Quaternary International xxx (2014) 1–9

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Macroinvertebrate community succession in the Three-Gorges Reservoir ten years after impoundment

Bin Li [a, b], Qing-hua Cai [a, *], Min Zhang [a], Mei-ling Shao [a]

[a] State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, PR China
[b] University of Chinese Academy of Sciences, Beijing 100049, PR China

A R T I C L E I N F O

Article history:
Available online xxx

Keywords:
Secondary succession
Macroinvertebrate community
Seasonal pattern
Inflow discharge
Sedimentation

A B S T R A C T

The Three-Gorges Reservoir (TGR) is one of the world's largest reservoirs, whose ecological effects have attracted much attention. Focusing on the macroinvertebrate community dynamics and its relationship with hydrological factors ten years after impoundment, we provide an overview of the macroinvertebrate community succession in the TGR including determining factors. Pioneer species in the TGR was *Polypedilum scalaenum* while *Nais inflata* became dominant during non-flooding seasons commencing the second impounding year with extremely high relative abundance (up to 97%). An increase of water-level fluctuation range in the third impoundment stage did not significantly alter the steady seasonal pattern of macroinvertebrate community which formed following the second impounding year. MRPP (Multi-response Permutation Procedure) analysis showed significant differences between-season ($A<0.3$, $P < 0.01$) except between summer and autumn ($A = -0.0165$, $P = 0.773$). Macroinvertebrate assemblages were evidently correlated with inflow discharge during flood seasons and water retention time during non-flood seasons. Macroinvertebrate density showed severe reduction in summer following high velocity inflow current, and disappeared in autumn following vast sedimentation. The macroinvertebrate community gradually became reestablished following reduction of inflow discharge and sedimentation and increase of water retention time in winter and spring. Our analyses suggest that macroinvertebrate community in the TGR is regulated by the subtropical monsoon climate, commencing with seasonal cycles of destruction followed by reestablishment.

1. Introduction

The Three-Gorges Reservoir (TGR) was initially impounded in June, 2003. After the water level reached the normal storage level 175 m in October 26, 2010, the TGR became a giant reservoir with a surface area of 1080 km^2, a length of 600 km and a capacity of 3.93×10^{10} m^3 (Huang et al., 2006). The impoundment in the TGR could be divided into three stages, among which the water fluctuation range increased gradually (Fig. 1). The hydrological regime of the TGR accounts for the operational pattern called “storing clear and releasing muddy”. During the flooding season, water level (145 m) is maintained in order to increase capacity for flood, when the reservoir becomes more like a river with a high water velocity and short water retention time and large amounts of sediment discharge. After the flood season, water level rises to 175 m, during which water retention time become longer and water with corresponding minor sediment load is retained in the reservoir (Wang, 2008; Xu et al., 2009a). The Three Gorges Dam (TGD) is located in Sandouping (Yichang, China) within the middle of the Yangtze River whose drainage basin covers an area of 1.8 million km^2, and experiences a subtropical monsoon climate (Chen et al., 2008). Influenced by monsoon activities and seasonal motion of subtropical highs, the annual precipitation and runoff vary significantly seasonally (Jiang et al., 2006). Most precipitation in the TGR area occurs in summer, 40%–50% of the annual total; only about 5% happens in winter (Cai et al., 2010).

The macroinvertebrate environment within reservoir experienced significant changes after impoundment (Hall et al., 1999; Scasso et al., 2001), followed by colonization and succession of organisms (Youngman et al., 1976; Wolfinbarger, 1999; Domingues et al., 2007; Jorcin et al., 2009). Ecologists have studied macroinvertebrate community colonization and secondary succession in newly formed reservoirs (Voshell and Simmons, 1984; Bass, 1992; Ruhí et al., 2010). However, little research on macroinvertebrate

* Corresponding author.
E-mail address: qhcai@ihb.ac.cn (Q. Cai).

