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Research Paper

Spatial Distribution of Macroinvertebrate Community along a Longitudinal Gradient in a Eutrophic Reservoir-Bay during Different Impoundment Stages, China

key words: Longitudinal distribution, Zonation, Impoundment, Xiangxi Bay, Three Gorges Reservoir

Abstract

The longitudinal patterns of the macroinvertebrate community in the Xiangxi Bay of the Three Gorges Reservoir (TGR) were investigated during the second (2nd) and third (3rd) impoundment stages (October 2006–July 2010), to test the effects of increased water level fluctuations (WLF) on the macroinvertebrates. By comparing to the former reports of the first (1st) impoundment stage (inter-annual WLF 4 m), we found that oligochaetes dominated in three different stages in the Xiangxi Bay. However, the total abundance of macroinvertebrates showed a dramatical decline from the 1st to 2nd stage (inter-annual WLF 11 m), but changed slightly from the 2nd to 3rd stage (inter-annual WLF 30 m). This indicated that higher WLF in the 2nd stage had already greatly reduced the macroinvertebrates abundance, thereby the disturbance in the 3rd stage could only slightly affect the already reduced abundance. Three longitudinal zones (the mainstream zone, the lacustrine zone and the transitional zone) were found based on the macroinvertebrate density, biomass, and taxa richness, combined with the geographical location of each site. Significant differences in density and biomass of macroinvertebrate were found among different zones ($P < 0.05$), yet no significant difference was found in taxa richness ($P > 0.05$). Two-way indicator species analysis showed that the community type in most sites varied in different seasons from the 2nd stage, exhibiting a dynamic zonation pattern, which differed with the stable pattern of the 1st stage. This seasonal feature was coupled to the seasonal changes of the WLF.

1. Introduction

Dam construction is considered as a disturbance to the former ecosystem, or the formation of a new system, by causing a series of ecological changes (Baxter, 1977). Impoundment after dam construction will lead to slowing down of the water velocity, increasing of the transparency, depletion of the dissolved oxygen and accumulation of nutrients (Baxter, 1977; Friedl and Wüest, 2002; Ye *et al.*, 2007). These abiotic impacts in turn have biologi-

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cal effects, by structuring influences on the diversity, density and the overall resilience of reservoir biota (FUREY *et al*., 2006; MCEWEN and BUTLER, 2010). Benthic macroinvertebrates are important in aquatic ecosystem and have widely been used as indicators of variations of environmental conditions (PHIPPS *et al*., 1995; PELLETIER *et al.,* 2010). They are usually affected by the sediment properties caused by the water disturbance (MCEWEN and BUTLER, 2010), and other changes of water environment factors, *e.g*., algal blooms, which could influence the food resources of macroinvertebrates (LOPES *et al*., 2000; WHITE *et al*., 2005).

Reservoirs formed by damming rivers always differ from natural lakes in the shape of their longitudinal profiles. Natural lakes are normally deepest in the central region, whereas reservoirs are almost always deepest just upstream from the dam. Thus, a gradient would form along the longitudinal axis of the reservoir. A typical reservoir can be divided into three zones: riverine zone (backwater), transitional zone (between riverine and lacustrine zone), and lacustrine zone (STRASKRABA and TUNDISI, 1999; WETZEL, 2001). The different zones have different physical and chemical characteristics, while environmental gradients always lead to the difference of biotic assemblages (BAXTER, 1977; VELHO *et al*., 2001; MORENO-OSTOS *et al*., 2008,). The size of each zone varies for each reservoir, depending on the morphometry, retention time, season, geographical location, etc. (STRASKRABA and TUNDISI, 1999; WETZEL, 2001).

Three Gorges Reservoir (TGR), built on the mainstream of the Yangtze River, is the largest reservoir in China. Since the first impoundment in June 2003, the aquatic system changed dramatically (XU *et al*., 2009; ZHANG *et al*., 2010). Most tributary rivers became bays. Xiangxi Bay is the largest tributary of the TGR near the dam, also the bay that was most widely studied. After the first impoundment, as water velocity slowed down and the water retention time prolonged, both the frequency and degree of algal blooms increased (YE *et al*., 2007; WANG *et al*., 2010). During this period, many biotic assemblages began to show a stable trend (SHAO *et al*., 2010). The physical and chemical parameters (YE *et al*., 2007), phytoplankton (XU *et al*., 2009; WANG *et al*., 2010), zoomacroinvertebrates (SHAO *et al*., 2010) and the concentration of nutrients in the sediments (ZHANG *et al*., 2009) displayed a longitudinal pattern. A stable community type zonation was recorded specially for macroinvertebrates, all through the year, without seasonal changes (SHAO *et al*., 2010). These results were obtained during the first stage, when the water level fluctuated between 135 m and 139 m above sea level, with the inter-annual water level fluctuations (WLF) of 4 m. However, in the second impoundment stage, the inter-annual WLF increased to 11 m, and reached to about 30 m in the third stage. Higher WLF would enhance the mechanical mixing of the water column, change the properties of the sediment, influence the habitat of organisms, and finally cause effects to the macroinvertebrates (BENSON and HUDSON, 1975; MCEWEN and BUTLER, 2010). Therefore, in this study, the macroinvertebrate communities during the second and third impoundment stages of the TGR were surveyed. The variations of the community structure and the longitudinal pattern of the macroinvertebrates along the Xiangxi Bay were analysed. We aimed to show: (1) Whether the marked difference of the WLF among different impoundment stages of the TGR could lead to changes of macroinvertebrate community? (2) whether the stable zonation pattern of the first stage be altered or not? (3) what kind of zonation pattern could develop under such a high WLF condition?

