Journal of Freshwater Ecology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tjfe20

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Published online: 07 Jan 2011.

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ABSTRACT

Sedimentation variables and benthic community data were collected at seven stations during four seasons in Xiangxi Bay of the Three Gorges Reservoir, China. Summer, the season of highest discharge into the reservoir, was characterized by the extreme sediment loading. The benthic macroinvertebrate community was dominated by oligochaetes across all seasons at most stations. In winter/spring, macroinvertebrate density and richness increased. Correspondence analysis showed that community structure differed among stations at the two ends of the bay in winter and among almost all stations in spring. However, no variable associated with sedimentation appeared to be associated with differences in the community.

INTRODUCTION

With impoundment of the Three Gorges Reservoir (TGR) in June 2003, vast areas of land were inundated, and the surface of the reservoir will reach 1,080 km^2 when the project is completed in 2009 (Wu et al. 2003, Zeng et al. 2006). A 25-km reach of the mouth of the Xiangxi River was inundated by the reservoir and now formed Xiangxi Bay (Shao et al. 2007). As a typical representative of bays of the TGR, Xiangxi Bay was investigated widely after its formation (e.g., Hu and Cai 2006, Ye et al. 2006a, Fu et al. 2006). As the system changed from a lotic to a more lentic-like state, Xiangxi Bay underwent severe eutrophication (Cai and Hu 2006, Ye et al. 2006b). Algal blooms frequently occurred in the bay in spring (Han et al. 2006). The substratum of Xiangxi Bay apparently changed after impoundment from cobble and gravel to silt and sand (Shao et al. 2006). To our knowledge, however, no related quantitative sedimentation studies exist on Xiangxi Bay or on similar bays.

Sediment loading can significantly impact aquatic ecosystems and these effects have been widely researched (e.g., Cohen et al. 1993, Wood and Armitage 1997, Donohue and Irvine 2004). Sedimentation by particulate inorganic matter (PIM) causes physical effects on the environment and organisms, such as decreasing the nutritional value of detritus (e.g., Graham 1990), filling interstitial spaces (e.g., Crisp 1989, Schälchli 1992), making the substratum unstable, or directly killing macroinvertebrates (e.g., Chou et al. 2004). Sedimentation by particulate organic matter (POM) limits nutrient transport to the bottom (Bloesch and Uehlinger 1986, Cocito et al. 1990). Sedimentation can also alter the grain size distribution, which can strongly influence benthic invertebrates (e.g., Cummins and Lauff 1969, Williams 1978, Sauter and Güde 1996, Beckmann et al. 2005). For example, it is reported that oligochaetes favor fine sediments, while chironomids favor coarser sediments (Callisto et al. 2005). Species distributed in tributary mouths usually prefer relatively fine substrata (Beckmann et al. 2005), while pollution-sensitive taxa often prefer substrate > 64 mm (Beauger et al. 2006).

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However, most analyses of grain size distribution were based on the sediments collected from the riverbed rather than newly deposited sediments.

The benthic assemblages in Xiangxi Bay have changed dramatically between 2003 and 2005, and oligochaetes dominated the system during the second year after the impoundment of the TGR (Shao et al. 2006). We investigated the seasonal patterns of sedimentation in Xiangxi Bay and their relationship with macroinvertebrate assemblages.

METHODS AND MATERIALS

Seven stations (X01 to X07) along a lengthways transect of Xiangxi Bay were surveyed in November 2005 (autumn), January 2006 (winter), April 2006 (spring) and July 2006 (summer). X01 was located near the mouth of the Xiangxi River, and X07 was upstream near the end of the bay. From X01 to X07, the depth of each station was approximately 70, 50, 30, 30, 20, 10, and 5 m, respectively.

Nine sedimentation variables were measured at each station for each survey, except in the case of X06 in July 2006 due to lost sediment traps (Table 1). These variables included the sedimentation rates of total particulate matter (TPM), PIM, and POM and %POM. We measured particle size of TPM including mean diameter (D_0), the percent of sand-size particles (%sand; grain size > 63 μm to < 2 mm), the percent of silt-size particles (%silt; grain size > 4 μm to < 63 μm), the percent of clay-size particles (%clay; grain size < 4 μm), and the diversity index of particle size (*D*).