http://dx.doi.org/10.1016/j.quaint.2014.06.017
1040-6182/

Please cite this article in press as: Li, B., et al., Macroinvertebrate community succession in the Three-Gorges Reservoir ten years after impoundment, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.06.017

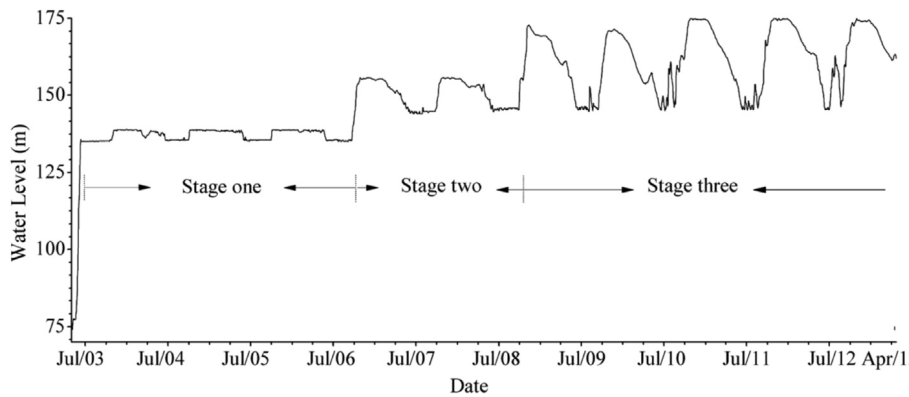

Fig. 1. Water level fluctuation of Three-Gorges Reservoir during ten years (from May 1st, 2003 to April 23rd, 2013.).

community succession within large deep-water reservoirs within a relatively long time scale has been conducted. The Three-Gorges Project (TGP) is the world's largest water-power project, and the TGR is one of the world's biggest reservoirs, whose ecological effect has been attracting much attention (Wu et al., 2003; Cai and Sun, 2012). After impoundment, variations were observed in water physicochemical characteristics (Kuang et al., 2005; Cao et al., 2006), trophic status (Ye et al., 2009; Xu et al., 2011), suspended solid (Xu et al., 2009a), sedimentation (Shao et al., 2008a), phytoplankton community (Ye et al., 2007; Xu et al., 2009b; Wang et al., 2011), zooplankton community (Xue et al., 2006; Zhou et al., 2008), and macroinvertebrate community (Shao et al., 2006, 2008b, 2010; Zhang et al., 2010). However, no systematic research has been conducted on the ecological evolution of the TGR during the ten years since first impoundment stage to the termination of the third impoundment stage. Before impoundment, Borutsky et al. (1959) investigated the macroinvertebrate community in the unfilled reservoir area. Chironomidae larvae were reported as most common, and Naididae was collected in some sites, while Tubificidae were rare. In addition, other taxa including larval Ceratopogonidae were also reported. After impoundment, the macroinvertebrate community within the mainstream of the TGR mainly comprised Naididae, Tubificidae and Chironomidae (Shao et al., 2008b; Zhang et al., 2010). The macroinvertebrate community changed significantly in the first year (Shao et al., 2008b). Evident seasonal pattern had formed since the second year, and this pattern remained during the second impoundment stage (Zhang et al., 2010). During the third impoundment stage, the water level fluctuation range increased from 11 m to 30 m. One purpose of our study was to determine if this fluctuation would have a significant effect on the macroinvertebrate community.

We analyze the evolution of macroinvertebrate community within the mainstream of the TGR and its relationship with hydrological factors during ten years after impoundment in order to reveal the succession rule of macroinvertebrate community within the TGR, and discuss the factors determining this rule. Our results may aid in evaluating macroinvertebrate community succession within other giant deep-water reservoirs.

2. Materials and methods

Two transects (CJ01, CJ04) were selected from routine sites in the long-time monitoring of the “Xiangxi River ecosystem monitoring station of Chinese Academy of Sciences/China Three Gorges Project Corporation”. CJ01 is located upstream of the dam, and CJ04 lies in the upper mouth of Xiangxi Bay. A site was selected on the left, middle, and right of each transect respectively (Fig. 2). A global positioning system (GPS) was used for locating the sites.

