (430.7 mg.m^{-2}). Much of this discrepancy in biomass was due to the lack of molluscs in Daoguanhe.

The highest density of macrozoobenthos in Daoguanhe reservoir occurred in November 2006, after which it decreased sharply, and remained steady from February 2007 to May 2007 (Fig. 3a). Density dropped again in August 2007. Spatial variability of benthic macroinvertebrate density was relatively low in Daoguanhe reservoir, ranging from 335.2 ind.m^{-2} to 339 ind.m^{-2} in the upper and middle reservoir segments, respectively, to a somewhat lower 280.3 ind.m^{-2} downstream (Fig. 3b and Table 4). Temporal and spatial fluctuations in macrofauna biomass in Daoguanhe reservoir followed a pattern similar to density. Dominant species in Daoguanhe reservoir made the greatest contribution to total abundance and the pattern of seasonal change reflected that of all macrofauna (Fig. 4a).

3.2.2. *Jinshahe reservoir*

In Jinshahe reservoir, 24 of the 29 benthic macroinvertebrate taxa, found in both reservoirs combined, were identified (Table 3). Insects were the most common (50.0%), followed by Oligochaeta (33.3%) and Mollusca (16.7%). The aquatic insects were also the most diverse group, accounting for 66.5% of the total abundance, with the highest value (71.7%) recorded in May 2007. However, because insects were mostly small individuals, the group as a whole comprised only 31.68% of the total biomass. Oligochaeta, however, accounted for the lowest biomass (9.9%) of three main macrobenthic groups in Jinshahe reservoir (Fig. 2). The dominant taxa were *Aulodrilus pluriseta*, *Cryptochironomus* sp. and *Polypedilum* sp., representing 47.9% of the total. *Aulodrilus pluriseta*, was the most abundant during nearly every sampling period at each reservoir location (Table 3). Only in August 2007 was the density of *A. pluriseta* eclipsed by either *Limnodrilus claparedianus*, *Aulodrilus* sp. (species unknown) or both. Although Mollusca density was relatively low in Jinshahe reservoir (2.4–7.5 ind.m^{-2}), this group made up a large percentage of the total biomass (762.2 mg.m^{-2} or 58.45%) due to the large size of individuals and weight of the shell (Fig. 2).

Seasonal fluctuations in Jinshahe reservoir were similar to Daoguanhe reservoir (Fig. 3). However, while abundance of benthic macroinvertebrates remained relatively consistent longitudinally in Daoguanhe reservoir, abundance in Jinshahe reservoir decreased rather dramatically from the upstream to downstream segments (Fig. 3b). The biomass pattern was somewhat different, showing a dramatic decrease from the upstream segment (1413.1 mg.m^{-2}) to the middle segment (681.3 mg.m^{-2}), but then increasing again to its highest level in the downstream segment of the reservoir (1675.7 mg.m^{-2}) (Table 4).

Table 3
Average density (ind.m^{-2}) of benthic macroinvertebrate taxa in Jinshahe reservoir over four sampling periods (November 2006 – August 2007)