Sediment traps were used to determine the newly deposited particulate matter. These traps (Huang 2000) were suspended 0.5 m above the bottom by an anchored rope. Two traps were placed at each station for each survey, and mean values were calculated for each station. Sediment traps were retrieved after 24 h to reduce risk of decomposition (Taguchi 1982, Koop and Larkum 1987). The collected materials, both sediments and water in the trap, were emptied into a polyethylene bottle. The bottle was shaken gently to mix the contents, and subsamples were taken from the mixture for various analyses following the procedure of Clavier et al. (1995). Five hundred mL of the mixture were filtered through a weighed pre-ignited glass fiber filter (Whatman GF/F), dried at 105° until constant weight, and weighed to determine TPM. Then each filter was ashed at 550° for 30 minutes and reweighed to calculate PIM. POM, treated as potential food resource for benthos, was determined by subtracting PIM from TPM. The organic content was computed as %POM = POM / TPM * 100%. The sedimentation rates of particles were calculated as $g \cdot m^{-2} \cdot d^{-1}$. An additional 500 mL of the mixture was taken for particle size analysis of TPM using a laser particle size analyzer (Mastersizer 2000, Malvern Instruments Ltd., UK). The output included particle size distribution and mean diameter of particles.

Macroinvertebrates were collected using a modified Peterson grab sampler (Liang 1987) (area 0.0625 m^2) once at each station for each survey. Samples were passed through a 200-μm mesh sieve, and material retained was preserved in 4% formaldehyde. Most specimens were identified at least to genus, and all macroinvertebrate densities were expressed as individuals m^{-2}.

In addition, monthly discharge data of the Xiangxi River after the impoundment (2004-2005) was supplied by Xianshan Hydrological Station, a station upstream from X07.

Heterogeneity of newly deposited sediment was determined from grain size data using a Simpson diversity index (*D*) (Brittain et al. 2001). The index was calculated using the formula $D = 1 - \sum p_i^2$, where p_i is the proportion of *i*th particle size classes.

Differences in sedimentation variables and macroinvertebrate density and richness among surveys were determined using a repeated measures analysis of variance (RM ANOVA; SPSS 13.0). Macroinvertebrate density and richness and sedimentation rates of

TPM, PIM, POM, and D_0 were $\log_{10}$-transformed prior to analyses, and percent metrics (%POM, %sand, %silt, and %clay) were arcsin-transformed. All RM ANOVAs were performed following the procedure of Vinueza et al. (2006). Mauchly's tests of sphericity were run for all RM ANOVAs. Greenhouse-Geisser corrections were chosen only when the data did not meet the sphericity assumptions. If within-subjects effects of RM ANOVA were significant, differences among the main effects of seasons were compared using Bonferroni adjusted confidence interval (95%). Differences among stations were assessed by mean values and coefficients of variation (CV) of each variable.

We compared the relative abundances of macroinvertebrates to determine differences in community structure among the four surveys using multi-response permutation procedures (MRPP; PC-ORD 4), with Euclidean distance as the distance measure, and correspondence analysis (CA; PC-ORD 4). MRPP is a nonparametric statistical method for testing the hypothesis of no difference in community structure between two or more *a priori* groups (Bestelmeyer and Wiens 2001, Hylander et al. 2005). CA is an indirect ordination method, which examines the primary gradients in community structure independently of measured environmental factors (Bestelmeyer and Wiens 2001).

To examine relationships between community structure and sedimentation variables, we performed a separate canonical correspondence analysis (CCA; CANOCO 4.5) for each survey. CCA is a multivariate analysis technique relating community composition to environmental variables (Didham et al. 1998). Bioplot scaling was chosen, and the scale of the CCA plot was a function of inter-sample distances. Rare species were downweighted. The criteria used to retain variables in the CCA model followed Peeters et al. (2004). In short, the contribution and significance of each variable was assessed in manual selection, and Monte Carlo permutation tests were used (number of permutations: 199) under the reduced model. The permutation was restricted to a linear transect design. The variable with the highest and significant ($p < 0.05$) contribution was included in each calculation until no variable had a significant contribution. Next, the variable with the highest variance inflation factor (VIF) was removed in each calculation until all VIFs were smaller than 20 (Peeters et al. 2004).

We examined relationship between sedimentation rates of TPM and discharge using an association test. However, due to lack discharge data of 2006, mean values of corresponding months in 2004 and 2005 were calculated for analysis. Also, we performed association tests to examine relationships between sedimentation variables and macroinvertebrate data (density and richness). All association tests were two-tailed and were performed with Pearson correlation test (SPSS 13.0).

RESULTS

PIM was the dominant component of TPM across all seasons at all stations (75.8-96.0%) (Table 1). Sedimentation rate of TPM differed between seasons ($p < 0.001$; Table 2) and was an order of magnitude higher in the summer than in other seasons at most stations. Similar patterns were also found both for PIM and for POM. Sedimentation rates of TPM correlated positively with discharge ($r = 0.984$, $p = 0.016$) (Fig.1). Silt-size particles dominated the trapped particles across all seasons at all stations (51.7-91.5%). All five particle size variables differed between seasons ($p < 0.05$ in all cases). Autumn was characterized by lower %clay than summer ($p = 0.043$), and spring was characterized by higher Simpson index than winter ($p = 0.028$) and summer ($p = 0.002$).