Samples were collected seasonally in winter (January), spring (April), summer (July) and autumn (October) with a modified Petersen grab (area 0.0625 m^2) once at each site. 40 surveys were performed during ten years from 2003 to 2013. A 200 μm mesh sieve was used for filtering samples, and materials remaining on the sieve were hand-picked and preserved in 10% formaldehyde. Most taxa were identified to genus or species, and the densities were expressed as individuals/m^2 (ind./m^2). Sampling methods refer to protocols for standard observation and measurement of the Chinese Ecosystem Research Network (CERN) (Cai, 2007). No samples were collected from a few sites due to high water velocity and coarse sediment.

The data of water level and inflow discharge of the TGR were provided by China Three Gorges Project Corporation. Storage capacity computational methods of the TGR at specific water levels are from Xu (2010). Water retention time (WRT) was calculated as:

$$\mathrm{WRT} = \frac{V_T}{Q_T},$$

following the method outlined by George and Hurley (2003) where V_T equals average capacity (m^3) of the period T (Day); Q_T represents the average inflow discharge ($m^3\ d^{-1}$) of the period T (Day).

Diversity of the community was evaluated by species richness (R) and Shannon–Wiener diversity index (H'):

$$H' = -\sum_{i=1}^{s} P_i \log_2 P_i$$

$$P_i = N_i/N$$

Where N_i is the density of species i; N is the total density of macroinvertebrates.

As the distance between the two transects (30 km) is negligible compared to the total length of the reservoir (600 km), spatial variation was not taken into account and the mean value of all sites was calculated for analyses. Univariate two-way analysis of variance (SPSS 19.0) was performed with the two hydrological variables WRT, inflow discharge (D) and the six community variables, total density (TD), richness (R), Shannon–Wiener diversity index (H'), relative abundance of Tubificidae (%T), relative abundance of Chironomidae (%C), relative abundance of Naididae (%N)