2. Materials and Methods

2.1. Study Area

The TGR is located at 29º16′–31º25′ N, 106º–110º 50′ E, in a subtropical monsoon climate region, China (Fig. 1). In this area, precipitation is higher in summer and lower in winter (JIANG *et al*., 2006). The dam is located in Yichang, Hubei Province. The whole impoundment plan of TGR included three stages (Fig. 2): the first (1st) impoundment stage was stated in June 2003, with the water level in front

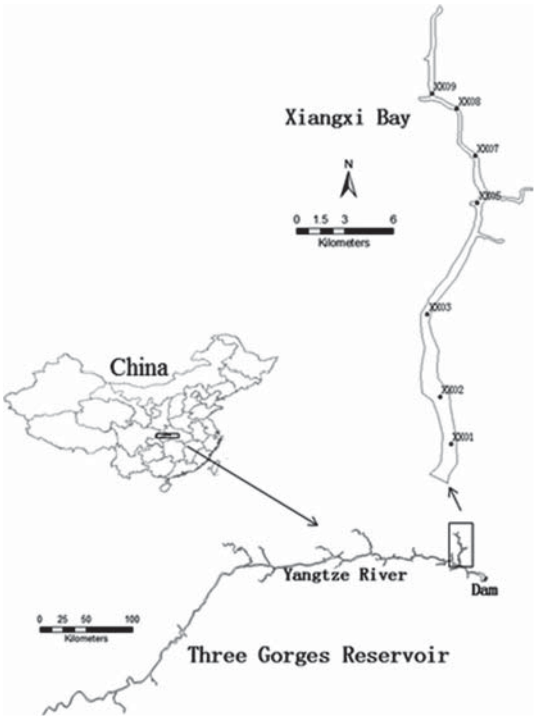

Figure 1. Location of sampling sites in the Xiangxi Bay, Three Gorges Reservoir, China.

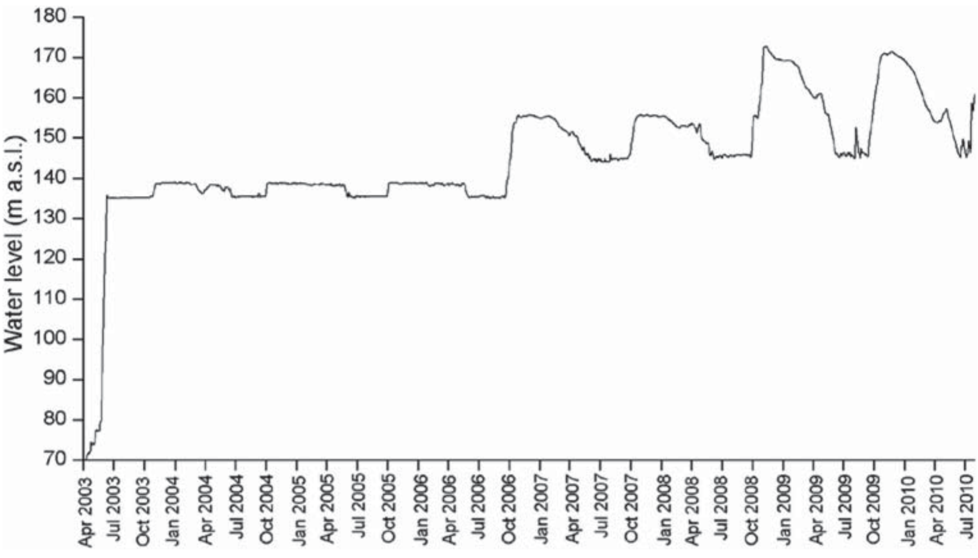

Figure 2. Water level fluctuations (meters above sea level, m a.s.l.) of the Three Gorges Reservoir, China.

of the dam becoming 135 m above sea level (the flood control water level) and 139 m (normal water level); the second (2nd) impoundment stage was started in October 2006, with the normal water level increasing to 156 m and the flood control water level 145 m; and the third (3rd) impoundment stage was started in October 2008, reaching a normal water level of 175 m (the corresponding capacity is 39.3 billion m^3). The TGR is operated as a mode of "storing clear and releasing muddy" every year. During the flood seasons (summer), lower water level must be maintained to prevent floods. In non-flood seasons, the reservoir is mainly used to store water. Usually, the impoundment operations each year were performed in October before the 3rd impoundment stage, and in September in the following years.

The Xiangxi River, is located 38 km upstream of Three Gorges Dam and is the largest tributary of TGR in Hubei Province, with a watershed area of 3099 km^2 (HUANG *et al*., 2006). After the 1st impoundment, the lower reach (about 21 km length) of the river evolved as the Xiangxi Bay, with the water depth in the mouth (at the confluence of the Xiangxi Bay and the mainstream of the TGR) fluctuating between 56 ~ 60 m. In the 3rd stage, as the water level increased in TGR, the length of the bay extended to about 27 km and 36 km during low and high water level periods respectively, and the depth in the mouth of the bay also increased, fluctuating between 70 ~ 100 m. The water depth gradually decreased from the mouth to the edge of the bay. In the edge (the upstream limit during low water level period of the 3rd stage), the depth reached about 5 m and 35 m during low and high water level periods respectively. Xiangxi Bay is a valley bay, with steep banks and without macrophytes developing in its littoral zone. The bottom sediment consists mainly of fine particles.

2.2. Field Sampling and Laboratory Processing of Samples

Seven sampling sites were set up along the Xiangxi Bay (Fig. 1). XX01 is located at approximately 2.33 km from the mouth of the bay and XX09 was near the edge of the bay (during the low water level period), at about 26.9 km from the mouth. The surveys were carried out seasonally from October 2006 to July 2010: January (winter), April (spring), July (summer) and October (autumn). The sampling of 2008 winter was delayed to February due to heavy snowstorms.