Sedimentation rates of TPM at X02 and X07 were low compared with other stations (Table 1). Also, similar trends were found both for PIM and for POM. However, the CVs of sedimentation rates at each station were relatively high because of the extreme sediment loading in summer. Furthermore, %POM, D_0 and %sand were all relatively high at X02. Also, the CVs of D_0, %sand, %silt and %clay were relatively high at X02.

A total of 35 macroinvertebrate taxa was collected during the study. They included two families of Oligochaeta (48.6% of the total taxa number), Chironomidae (45.7%), Tipulidae (2.9%), and Nematoda (2.9%). Taxon richness was different between surveys ($p = 0.034$; Table 2). Autumn had lower taxon richness than winter ($p = 0.026$) and spring ($p = 0.001$). Densities differed between surveys ($p = 0.009$), and densities in spring were significantly higher than those in winter ($p = 0.035$). Except in cases of X02 and X07 in January 2006, oligochaetes became the sole dominant group (66.7-100%) (Table 1).

Stations in the middle stretch of the bay (X03-X06) had high densities of macroinvertebrates compared with other stations (Table 1). Especially, mean densities in X03-X05 were an order of magnitude higher than those in X01, X02, and X07. Oligochaetes absolutely dominated communities in X03-X06. Mean relative abundances of oligochaetes in these four stations were all higher than 97% and the CVs were all lower than 4%.

Table 1. Sedimentation variables and macroinvertebrate data collected at seven stations during four seasons. Values are means (± SE). CV = coefficient of variation. The mean sediment values for station X06 are not calculated since the July (summer) sediment traps were lost.

	X01	X02	X03	X04	X05	X06	X07
Total particulate matter ($g \cdot m^{-2} \cdot d^{-1}$), TPM							
Mean	114.5 (79.9)	49.7 (35.6)	180.3 (149.9)	254.6 (208.6)	95.3 (68.4)		43.3 (18.9)
CV	139.7%	143.4%	166.3%	163.8%	143.6%		87.5%
Particulate inorganic matter ($g \cdot m^{-2} \cdot d^{-1}$), PIM							
Mean	105.8 (73.8)	44.3 (33.6)	168.4 (141.8)	239.1 (195.8)	88.6 (64.3)		38.9 (17.1)
CV	139.4%	151.6%	168.3%	163.8%	145.1%		87.7%
Particulate organic matter ($g \cdot m^{-2} \cdot d^{-1}$), POM							
Mean	8.6 (6.1)	5.4 (2.2)	11.9 (8.2)	15.6 (12.8)	6.7 (4.3)		4.4 (1.9)
CV	142.8%	82.8%	137.8%	164.6%	126.7%		87.9%
Organic content, %POM							
Mean	8.4 (2.1)	19.6 (4.2)	10.6 (1.8)	6.6 (1.2)	12.5 (4.1)		11.7 (2.4)
CV	50.3%	43.3%	34.8%	35.4%	66.1%		40.7%
Mean particle size (μm), D_0							
Mean	18.0 (3.9)	60.4 (30.3)	27.0 (7.3)	25.8 (5.1)	29.4 (8.6)		26.5 (2.8)
CV	43.7%	100.2%	53.8%	39.3%	58.3%		21.2%
Percent of sand-size particles, %sand							
Mean	3.3 (1.5)	17.1 (9.7)	8.5 (3.7)	7.1 (2.8)	83.3 (3.9)		6.7 (1.0)
CV	93.9%	113.1%	86.8%	79.8%	94.9%		31.3%
Percent of silt-size particles, %silt							
Mean	81.0 (4.7)	73.4 (7.5)	78.1 (4.2)	82.3 (2.3)	84.7 (3.0)		86.3 (1.2)
CV	11.6%	20.3%	10.6%	5.5%	7.0%		2.7%
Percent of clay-size particles, %clay							
Mean	15.8 (4..4)	9.4 (4.7)	13.4 (3.6)	10.6 (3.3)	7.0 (2.2)		7.0 (0.4)
CV	55.4%	99.4%	53.2%	62.8%	62.4%		10.1%
Simpson diversity index, *D*							
Mean	0.3 (0.1)	0.4 (0.0)	0.4 (0.1)	0.3 (0.0)	0.3 (0.0)		0.2 (0.0)
CV	40.6%	24.3%	31.7%	22.2%	32.9%		15.0%
Density (ind./m^2)							
Mean	1,552 (1,189)	3,544 (1,496)	26,066 (1,852)	27,804 (4,648)	35,854 (12,291)	8,352 (3,675)	1,068 (584)
CV	153.2%	84.4%	14.2%	33.4%	68.6%	88.0%	109.3%
Richness							
Mean	5.0 (1.6)	8.5 (2.2)	10.5 (1.6)	9.8 (1.9)	6.8 (2.0)	7.0 (1.3)	6.0 (1.7)
CV	63.2%	51.3%	29.6%	38.7%	59.7%	36.9%	57.7%
Relative abundance of oligochaetes (%)							
Mean	80.5 (6.8)	76.4 (15.1)	98.0 (1.2)	99.0 (0.5)	99.6 (0.3)	97.1 (1.9)	70.9 (23.7)
CV	16.9%	39.4%	2.5%	1.0%	0.5%	3.9%	66.9%