Taxon	2006–11			2007–2			2007–5			2007–8		
	I	II	III	I	II	III	I	II	III	I	II	III
Oligochaeta												
Limnodrilus hoffmeisteri Claparède	6.4	16.4	16.4	0	0	10.7	0	0	5.3	0	0	0
Tubifex sinicus Chen	16.4	32.0	16.0	16.4	16.4	10.7	5.3	10.7	0	5.3	7.2	0
Aulodrilus pluriseta Piguet	64.4	32.8	113	64.7	48.4	64.7	32.8	64.8	48.6	14.8	9.6	26.4
Aulodrilus pigueti Kowalewski	0	32.0	0	10.7	0	32.6	0	16.0	10.7	9.2	3.2	0
Aulodrilus sp.	16.0	0	12.8	6.4	19.2	0	0	0	10.7	17.6	20.8	14.4
Limnodrilus claparedianus Ratzel	0	0	5.3	12.5	10.7	16.0	10.7	0	5.3	16.4	16.4	32.7
Nais communis Piguet	5.3	0	16.0	0	16.0	0	0	0	16.0	0	0	0
Aulophorus furcatus Müller	0	0	0	0	0	0	0	16.0	0	0	0	0
Diptera Chironomidae												
Orthocladius sp.	64.4	32.8	16.4	48.3	32.8	16.0	32.8	0	0	32.8	16.4	0
Cryptochironomus fuscimanus Kieffer	32.8	0	0	16.0	0	0	0	32.8	16.0	48.9	16.0	12.8
Cryptochironomus sp.	96.7	64.3	32.8	144	33.6	5.3	112	0	0	129	96.0	12.8
Tendipes attenuatus Walker	32.8	16.0	0	5.3	0	0	0	0	0	0	0	0
Polypedilum sp.	112	16.0	0	80.4	32.8	10.7	128	32.8	16.0	32.6	32.3	16.0
Procladius sp.	48.0	0	0	16.4	0	0	64.0	16.0	0	12.8	11.2	8.0
Procladius choreus Meigen	0	0	0	10.7	0	0	16.0	80.3	0	0	0	0
Tanytarsus sp.	64.0	0	5.3	64.7	0	32.8	0	0	0	5.3	5.3	0
Clinotanypus sp.	5.3	0	0	0	10.7	0	32.0	0	0	0	0	0
Lauterbornia sp.	5.3	0	0	32.8	0	0	0	64.4	32.8	11.2	8.0	6.4
Einfeldia sp.	0	16.0	0	0	0	0	32.0	0	0	9.6	5.3	0
Ephemeroptera												
Caenis sp.	0	0	0	32.0	0	0	0	0	0	0	0	0
Mollusca												
Bellamya purificata Heude	0	5.3	5.3	0	0	0	5.3	0	5.3	3.4	2.3	3.2
Semisulcospira cancellata Benson	0	0	0	0	0	0	5.3	0	0	5.3	0	0
Ancylus sp.	5.3	0	10.7	5.3	0	5.3	0	0	10.7	0	0	0
Corbicula fluminea Müller	0	0	0	0	0	5.3	0	0	0	8.7	2.3	9.6

Note: I: Upstream, II: Middle stream, III: Downstream

Abundance and biomass of dominant species in Jinshahe tended to remain more stable than in Daoguanhe during the study period (Fig. 4).

3.3. Relationship between water quality parameters and biological metrics

For most of the abiotic and biotic parameters evaluated in this study, the correlation coefficients were low and not significant. In Daoguanhe reservoir, there was a significant negative correlation between the density of aquatic insects and water depth, and a significant positive correlation between the abundance of Oligochaeta and TN or TP ($P < 0.05$) (Table 5). While the positive relationship between insect density and TN or TP in Daoguanhe reservoir was not significant, the correlation coefficients were higher than any other non-significant parameters. In Jinshahe reservoir, these relationships were significant, with insect density–TN and –TP correlation coefficients of 0.834 and 0.879, respectively (Table 6). As in Daoguanhe, the density of aquatic insects in Jinshahe reservoir showed a significant negative correlation with depth. There was a significant positive correlation between TN or TP and oligochaete abundances in Jinshahe. There was an inverse correlation between the density of molluscs and TN or TP, although this relationship was not significant.