A 5-liter Van Dorn sampler was used to collect water at the 0.5 m depth underwater, for chemical (TN, NO_3–N, NH_4–N, TP, PO_4–P and SiO_2–Si) and chlorophyll *a* (Chl *a*) analysis. Chl *a* was measured weekly in the sampling month in order that the average value could represent real status of the month, and other samples were measured once in the middle of the month. The samples for chemical analysis were stored in a plastic bottle pre-cleaned by the *in-situ* water and acidified to pH < 2 with sulfuric acid. Chemical parameters were measured with a segmented flow analyzer (Skalar San++). The water sample for Chl *a* measurement was filtered through a weighed and pre-ignited glass fiber filter (Whatman GF/C, 1.2 μm). The concentration of Chl *a* was determined by spectrophotometry (Shimadzu UN 1800 spectrophotometer). Transparency (Sd, using 20 cm diameter Secchi disk) and temperature (WT) of the surface water (YSI EDS 6600) were also measured. Macroinvertebrates were collected with a modified Petersen grab (extraction area of 0.0625 m^2) once at each site. Samples were passed through a 200 μm mesh sieve, and organisms retained on the sieve were fixed and preserved in 10% formaldehyde. Most taxa were identified to genus or species. The density and biomass (in wet weight) were expressed as individuals/m^2 (ind/m^2) and g/m^2 respectively.

The water level data of the TGR was provided by China Three Gorges Project Company.

Sampling methods were based upon protocols for standard observations and measurements of the Chinese Ecosystem Research Network (CERN) (HUANG *et al*., 2000; CAI, 2007).

2.3. Data Analysis

To analyse the similarity of the macroinvertebrate communities among different sites, cluster analysis based on the macroinvertebrates density, biomass and taxa richness was carried out using Euclidean distance with the Ward's method (Statistica 6.0 software). One-way ANOVA was used to examine the differences of macroinvertebrate density among different zones (SPSS 16.0 software).

TWINSPAN (two-way indicator species analysis) classification was carried out (PC-ORD 4.0 software) to analyse the community types and determine their characteristic species (MCCUNE and MEFFORD, 1999). The characterization of the community types was based on the concept of fidelity and constancy. Fidelity (on a scale ranging from 1 to 5) refers to the degree to which species are confined to particular groups, and constancy (ranging from 0 to 100%) refers to the number of times each species appear in every particular group (VOGIATZAKIS *et al*., 2003). Species with constancy between 30% and 75%, while at the same time having fidelities between 3 and 5, were usually termed characteristic species. However, in the Xiangxi Bay, as the constancy of the dominant species usually exceeds 75% (SHAO *et al.*, 2010), then species with constancy ≥ 30 % and fidelity between 3 and 5 were used to name the community, in order to distinguish differences in the macroinvertebrate communities among sites.

CANOCO 4.5 software was used to analyse the relationship between macroinvertebrate community and water environmental variables (SMILAUER and TER BRAAK, 2002). Firstly, only biotic data (relative abundance of the species) was analysed with a direct gradient Detrended Correspondence Analysis (DCA). DCA analysis indicated that the length of gradient was 2.608 in the 2nd stage, thus, Redundancy Analysis (RDA) was used. Similarly, the length of gradient was 8.649 for the 3rd stage, so, Canonical Correspondence Analysis (CCA) was applied. Due to the correlation between the environmental factors, the forward selection method and the Monte Carlo permutation test were used to select significant parameters. Those factors, which had a high correlation ($|r| > 0.5$), and a high variance inflation factor (> 20) were eliminated one by one.

Diversity of the community was described with Shannon-Wiener diversity index (*H'*):

$$H' = -\sum P_i \ln P_i$$

Where P_i is the relative abundance of the species *i*; $P_i = N_i/N$, N_i is the density of the species *i*, and *N* is the total density of the macroinvertebrates.

Data of Chl *a* represent the average values of weekly measures made within each sampling month. The relative abundance of species was used for TWINSPAN and DCA/CCA/RDA. Environmental data for cluster analysis and CCA/RDA was transformed as follows in order to eliminate dimensionality:

$$x'_{ij} = \frac{x_{ij}}{\max\{x_{ij}\}}$$

3. Results

3.1. Macroinvertebrate Community Structure

Mean density and Shannon-Wiener diversity index of macroinvertebrates in the Xiangxi Bay during the 2nd and the 3rd impoundment stages were displayed in Figure 3. After the 2nd stage, clear seasonal patterns of macroinvertebrate density appeared with the maximum in spring each year. During the 2nd stage, the highest density was obtained in April 2007 (6018.67 ind/m^2), and the lowest in October 2007 (685.7 ind/m^2). During the 3rd stage, the maximum density of macroinvertebrates was also obtained during spring (7450.7 ind/m^2, April 2009), and the lowest was in January 2009 (842.7 ind/m^2). Generally, higher Shannon-Wiener diversity were calculated for winter and spring.

Oligochaeta, mainly Tubificinae and Naidinae were the dominant groups in the Xiangxi Bay. In April, Tubificinae and Naidinae dominated the community, with the latter as the most abundant (relative abundance in density of 60–90%). However, in the other seasons, Tubificinae was the dominant group with a relative abundance over 90%. Chironomidae usually showed higher density in July, and mainly consisted of *Procladius* sp.