Community structure differed significantly ($p = 0.02$) between seasons as shown by MRPP. The average distance (similarity) among stations in summer was the shortest (0.1820), which meant there was a much higher similarity in community structure among stations during summer. Average distance was 0.3307 in autumn, 0.5614 in spring, and 0.7493 in winter. Fig. 2 shows assemblage structures by all samples. The first two ordination axes accounted for 58.8% of the cumulative variance. Community structures in autumn and summer were similar. In winter, community structure varied between stations X01, X02 and X07. In spring, community structure differed among nearly all stations.

Sedimentation appeared to have little effect on benthic communities as no significant sedimentation variable was found in the four CCAs and no correlations were observed between sedimentation variables and macroinvertebrate density and richness.

DISCUSSION

It is important to note that our study was confined to one bay of the TGR. Consequently, it is possible that our results do not comprehensively describe the relationship between sedimentation and the benthic community. Before the study, we attempted to select a bay with no or slight sedimentation as a reference bay. However, the seasonal pattern of discharge of the whole TGR is profoundly controlled by monsoons. Because extensive destruction of vegetation has occurred in the upper reaches (Hui et al. 2000, Yin and Li 2001), sediment loads significantly increase during the flood season. In our study, the positive correlation between discharge and sedimentation rates of TPM was demonstrated. The characteristic – the seasonal pattern of sediment loads – is also reflected by the operation pattern of the TGR (i.e., storing clear water after flood seasons

Table 2. Summary of RM ANOVA for sedimentation variables and macroinvertebrate density and richness.

Variable	Mauchly's test of sphericity	Test of within-subjects effects							Pairwise comparisons
		Source		SS	df	MS	F	p	
TPM	$p = 0.784$	Sphericity assumed	Season Error	6.150 0.919	3 15	2.050 0.061	33.478	< 0.001	Nov. 2005-July 2006, $p = 0.005$ Jan. 2006-July 2006, $p < 0.001$ Apr. 2006-July 2006, $p = 0.009$
PIM	$p = 0.822$	Sphericity assumed	Season Error	6.505 1.028	3 15	2.168 0.069	31.637	< 0.001	Nov. 2005-July 2006, $p = 0.004$ Jan. 2006-July 2006, $p < 0.001$ Apr. 2006-July 2006, $p = 0.011$
POM	$p = 0.204$	Sphericity assumed	Season Error	4.123 0.542	3 15	1.374 0.036	38.028	< 0.001	Nov. 2005-July 2006, $p = 0.024$ Jan. 2006-July 2006, $p < 0.001$ Apr. 2006-July 2006, $p = 0.005$
%POM	$p = 0.983$	Sphericity assumed	Season Error	0.060 0.087	3 15	0.020 0.006	3.455	0.044	
D_0	$p = 0.301$	Sphericity assumed	Season Error	0.647 0.765	3 15	0.216 0.051	4.229	0.024	
%sand	$p = 0.607$	Sphericity assumed	Season Error	0.234 0.235	3 15	0.078 0.016	4.973	0.014	
%silt	$p = 0.797$	Sphericity assumed	Season Error	0.117 0.075	3 15	0.039 0.005	7.843	0.002	
%clay	$p = 0.062$	Sphericity assumed	Season Error	0.135 0.084	3 15	0.045 0.006	7.967	0.002	Nov. 2005-July 2006, $p = 0.043$
D	$p = 0.140$	Sphericity assumed	Season Error	0.098 0.049	3 15	0.033 0.003	9.985	0.001	Jan. 2006-Apr. 2006, $p = 0.028$ Apr. 2006-July 2006, $p = 0.002$
Density	$p = 0.131$	Sphericity assumed	Season Error	2.670 3.085	3 18	0.890 0.171	5.194	0.009	Jan. 2006-Apr. 2006, $p = 0.035$
Richness	$p = 0.037$	Greenhouse-Geisser	Season Error	0.650 0.627	1.274 7.643	0.510 0.082	6.222	0.034	Nov. 2005-Jan. 2006, $p = 0.026$ Nov. 2005-Apr. 2006, $p = 0.001$