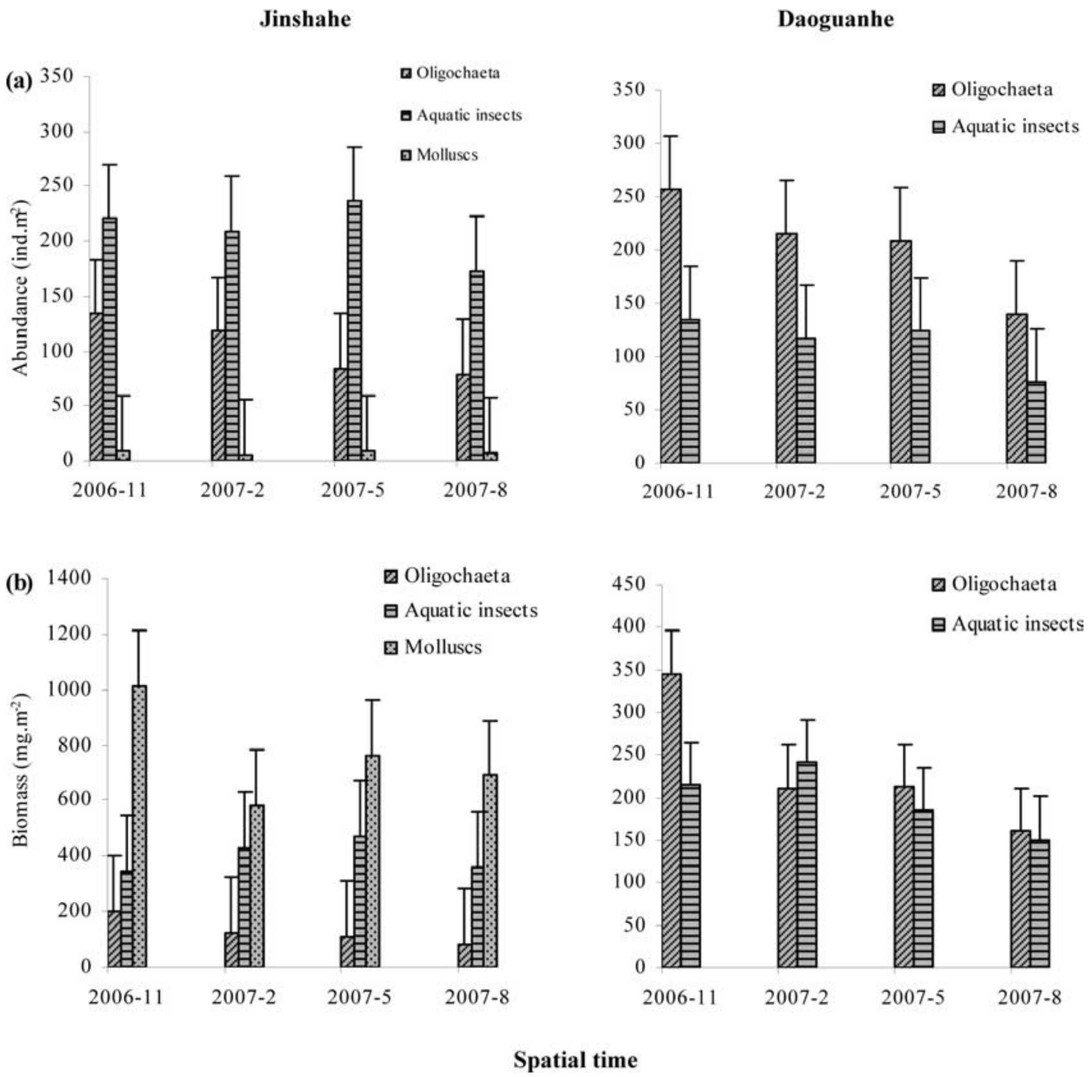

Fig. 2. Abundance (a) and biomass (b) of oligochaetes, aquatic insects and molluscs in Jinshahe and Daoguanhe reservoirs. Data are expressed as the mean ± SE (n = 9).

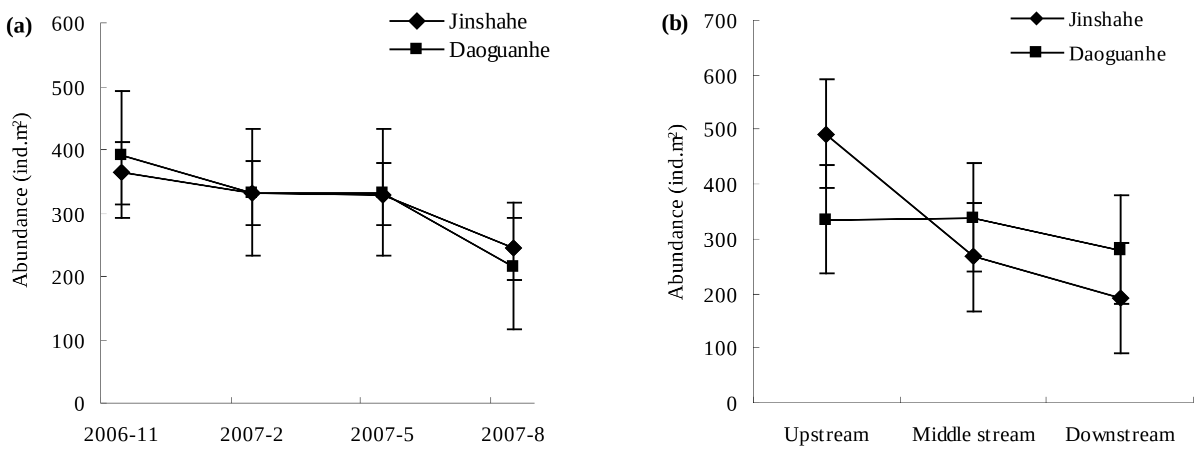

Fig. 3. Seasonal trends (a) and horizontal variation (b) of benthic macroinvertebrate abundance in Jinshahe and Daoguanhe reservoirs. Data are expressed as the mean ± SE (n = 9 and 12, respectively).