Spatially, during the 2nd impoundment stage, higher macroinvertebrate densities (> 2000 ind/m^2) were obtained at 6 ~ 20 km from the river mouth (Fig. 4). After the 3rd impoun ment, this range enlarged, and even extended to the site located at 25 km from the river mouth. By comparison, the biomass during the 2nd stage was much higher than in the 3^{rd} stage, and the range of the region with higher values shortened after the 3rd stage. The region with high taxa richness moved from upstream to downstream. The region with a taxa richness > 5 was located in the range of 7.5 ~ 20 km from the river mouth during the 2nd stage, while this range moved to the region located at 3 ~ 16 km from the river mouth during the 3^{rd} impoundment stage.

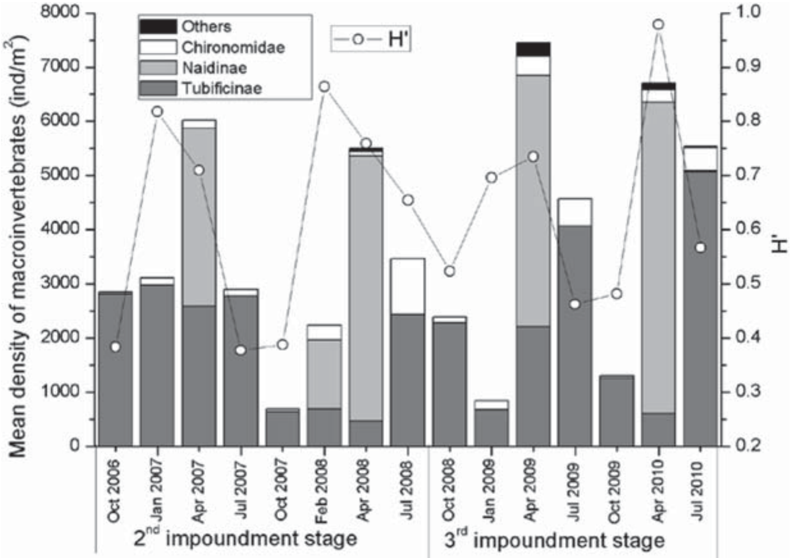

Figure 3. Mean density of macroinvertebrates in the Xiangxi Bay from October 2006 to July 2010.

Cluster analysis based on macroinvertebrates density, biomass and taxa richness divided the samples into two main groups (Fig. 5). Group 1 was formed by sites located near the mouth and in the edge of the bay (XX01, XX02, XX07, XX08 and XX09), while group 2 was formed by sites located in the middle region (XX03 and XX05). Macroinvertebrates density for both the two groups increased from the 2nd to the 3rd stage (Fig. 6), while the biomass showed an opposite trend. The taxa richness of group 1 increased from the 2nd to the 3rd stage, but that of group 2 decreased. Although XX01, XX02, and XX07, XX08, XX09 belonged to one group in relation to macroinvertebrates, they were separated according to their geographical location. Thus, we separated this group based on their geographical positions: XX01 and XX02 were located in zone I; XX07, XX08 and XX09 in zone III. XX03 and XX05 belonged to zone II. Significant differences among different zones were found for density and biomass in both stages (one-way ANOVA, $P < 0.05$), but not for taxa richness ($P > 0.05$).

3.2. TWINSPAN classification based on the macroinvertebrate community

TWINSPAN classification showed that the longitudinal zonation of the Xiangxi Bay displayed a seasonal pattern (Table 1). Four groups were obtained. The community types and the characteristic species of each group were listed in Table 2. There was only one sample in Group 3, therefore it was excluded in the analysis of the community types. *Limnodrilus hoffmeisteri* was the dominant species in all the other groups due to its high relative abundance. In autumn, the community type was stable from XX02 to XX07 and XX09 (Group 1, *Limnodrilus-Branchiura*) during the 2nd stage, while the community types of XX01 and XX08 fluctuated between years. During the 3rd stage, the community type of XX01 did not show yearly fluctuations (Group 2, *Limnodrilus-Procladius* type), while the community type of in the middle region (XX03, XX07 and XX08) remained as Group 1 type. In winter,