and releasing muddy water during flood seasons). The seasonal pattern of sedimentation in Xiangxi Bay (i.e., sediment loading significantly higher in summer than in other seasons) was consistent with the sedimentation characteristic of the whole TGR. Therefore, it seemed that the seasonal pattern of sedimentation in Xiangxi Bay was representative for bays of the TGR, even for bays of subtropical canyon-shaped reservoirs.

Sedimentation did not significantly influence benthic community structure, which was more strongly related to the characteristics of the bay. Sedimentation variables and macroinvertebrate composition indicated that stations in the middle stretch of the bay were quite different from the other stations. Bays, like reservoirs, have longitudinal zonation (Straškraba and Tundisi 1999). Furthermore, owing to lack of a dam, the mouth of a bay will also be influenced by the main stem (Beckmann et al. 2005). Therefore, spatial position should be emphasized when efforts are made to detect factors which significantly influence benthic community structure. Secondly, although significant impacts of sedimentation on benthos have been found (e.g., Quinn et al. 1992, Donohue et al. 2003, Donohue and Irvine 2004), the majority of taxa in these previous studies were sensitive species. However, our results showed that the benthic community in Xiangxi Bay was dominated by oligochaetes, which are tolerant of high sediment loading (Donohue and Irvine 2004). In addition, the dominance of fine sediments benefits oligochaetes (Callisto et al. 2005). Therefore, when oligochaetes dominated the benthic community, sedimentation appeared to have little influence on community structure in the present study. In order to quantify the impacts of sedimentation on benthic communities, studies should be performed once a bay is formed, because the benthic community in a bay usually changes dramatically during the initial period of the operation of a reservoir (Shao et al. 2006, Shao et al. 2007).

When oligochaetes dominate the community, there are two directions for study suggested by our results. First, the seasonal pattern of the benthic community structure

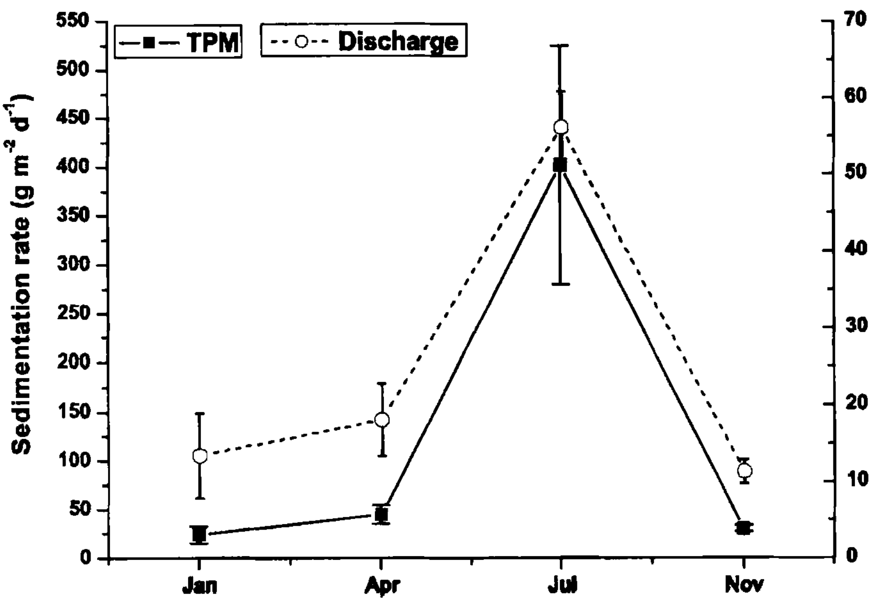

Figure 1. The average discharge of the Xiangxi River from 2004 to 2005 (mean ± SE, n = 2) (unpublished data provided by Xingshan Hydrological Station) and mean sedimentation rates of TPM in November 2005, January 2006, April 2006, and July 2006 (mean ± SE, n = 6-7).