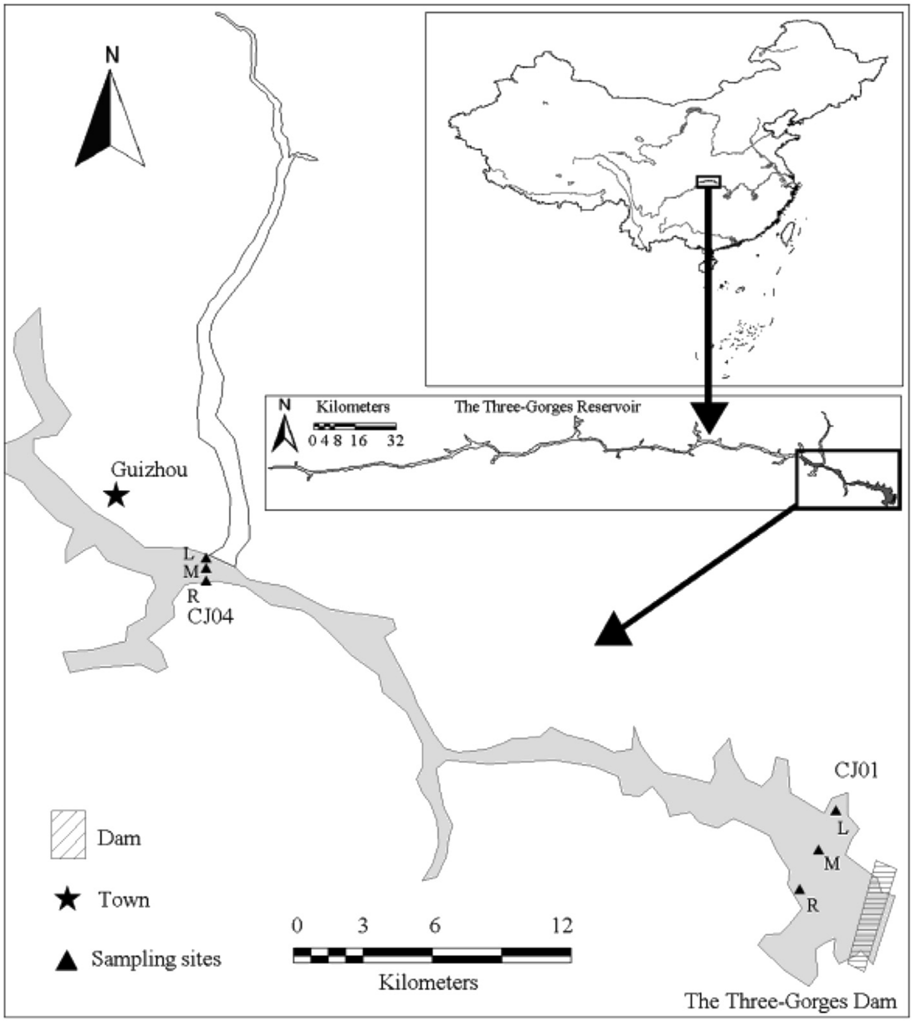

Fig. 2. Distribution of sampling sites in the TGR.

in order to examine the difference of each variable among seasons and the three impoundment stages. To improve the normality and homogeneity, D, TD, R, H', %T, %C and %N were transformed by $\log(y+1)$. If interaction between the two factors (season and stage) was not significant, it was removed from the model. If the among-groups difference was significant, multiple comparisons were performed. LSD (Least Significant Difference) test was carried out only when homogeneity was found. Otherwise, the Tamhane test was performed. Canonical correspondence analysis (CCA, Canoco for Windows 4.5) was conducted to explore the relationship between the hydrological variables and macroinvertebrate community. Five-day mean values of WRT and inflow discharge preceding fifteen days from the sampling day were calculated for variance analyses and CCA (e.g., if sample was collected in July 15th, mean value of WRT and inflow discharge from June 28th to July 2nd was calculated) (Zhang, 2012). Non-Metric Multidimensional Scaling (NMS) ordination was used for grouping all seasons, and Bray–Curtis was selected as the distances measure method. Multi-response Permutation Procedure (MRPP) was conducted for examining specific similarity between groups, which was expressed as *A* (Zhang et al., 2010). As the macroinvertebrate community of the TGR was chaotic in the first impounding year (Shao et al., 2008b; Zhang et al., 2010), the winter of 2005 was taken as the starting point in variance analyses, CCA, NMS ordination, and MRPP analyses. As no macroinvertebrates were collected in the summer of 2012, this season was removed from the CCA, NMS ordination and MRPP analyses, the latter two analyses both performed with PC-ORD 5.0.

3. Results

A total of 49 taxa were collected during the ten years' surveys, and mainly comprised three groups: Chironomidae, Tubificidae and Naididae (Fig. 3). Ten taxa were found in common among the three impoundment stages as follows: *Polypedilum scalaenum*, *Branchiura sowerbyi*, *Limnodrilus hoffmeisteri*, *Nais inflata*, *Stictochironomus* sp., *Teneridrilus mastix*, *Nais variabilis*, *Paranais frici*, *Procladius* sp., *Bothrioneurum vejdovskyanum,* and *Nematoda* spp. *Polypedilum scalaenum* was the most frequent taxon, occurring in 70% of all the 40 surveys. Other frequent taxa included: *B. sowerbyi* and *Procladius* sp., 50%; *N. inflata* and Nematoda spp., 45%; *T. mastix*, 37.5%; *Stictochironomus* sp., 35% and *L. hoffmeisteri*, 32.5%.