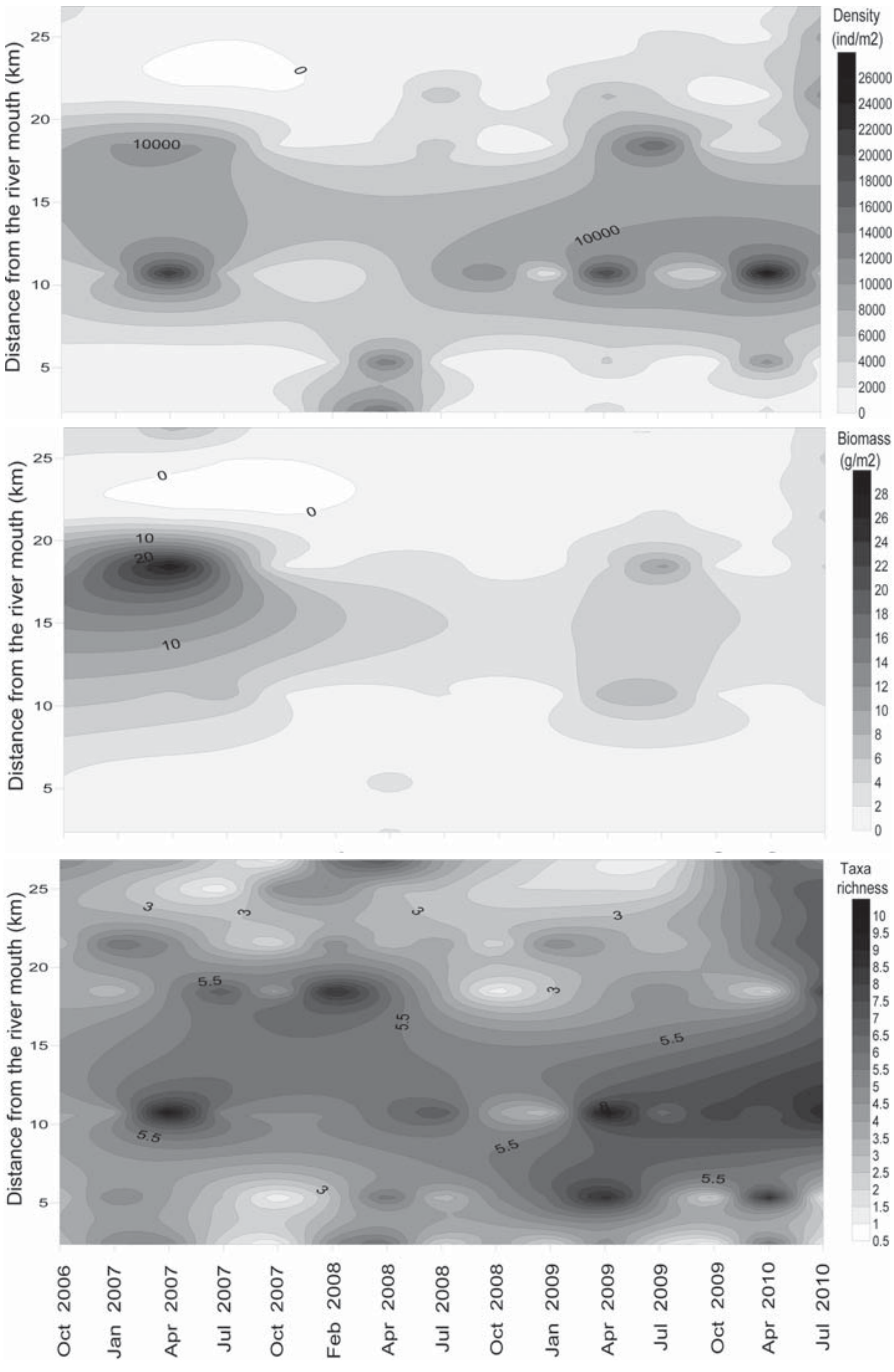

Figure 4. Density, biomass, and taxa richness of the macroinvertebrates along the Xiangxi Bay from October 2006 to July 2010.

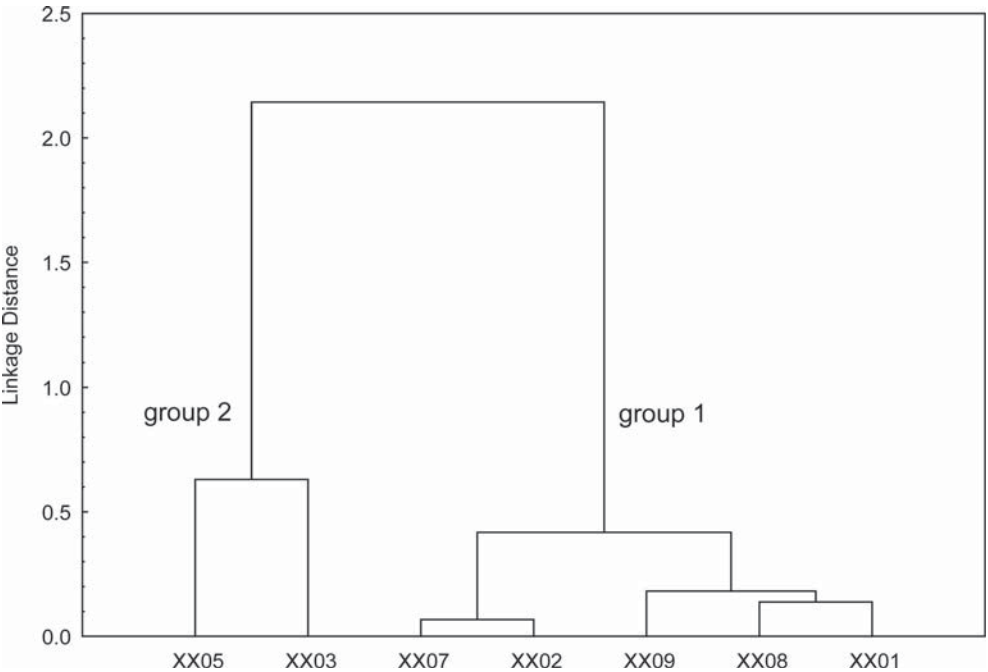

Figure 5. Cluster analysis based on the macroinvertebrate density, biomass, and taxa richness in the sampling sites from October 2006 to July 2010. Major groups formed are indicated.

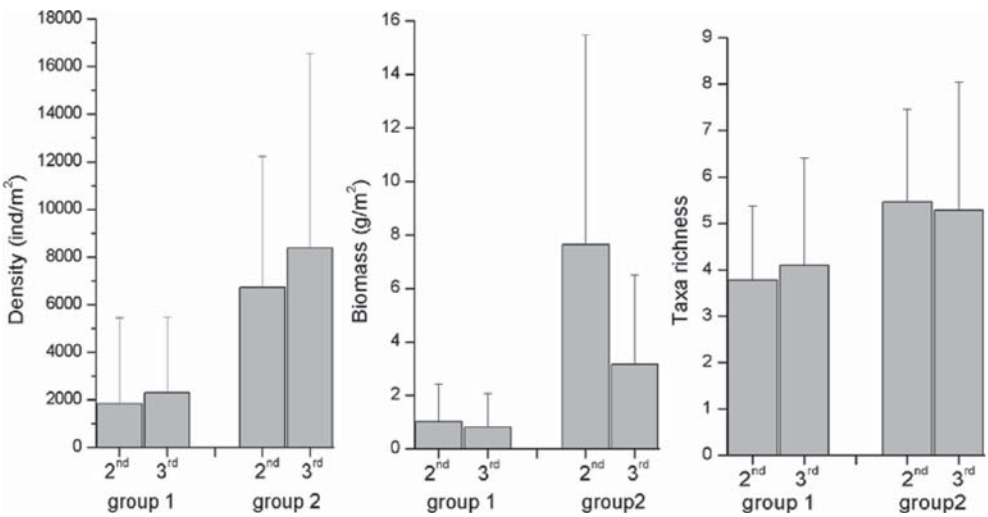

Figure 6. Mean and standard deviation of density, biomass and taxa richness of macroinvertebrates in the groups obtained in the cluster analysis from October 2006 to July 2010. See sites located within each group in Figure 5.