found in the present study is that community structure was similar in summer and autumn and differed in winter and spring. This pattern seemed to be related to the characteristic of sedimentation. The environment in summer was quite unstable due to extreme sediment loading, which might result in limited survival only by the most tolerant species. However, quantitative effects could not be obtained from our study. For example, our study showed that average distance between stations was inversely correlated with the sedimentation of TPM (r = -0.755) but not significantly (p = 0.245). Community homogenization has been observed with different stressors, such as invasion by nonindigenous species (Rahel 2002). Other studies have tested whether heavy-metal pollution homogenized benthic invertebrate composition (Pollard and Yuan 2006). Considering the annual cycle of sedimentation, long-term monitoring should be performed in this kind of dynamical system to determine whether the extreme sedimentation represents the main environmental stressor to macroinvertebrates or not. Secondly, that density and richness were significantly high in spring reminds us the importance of food quality (Cocito et al. 1990, Vos et al. 2002), since the quantity of food (POM) did not change significantly in spring. In spring, the dramatic characteristic of bays of the TGR is occurrences of algal blooms, especially of dinoflagellates and diatoms (Cai and Hu 2006, Zhou et al. 2006). Many studies demonstrated that high-quality food could be supplied for benthos by phytodetrital sedimentation following blooms (Goedkoop and Johnson 1996, Ahlgren et al. 1997). Therefore, to quantify the effects of sedimentation on benthic community, components of POM should be considered. It was very possible that blooms in spring played an important role for the benthic communities and a large amount of algal phytodetritus depositing on the substratum increased the heterogeneity of sediments. However, to test these hypotheses, related experiments should be designed and performed.

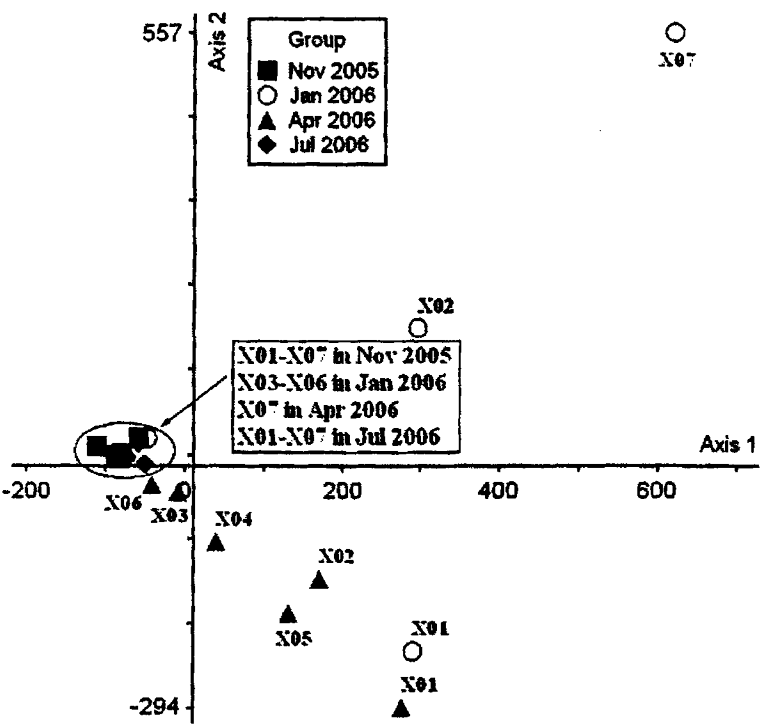

Figure 2. CA ordination of all samples. λ_1 = 0.6911, λ_2 = 0.5980.

ACKNOWLEDGMENTS

The study was supported by National Natural Science Foundation of China (No. 30330140, 40671197), the National Basic Research Priorities Programme (973 Programme) (No. 2002CB412300), and the Key Project of Knowledge Innovation Program of CAS (No. KZCX2-YW-427). We thank Yaoyang Xu, Lin Ye, Shuang Han, Xinghuan Jia, Aijiao Zhu, and Jianliang Yao for their assistance in the field and lab. Special thanks are due to Nancy E. Karraker and Tao Tang for their inspired comments on the manuscript.

LITERATURE CITED

Ahlgren, G., W. Goedkoop, H. Markensten, L. Sonesten, and M. Boberg. 1997. Seasonal variations in food quality for pelagic and benthic invertebrates in Lake Erken - the role of fatty acids. Freshwater Biol. 38: 555-570.

Beauger, A., N. Lair, P. Reyes-Marchant, and J.-L. Peiry. 2006. The distribution of macroinvertebrate assemblages in a reach of the River Allier (France), in relation to riverbed characteristics. Hydrobiologia 571: 63-76.

Beckmann, M.C., F. Schöll, and C.D. Matthaei. 2005. Effects of increased flow in the main stem of the River Rhine on the invertebrate communities of its tributaries. Freshwater Biol. 50: 10-26.