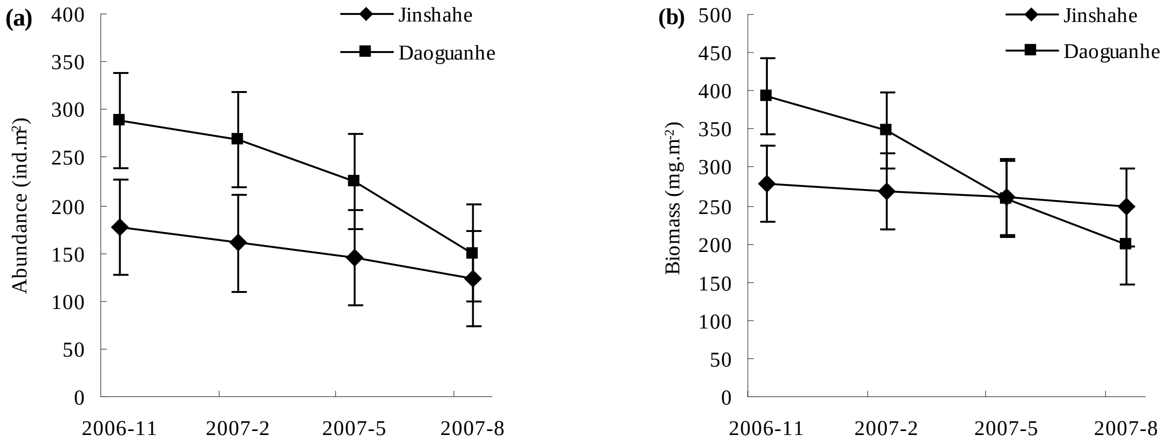

Fig. 4. Seasonal trends in abundance (a) and biomass (b) of the dominant species in Jinshahe and Daoguanhe reservoirs. Data are expressed as the mean ± SE (n = 9).

Table 4
Spatial differences in density (ind.m^{-2}) and biomass (mg.m^{-2}) of macrobenthic species in the two reservoirs

Site	Time	Upstream		Middle stream		Downstream		Whole reservoir	
		Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass
J	06-11	575.4	1177.8	264.0	1158.4	249.5	2355.1	362.9	1563.8
	07-2	563.3	1523.9	220.7	338.6	211.2	1541.5	331.7	1134.7
	07-5	476.5	1497.5	333.8	572.9	177.4	1511.2	329.2	1343.9
	07-8	353.7	1453.3	250.4	655.4	126.7	1295	243.6	1134.6
	Average	492.2	1413.1	267.2	681.3	191.2	1675.7	316.8	1294.3
D	06-11	386.2	639.8	500.2	580.6	289.1	460.8	391.8	560.4
	07-2	311.7	493.6	338.6	492.4	347.4	372.1	332.6	452.7
	07-5	385.9	435.8	338.2	426.1	274.2	332.4	332.8	398.1
	07-8	257.1	431.1	178.9	253.9	210.4	250.2	215.5	311.7
	Average	335.2	500.1	339.0	438.3	280.3	353.9	318.2	430.7

Note: J: Jinshahe reservoir, D: Daoguanhe reservoir

Table 5
Correlation matrix of benthic macroinvertebrate density and several abiotic environmental parameters in Daoguanhe reservoir

	Season	Depth	TN	TP	NH_4^+-N	NO_3^--N	Oligochaeta	Insecta
Season	1.000							
Depth	–0.317	1.000						
TN	0.558	0.312	1.000					
TP	–0.711	0.197	0.538	1.000				
NH_4^+-N	0.519	0.215	0.512	0.393	1.000			
NO_3^--N	–0.331	0.223	0.573	0.287	0.169	1.000		
Oligochaeta	0.016	0.416	0.878*	0.832*	0.443	0.379	1.000	
Insecta	0.290	–0.814*	0.613	0.713	0.372	0.321	–0.349	1.000

*P < 0.05

Table 6
Correlation matrix of benthic macroinvertebrate density and several abiotic environmental parameters in Jinshahe reservoir