only the communities in XX01 (Group 4, *Limnodrilus-Nais-Stictochironomus*) and XX05 (Group 1) were relatively stable. In spring, during the 1st year of the 2nd stage, the community type was not stable (Group 1 and Group 4), while after that, the community remained as Group 4 along the bay except XX09. In summer, the commumity was relatively stable in the region of XX02 ~ XX05 (*Limnodrilus-Procladius* type) from the 2nd year of the 2nd stage, but with fluctuations for other sites.

Table 1. TWINSPAN classification results based on the species relative abundance of macroinvertebrates in the Xiangxi Bay from October 2006 to July 2010. 0: macroinvertebrate density is zero; N: no macroinvertebrate samples.

		XX01	XX02	XX03	XX05	XX07	XX08	XX09
Autumn	Oct-06	G2	G1	G1	G1	G1	0	G1
	Oct-07	G1	G1	G1	G1	G1	G1	G1
	Oct-08	G2	G2	G1	G1	G1	G1	0
	Oct-09	G2	G1	G1	G2	G1	G1	G2
Winter	Jan-07	G4	G1	G1	G1	G4	0	G4
	Feb-08	G4	G4	G4	G1	G4	G4	G4
	Jan-09	G4	G1	G4	G1	G2	G4	0
	Jan-10	N	N	N	N	N	N	N
Spring	Apr-07	G4	G1	G4	G1	G4	0	G1
	Apr-08	G4	G4	N	G4	G4	G4	G2
	Apr-09	G4	G4	G4	G4	G4	G4	G1
	Apr-10	G4	G4	G4	G4	G4	G4	
Summer	Jul-07	G1	G2	G2	G1	G2	G1	0
	Jul-08	G4	G2	G2	G2	G2	G2	G2
	Jul-09	G2	G2	G2	G2	G1	G1	G2
	Jul-10	G3	G2	G2	G2	G1	G2	G1

G: Group

Table 2. Community type according to characteristic species of each group classified by TWINSPAN in the Xiangxi Bay during different impoundment stages.

Group	Community type	Characteristic species	Fidelity Degree	Constancy (%)
1	*Limnodrilus-Branchiura*	*Limnodrilus hoffmeisteri*	5	98
		Branchiura sowerbyi	3	33
2	*Limnodrilus-Procladius*	*Limnodrilus hoffmeisteri*	4	88
		Procladius sp.	3	73
3	–	–	–	–
4	*Limnodrilus-Nais-Stictochironomus*	*Limnodrilus hoffmeisteri*	3	73
		Nais inflata	3	67
		Stictochironomus sp.	3	58

Group 3 was excluded in the analysis because of the insufficient sample number in this group

3.3. Relationship between Macroinvertebrates and Water Environmental Variables

After systematically eliminating environmental variables, five factors entered the final RDA for the 2nd stage, and four entered the final CCA of the 3rd stage. The results were displayed in Figure 7. The first two axes explained most of the relationships between species and environmental variables, in both stages. In the 2nd stage, they explained 76.1% of the macroinvertebrate community variance, while in the 3rd stage, the explanation to the species-environmental variables relationship was up to 80.6%.

During the 2nd stage (Fig. 7a), only the effects of Sd, TP and WT were significant in determining differences among sites ($P < 0.05$). In spring, most sites were characterized by higher concentration of TP and low WT, while during summer, a higher influence of high WT and low concentration of TP was observed. In autumn, the sites were mainly influenced by lower WT, and in winter the effect of higher Sd and lower level of NH_4–N became relatively higher. In the 3rd stage (Fig. 7b), the influence of TN was the most significant, explaining 19% of the variance ($P < 0.05$). During spring, sites were mainly influenced by low level of TN and high Sd, and by high concentration of TN and low Sd during summer. In autumn and winter, most sites were characterized by low concentration of NH_4–N. The