Bestelmeyer, B.T. and J.A. Wiens. 2001. Ant biodiversity in semiarid landscape mosaics: the consequences of grazing vs. natural heterogeneity. Ecol. Appl. 11: 1123-1140.

Bloesch, J. and U. Uehlinger. 1986. Horizontal sedimentation differences in a eutrophic Swiss lake. Limnol. Oceanogr. 31: 1094-1109.

Brittain, J.E., S.J. Saltveit, E. Castella, J. Bogen, T.E. Bønsnes, I. Blakar, T. Bremnes, I. Haug, and G. Velle. 2001. The macroinvertebrate communities of two contrasting Norwegian glacial rivers in relation to environmental variables. Freshwater Biol. 46: 1723-1736.

Cai, Q.H. and Z.Y. Hu. 2006. Studies on eutrophication problem and control strategy in the Three Gorges Reservoir. Acta Hydrobiologica Sinica 30: 7-11.

Callisto, M., M. Goulart, F.A.R. Barbosa, and O. Rocha. 2005. Biodiversity assessment of benthic macroinvertebrates along a reservoir cascade in the lower São Francisco river (northeastern Brazil). Braz. J. Biol. 65: 229-240.

Chou, L.M., J.Y. Yu, and T.L. Loh. 2004. Impacts of sedimentation on soft-bottom benthic communities in the southern islands of Singapore. Hydrobiologia 515: 91-106.

Clavier, J., P. Chardy, and C. Chevillon. 1995. Sedimentation of particulate matter in the south-west lagoon of New Caledonia: spatial and temporal patterns. Estuar. Coast. Shelf Sci. 40: 281-294.

Cocito, S., S. Fanucci, I. Niccolai, C. Morri, and C. N. Bianchi. 1990. Relationships between trophic organization of benthic communities and organic matter content in Tyrrhenian Sea sediments. Hydrobiologia 207: 53-60.

Cohen, A.S., R. Bills, C.Z. Cocquyt, and A.G. Caljon. 1993. The impact of sediment pollution on biodiversity in Lake Tanganyika. Conserv. Biol. 7: 667-677.

Crisp, D.T. 1989. Some impacts of human activities on trout, *Salmo trutta*, populations. Freshwater Biol. 21: 21-33.

Cummins, K.W. and G.H. Lauff. 1969. The influence of substrate particle size on the microdistribution of stream macrobenthos. Hydrobiologia 34: 145-181.

Didham, R.K., P.M. Hammond, J.H. Lawton, P. Eggleton, and N.E. Stork. 1998. Beetle species responses to tropical forest fragmentation. Ecol. Monogr. 68: 295-323.

Donohue, I., E. Verheyen, and K. Irvine. 2003: *In situ* experiments on the effects of increased sediment loads on littoral rocky shore communities in Lake Tanganyika, East Africa. Freshwater Biol. 48: 1603-1616.