	Season	Depth	TN	TP	NH_4^+-N	NO_3^--N	Oligochaeta	Insecta	Mollusca
Season	1.000								
Depth	0.061	1.000							
TN	0.615	0.282	1.000						
TP	–0.200	–0.345	0.289	1.000					
NH_4^+-N	0.665	0.117	0.531	0.379	1.000				
NO_3^--N	–0.740	0.323	0.436	0.287	0.371	1.000			
Oligochaeta	0.738	0.339	0.803*	0.859*	0.562	0.356	1.000		
Insecta	0.092	–0.834*	0.834*	0.879*	–0.125	0.277	0.367	1.000	
Mollusca	–0.393	0.512	–0.417	–0.213	–0.247	0.153	0.191	0.279	1.000

*$P < 0.05$

Based on the results obtained from 72 samples, a comprehensive bioassessment of water quality of the two reservoirs were conducted using the Goodnight–Whitley, Shannon–Wiener and Margalef indices (Table 7). The results showed that Daoguanhe reservoir could be classified as a moderately polluted lentic system, while Jinshahe reservoir was slightly polluted, with a lower level of anthropogenic pollutants (Table 8). The results of the assessment using these three biological indices correspond to the TN, TP and transparency data from the two reservoirs.

4. Discussion

Long-term variability in mean abundance and biomass of major taxonomic groups generally suggests major shifts in species composition. Compared with earlier studies [21,22], both abundance and biomass of benthic macroinvertebrates in Daoguanhe reservoir have undergone substantial changes. Abundance was increased largely from 1980 to 2007. The highest measured benthic macroinvertebrate biomass occurred in 1999, due primarily to Mollusca (data not shown). An increase in the standing crop of benthic organisms is often regarded as an indication of heavily pollution, where secondary production follows in sequence with higher primary production. Tourism is growing rapidly in this region of China, bringing with it more people and, of course, more hotels, entertainment venues and other commercial establishments. These developments result in higher point and nonpoint source inputs of organic matter to water bodies such as Daoguanhe reservoir. The decomposition

Table 7
Evaluation criteria for the benthic macroinvertebrate biological and diversity indices

Index	Standard			
	Clean	Slightly polluted	Moderately polluted	Heavily polluted
Goodnight–Whitley	<60%	60%-	–80%	>80%
Shannon–Wiener	>3.0	3.0–2.0	2.0–1.0	<1.0
Margalef	>3.0	3.0–2.0	2.0–1.0	<1.0

Table 8
Water quality assessment of Daoguanhe and Jinshahe reservoirs

Index	Jinshahe reservoir		Daoguanhe reservoir	
	Mean values	Evaluation results	Mean values	Evaluation results
Goodnight–Whitley	31.1%	Clean	64.8%	Slightly polluted
Shannon–Wiener	2.37	Slightly polluted	1.57	Moderately polluted
Margalef	3.09	Clean	1.39	Moderately polluted

of excess organic matter can lead to oxygen depletion in the benthic environment which, combined with nutrient enrichment, leads to the water quality deterioration. As a result, benthic macroinvertebrate species composition was different in Daoguanhe reservoir, with the most obvious change being the loss of Mollusca, which generally require relatively clean water and muddy, sandy sediment where aquatic macrophytes can flourish [23].

Compared with Daoguanhe (10 macroinvertebrate taxa), Jinshahe reservoir was a much more diverse environment (24 taxa). Jinshahe was designed primarily for extensive agriculture use and therefore agricultural run-off is the main source of water. With less organic pollution, dissolved oxygen concentrations and transparency were higher and nutrients were lower. Correlation analysis indicated a pronounced positive relationship between the concentration of TP and TN and the density of oligochaetes and aquatic insects (mostly chironomids), but a negative relationship (although not significant) with mollusc density.

Aquatic insect emergence was observed when water temperature reached above 13–15°C. The emergence of mature insects releases a significant amount of benthic macroinvertebrate biomass from the water body. In autumn and winter, as the temperature drops, insects remain submerged and increase in biomass. These cyclic events explain why abundance and biomass of aquatic insects recorded in May 2007 and August 2007 were lower than those in November 2006 and February 2007 in Daoguanhe reservoir. The behavior of fish in the reservoir also influences the benthic macroinvertebrate assemblage. Most fish reproduce in the spring and summer when water temperature rises to a certain range. This increase in activity stimulates the need for more energy intake, thus greater feeding/predation rates. Fish activity declines in the autumn and winter which helped to bolster the density and biomass of benthic macro-fauna in the two reservoirs in November 2006 and February 2007.