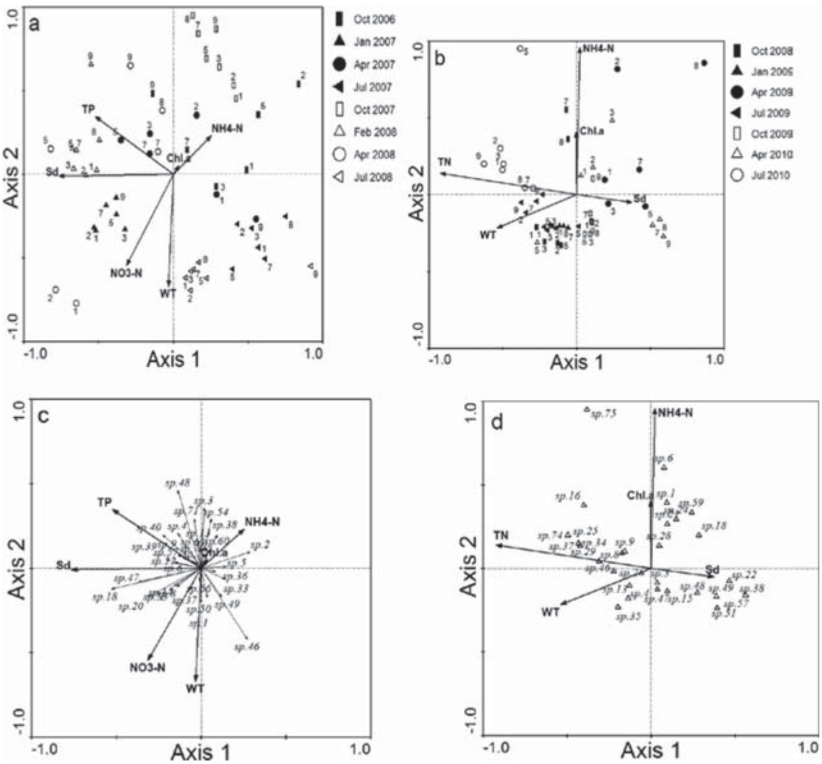

Figure 7. Relationship between macroinvertebrates and water environmental factors in the Xiangxi Bay from October 2006 to July 2010. Figure a and c are the results of the Redundancy Analysis; b and d are the results of Canonical Correspondence Analysis (a: relationship between sampling sites and environmental factors in the 2nd impoundment stage; b: relationship between sampling sites and environmental factors in the 3rd impoundment stage; c: relationship between species (sp.) and environmental factors in the 2nd impoundment stage; d: relationship between species and environmental factors in the 3rd impoundment stage). Numbers in figure a and b represent the names of the sampling sites, *e.g.*, 1 represents XX01.

influence of WT in the 3rd stage declined compared to the 2nd stage, and the distribution of the sampling sites became more concentrated. *Nais inflata* (sp. 18), *Procladius* sp. (sp. 46) and *Polypedilum scalaenum* group (sp. 48) abundance was the most influenced during the 2nd stage (Fig. 7c). *N. inflata* was mainly affected by Sd, and distributed in the region with relatively higher transparency. *Procladius* sp. abundance was determined by low concentration of TP, low Sd and high WT, while the higher abundance of *P. scalaenum* group was associated to higher concentration of TP and low WT. During the 3rd stage (Fig. 7d), the effect of Sd on the abundance of *N. inflata* decreased, distributing mainly in the region with low WT and high Sd. The dominant species of the Xiangxi bay – *Limnodrilus hoffmeisteri* (sp. 2), was slightly influenced by the water environmental factors, and distributed in the relatively high NH_4–N and Chl *a* region in the 2nd stage, while in the 3rd stage, it was located in the centre of the ordination axes, indicating that it was less influenced by the water environmental factors.

4. Discussion

4.1 Macroinvertebrate Community in Different Impoundment Stages

Oligochaetes and chironomids are the typical dominant populations of newly filled reservoirs, as they can avoid the effect of dramatic water disturbance through burrowing and rapid recolonization (Kaster and Jacobi, 1978). In the Xiangxi Bay, chironomids had relatively higher abundances in the first year after the impoundment of TGR, but from August 2004, oligochaetes became the dominant group (relative abundance of total density over 90%), with the highest density in the middle reach (Shao, 2008). Compared to that in the 1st stage (over 15000 ind/m^2 in April 2006, estimated from Shao (2008)), the macroinvertebrate density of the bay declined dramatically from the 2nd impoundment stage, but the dominance of oligochaetes was not affected. Generally, oligochaetes are able to replace the less tolerant groups and increase in number in sediment rich in organic matter (Newrkla and Wijegoonawardana, 1987). Therefore, the high density of *Limnodrilus hoffmeisteri* in the middle reach of the Xiangxi Bay indicated that the organic matter in the sediment of this zone was relatively higher, compared to that in the edges of the bay.

Large WLF nearly always cause a major decline in the macroinvertebrate abundance (Cowell *et al.*, 1987; Kaster and Jacobi, 1978). From the 2nd impoundment stage, the inter-annual WLF of TGR increased from 4 m to 11 m, and then caused the steep decline of macroinvertebrate density in the Xiangxi Bay. However, when the WLF increased to 30 m in the 3rd impoundment stage, the macroinvertebrate density did not show significant differences compared to that in the 2nd stage. The reason should be that the water disturbance in the 2nd stage had already greatly reduced the macroinvertebrate density, and thereby the disturbance occurred in the 3rd stage could only slightly affect the already reduced density. This change was very similar with the effect of WLF to macrophytes studied by Richardson *et al*. (2002), which showed that the water level drawdown resulted in the decrease of the biomass of macrophytes, with more remarkable decline during the first year.

4.2. Macroinvertebrates Zonation Pattern under the Condition of Higher Water Level Fluctuations

The zonation pattern based on the macroinvertebrates density, biomass and taxa richness did not show changes as the increase of the water level fluctuations after the 2nd impoundment stage. It displayed a similar pattern with that obtained during the 1st stage: mainstream zone (XX01-XX02), lacustrine zone (XX03-XX05) and transitional zone (XX07-XX09), named by SHAO *et al*. (2010). Some studies indicated that, in the mouth of the tributary (the mainstream zone), the reduction of current velocity is likely to cause increased sedimentation of fine suspended particles (BECKMANN *et al*., 2005). However, when the current velocity becomes faster due to the rising water level of the main stem, current may erode sediment previously deposited. Consequently, environmental conditions in the tributary mouth habitats are likely to fluctuate. Unstable habitats usually have fewer species that more stable ones (see *e.g.*, BEGON *et al*., 1996). Therefore, in the Xiangxi Bay, there was no regularity for the macroinvertebrate density in the mainstream zone during all impoundment stages, due to the disturbance of the Yangtze River backwater. In the lacustrine zone, the density and biomass of macroinvertebrates were higher. The higher sedimentation rate of the suspended matter in this zone (SHAO, 2008) indicated a higher environmental stability. NOGUEIRA *et al*. (1999) proved that lacustrine zones were more stable and not easily affected by factors such as the rainfall intensity. Therefore, in our study the more stable environmental conditions within the lacustrine zone were the main factor determining the higher density and biomass of macroinvertebrates. In the transitional zone, no regular pattern of the macroinvertebrate community appeared during the 2nd stage, while the density showed a gradual increase from the 3rd impoundment stage. According to SHAO *et al*. (2010), as water level increases, XX07 would become a lacustrine site as also was found for XX06. However, the result of our research indicated that, despite four years passed after the 2nd impoundment stage, XX07 still belonged to the transitional zone (relatively unstable), and the density of macroinvertebrates increased only from the 3rd impoundment stage. This indicated that it began to evolve to lacustrine conditions just after the last impoundment.