Donohue, I. and K. Irvine. 2004. Seasonal patterns of sediment loading and benthic invertebrate community dynamics in Lake Tanganyika, Africa. Freshwater Biol. 49: 320-331.
Fu, C.Y., T. Fang, and N.S. Deng. 2006. The research of phosphorus of Xiangxi River nearby the Three Gorges, China. Environ. Geol. 49: 923-928.
Goedkoop, W. and R.K. Johnson. 1996. Pelagic-benthic coupling: profundal benthic community response to spring diatom deposition in mesotrophic Lake Erken. Limnol. Oceanogr. 41: 636-647.
Graham, A.A. 1990. Siltation of stone-surface periphyton in rivers by clay-sized particles from low concentrations in suspension. Hydrobiologia 199: 107-115.
Han, X.Q., L. Ye, Y.Y. Xu, and Q.H. Cai. 2006. Analysis of the spatial and temporal changes of chlorophyll *a* concentration in Xiangxi Bay in spring and its impact factors. Acta Hydrobiologica Sinica 30: 89-94.
Hu, Z.Y. and Q.H. Cai. 2006. Preliminary report on aquatic ecosystem dynamics of the Three Gorges Reservoir before and after impoundment. Acta Hydrobiologica Sinica 30: 1-6.
Huang, X. F. (eds.). 2000. Survey, observation and analysis of lake ecology. Standards Press of China, Beijing.
Hui, Y., X.H. Zhang, and Z.J Chen. 2000. Present situation and strategy about the natural environment of the Xiangxi River basin. Resour. Environ. Yangtze Basin 9: 27-33.
Hylander, K., M. Dynesius, B.G. Jonsson, and C. Nilsson. 2005. Substrate form determines the fate of bryophytes in riparian buffer strips. Ecol. Appl. 15: 674-688.
Koop, K. and A.W.D. Larkum. 1987. Deposition of organic material in a coral reef lagoon, One Tree Island, Great Barrier Reef. Estuar. Coast. Shelf Sci. 25: 1-9.
Liang, Y.L. 1987. Preliminary study of the aquatic Oligochaeta of the Changjiang (Yangtze) River. Hydrobiologia 155: 195-198.
Peeters, E.T.H.M., R. Gylstra, and J.H. Vos. 2004. Benthic macroinvertebrate community structure in relation to food and environmental variables. Hydrobiologia 519: 103-115.
Pollard, A.I. and L. Yuan. 2006. Community response patterns: evaluating benthic invertebrate composition in metal-polluted streams. Ecol. Appl. 162: 645-655.
Quinn, J.M., R.J. Davies-Colley, C.W. Hickey, M.L. Vickers, and P.A. Ryan. 1992. Effects of clay discharges on streams. Hydrobiologia 248: 235-247.
Rahel, F.J. 2002. Homogenization of freshwater faunas. Annu. Rev. Ecol. Syst. 33: 291-315.
Sauter, G. and H. Güde. 1996. Influence of grain size on the distribution of tubificid oligochaete species. Hydrobiologia 334: 97-101.
Schälchli, U. 1992. The clogging of coarse gravel river beds by fine sediment. Hydrobiologia 235/236: 189-197.
Shao, M., Z. Xie, L. Ye, and Q. Cai. 2006. Changes in the benthic macroinvertebrates in Xiangxi Bay following dam closure to form the Three Gorges Reservoir. J. Freshwater Ecol. 21: 717-719.
Shao, M., Z. Xie, L. Ye, and Q. Cai. 2007. Monthly change of community structure of zoobenthos in Xiangxi Bay after impoundment of the Three Gorges Reservoir, China. Front. Biol. China 2: 229-234.
Straškraba, M. and J.G. Tundisi. 1999. Guidelines of lake management (volume 9): reservoir water quality management. International Lake Environment Committee.
Taguchi, S. 1982. Sedimentation of newly produced particulate organic matter in a subtropical inlet, Kaneohe Bay, Hawaii. Estuar. Coast. Shelf Sci. 14: 533-544.
Vinueza, L.R., G.M. Branch, M.L. Branch, and R.H. Bustamante. 2006. Top-down herbivory and bottom-up El Niño effects on Galápagos rocky-shore communities. Ecol. Monogr. 76: 111-131.

Vos, J. H., P. J. van den Brink, F. P. van den Ende, M. A. G. Ooijevaar, A. J. P. Oosthoek, J. F. Postma, and W. Admiraal. 2002. Growth response of a benthic detritivore to organic matter compositon in sediments. J. N. Am. Benthol. Soc. 21: 443-456.
Williams, D.D. 1978. Substrate size selection by stream invertebrates and the influence of sand. Limnol. Oceanogr. 23: 1030-1033.
Wu, J., J. Huang, X. Han, Z. Xie, and X. Gao. 2003. Three-Gorges Dam – Experiment in habitat fragmentation? Science 300: 1239-1240.
Wood, P.J. and P.D. Armitage. 1997. Biological effects of fine sediment in the lotic environment. Environ. Manage. 21: 203-217.
Ye, L., Y.Y. Xu, X.Q. Han, and Q.H. Cai. 2006a. Daily dynamics of nutrients and chlorophyll *a* during a spring phytoplankton bloom in Xiangxi Bay of the Three Gorges Reservoir. J. Freshwater Ecol. 21: 315-321.
Ye, L., Y.Y. Xu, and Q.H. Cai. 2006b. The spatial and temporal distribution of nitrate and phosphate in the Xiangxi Bay, Three Gorge Reservoir region during the spring bloom period. Acta Hydrobiologica Sinica 30: 75-79.
Yin, H. and C. Li. 2001. Human impact on floods and flood disasters on the Yangtze River. Geomorphology 41: 105-109.
Zeng, H., L. Song, Z. Yu, and H. Chen. 2006. Distribution of phytoplankton in the Three-Gorge Reservoir during rainy and dry seasons. Sci. Total Environ. 367: 999-1009.
Zhou, G.J., Q.J. Kuang, Z.Y. Hu, and Q.H. Cai. 2006. Assessment of algal diversity and water blooms prevention in four tributaries of Three Gorges Reservoir. China Environmental Science 26: 337-341.

Received: 2 August 2007 Accepted: 26 November 2007