For macrofauna, especially Oligochaeta and aquatic insects, standing crop relative to sediment type generally changes in the following order: sapropel > ooze > clay > sand, with a significant decrease in organism density with each 1 m of depth [24]. In Daoguanhe reservoir, the upstream and mid-stream sediment was clay; downstream sediment was primarily sapropel. However, benthic macroinvertebrate standing crop in the upstream and middle stream segments was much higher than in the downstream reach. In Jinshahe reservoir, sediments at all three sampling stations were sandy clay, ooze and sand; the highest macroinvertebrate density also occurred upstream. These data indicate that other factors, such as depth, are influencing abundance and biomass, possibly to a greater degree than sediment composition. Average densities of the macroinvertebrates were similar (about 300 ind.m^{-2}) in Daoguanhe and Jinshahe reservoirs, with an average depth of 9.19 and 12.53 m, respectively. However, the average depth in Taoyuanhe reservoir, another water body studied at the same time (data not shown) was 16.38 m. The density of benthic fauna in this reservoir was 209 ind.m^{-2}, substantially lower than either Daoguanhe or Jinshahe. Water depth, therefore, may be an important factor influencing benthic macroinvertebrate standing crop.

Some species have been shown to be particularly responsive to certain environmental conditions and can there be referred to as environmental indicators [25–27]. Certainly not all species fall into this category; many are highly tolerant of a wide range of chemical and physical conditions. Those that do show extra sensitivity to environmental pollution have often been used to monitor significant environmental changes. *Limnodrilus hoffmeisteri* and *Tokunagayusurika akamusi*, the dominant species in Daoguanhe reservoir, are two typical pollution tolerant species in heavily polluted waters [28,29]. Their presence suggests a highly polluted environment, which supports previous studies in Donghu lake, China [30] which found that the density distribution of *L. hoffmeisteri* was positively correlated with lake trophic level. In Kasumigaura, a heavily polluted lake in Japan, density of *T. akamusi* was high. In Jinshahe reservoir the dominant species were *Aulodrilus pluriseta*, *Cryptochironomus* sp. and *Polypedilum* sp. which favor relatively clean water.

Comprehensive bioassessment using three biodiversity indices confirmed that Daoguanhe reservoir is a moderately polluted water body, reflecting significant organic pollution, while Jinshahe reservoir receives a much lower level of pollution, and is classified as clean/slightly polluted. In Daoguanhe reservoir, Mollusca was not present. The two dominant species, *Limnodrilus hoffmeisteri*, an oligochaete, and *Tokunagayusurika akamusi*, a chironomid dipteran, are both known to be pollution-tolerant. Overall, the benthic macroinvertebrate community of Daoguanhe reservoir tended to be simple, and this simplicity was well reflected in the biological indices. However, in Jinshahe reservoir, which receives only agricultural run-off, the diversity indices were higher and indicated a healthier benthic community. There was a negative relationship between diversity indices and the trophic level of the reservoir, especially Shannon's diversity index which closely reflected the level of reservoir pollution. These data indicate that the diversity index will not only reflect the characteristics of the benthic macroinvertebrate community, but may also be used as a general monitoring tool to evaluate real-time changes in the quality of the aquatic environment.

5. Summarizing conclusions

There were substantial differences in species composition, dominant species, abundance, biomass and diversity of benthic macroinvertebrates between the two reservoirs. The variables that most affected the benthos were temperature, depth of water, sediment and nutrition. Based on the biological indices and physical and chemical characteristics, Daoguanhe reservoir is a moderately polluted lentic water body while Jinshahe reservoir is considered slightly polluted. Daoguanhe reservoir is more highly polluted, which is reflected in reduced biodiversity. The standing crop of the benthic macroinvertebrates, on the other hand, is higher in Dauguanhe reservoir, as a result of greater densities of pollution-tolerant species such as *Limnodrilus hoffmeisteri* and *Tokunagayusurika akamusi*. A clear decrease in biodiversity can be attributed to water pollution. The data presented here illustrate the importance of benthic macroinvertebrates in the food web of these aquatic ecosystems and suggest that monitoring the health of benthic organisms can be an effective way of evaluating long-term changes in reservoir ecosystems.

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