Although the longitudinal zonation pattern of density and biomass of macroinvertebrates did not show the expected changes during the 2nd and the 3rd impoundment stage, the zonation pattern of the community type was affected. Opposite to what happened during the 1st stage impoundment, when a stable status was observed all through the year (SHAO *et al*., 2010), our results showed that zonation based on community type displayed a seasonal pattern. The seasonal feature of the community type was coupled to the seasonal changes of WLF. In autumn, from the 3rd impoundment stage, as the WLF increased, more *Procladius* sp. larvae were collected, even in XX05 which was located in the middle reach of the Xiangxi Bay. *Procladius* has not been usually considered a good indicator, because of its free-living habit (KANSANEN *et al*., 1984). In winter, the zonation was not stable in both the 2nd and the 3rd stages. During the high water level period in winter, the WLF was very low, and the water environment was stable. Theoretically, stable environment led to stable community (see *e.g.*, BEGON *et al*., 1996). Nevertheless, the community of the bay in winter varied and mainly consisted of two types: G1 and G4, similar with that of autumn (mainly G1) and spring (mainly G4). Therefore, we concluded that, the zonation pattern was in a transitional stage between autumn and spring, and the community type was mainly influenced by seasonal factors, *e.g.*, low water temperature and the reduction of food. Spring was characterized by the *Limnodrilus-Nais-Stictochironomus* community type, mainly due to the increase of *N. inflata* abundance. Little is known about the basic ecological information of this species. Some studies showed that they are frequent in Yangtze River, especially in January and April (SHAO *et al*., 2008; ZHANG *et al*., 2010). In addition, this study showed that they were dominant in spring. According to the results obtained, we conclude that *N. inflata* prefers sites with higher transparency, lower water temperature and water disturbance. In summer, with frequent flood episodes, the community was mainly dominated by *L. hoffmeisteri* and *Procladius* sp., which represent the community status under high environmental stress (OLIVER, 1971; WETZEL, 2001). Because flood in summer usually causes sudden changes in all environmental parameters such as water flow, thermic regime, oxygen conditions, nutrient gradients, etc., all these changes could influence the organisms' habitat and food resources (GODLEWSKA *et al*., 2003). Therefore, this might be the main reason leading to the community type in summer (dominated by more tolerant species).

4.3. The Influence of the Water Environmental Factors

The effect of the water environmental factors to macroinvertebrates differed in different impoundment stages. During the latter two years of the 1st stage, only the effect of TP was significant (Shao *et al.*, 2008), while in the 2nd stage, TP, Sd and WT affected the abundance of macroinvertebrates significantly. Moreover, in the 3rd stage, fewer factors caused significant influence to the macroinvertebrates composition (only TN). It is obvious that the nutrients in the water always affected the abundance of the macroinvertebrates of the Xiangxi Bay. Nutrients are essential for the growth of phytoplankton, while phytoplankton sedimentation is one of the most important food source for macroinvertebrates (Vos *et al.*, 2002). Therefore, nutrients in the water became the indirect reason influencing the macroinvertebrate community. However, these factors did not show evident effects to *L. hoffmeisteri* on the Xiangxi Bay, as was also found by Nijboer *et al.* (2004). *L. hoffmeisteri* is a tolerant and widespread species. It commonly appears in a wide range of habitats, and can bear higher environmental pressure. As the dominant group of the Xiangxi Bay, the decline of its density was the main reason leading to the density decline of the whole bay. From the 2nd impoundment stage, the inter-annual WLF increased, which would enhance the water disturbance degree. Strong water disturbance could cause the sedimentation decline of the suspended organic matter (De Cesare *et al.*, 2001), and speed up the decomposition of the organic matter in the sediments (Wildman *et al.*, 2010). Therefore, the food quantity and quality of the macroinvertebrates would decrease (Vos *et al.*, 2002; Godlewska *et al.*, 2003). Additionally, the water disturbance could directly influence the habitat of macroinvertebrates, for example by re-suspending the sediment. All of these finally led to the decline of the macroinvertebrates density. Therefore, large WLf was the primary cause for the decline of macroinvertebrate density after the 2nd impoundment.

In summary, as the increase of the WLF from the 2nd impoundment stage, oligochaetes still dominated the macroinvertebrate community of the Xiangxi Bay. The macroinvertebrates density and biomass dramatically declined but the spatial pattern was not affected. The zonation of the macroinvertebrate community type displayed seasonal variations, which were coupled to the seasonal changes of WLF. This differed with the stable status of the 1st stage. The number of water environmental factors influencing the macroinvertebrate community was higher in the 2nd stage in relation to the 1st stage, but decreased during the 3rd stage. This implied that the macroinvertebrate community experienced a stable-fluctuant-stable sequence from the first-second-third impoundment stage.

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