Polypedilum scalaenum was the pioneer species of the TGR. The pioneer community lasted for half a year until the spring of 2004, when other taxa became established. The community makeup in the following year was labile, as the dominant taxon changed. After that, *N. inflata* was always the dominant species in the spring macroinvertebrate community commencing in 2005. In winter,

Please cite this article in press as: Li, B., et al., Macroinvertebrate community succession in the Three-Gorges Reservoir ten years after impoundment, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.06.017

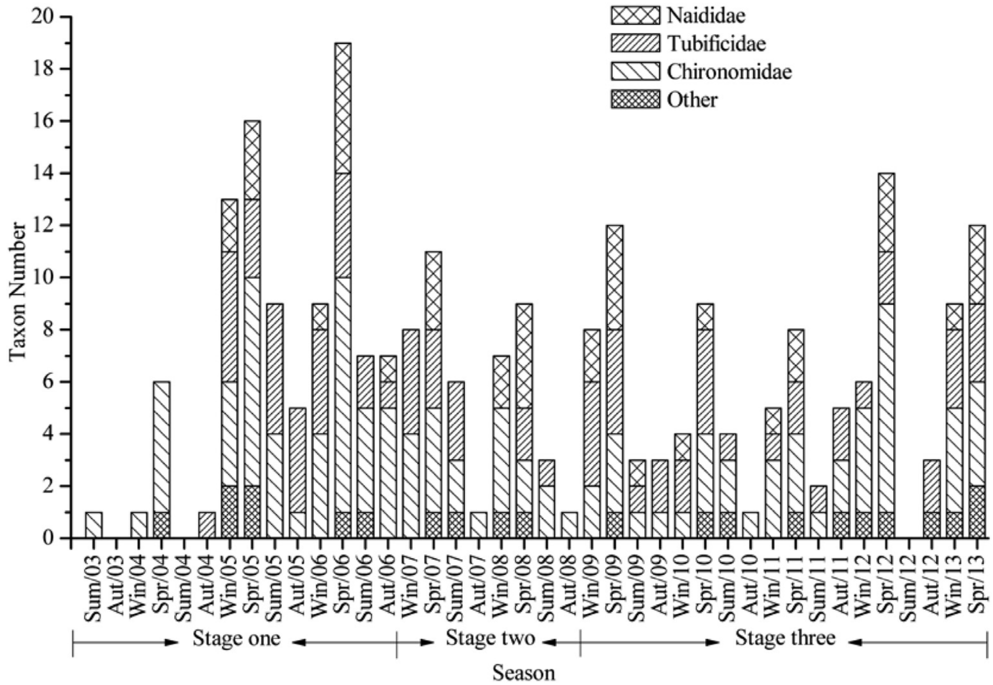

Fig. 3. Taxon composition of macroinvertebrate community in each season.

Polypedilum scalaenum was predominant from 2005 to 2007, after which they were replaced by *N. inflata* or *Stictochironomus* sp. A stochastic dynamic was presented in the evolution of the community in summer and autumn (Table 1, Fig. 4).

variables showed significant differences among seasons, while only WRT, R and H' showed significant differences among stages. WRT significantly increased while R noticeably decreased in the subsequent two stages compared to the first stage. H' exhibited a significant difference between the first two stages. Significant differences occurred among all variables between summer and spring but not between summer and autumn. Community variables were significantly different between winter and spring, but not hydrological variables. All variables except *H*&prime represented significant differences between spring and autumn. (Table 2)

Table 1
Dominant species of each season during the ten years after impoundment.

Season	Dominant species	Relevant abundance (%)	Season	Dominant species	Relevant abundance (%)
Sum/03	*Polypedilum scalaenum*	100	Spr/09	*N. inflata*	81.3
Win/04	*Polypedilum scalaenum*	100	Sum/09	*N. inflata*	45.7
Spr/04	*Tanytarsus* sp.	28.6	Aut/09	*B. sowerbyi*	50.0
Aut/04	*Tubificidae* sp.1	100		*Polypedilum scalaenum*	33.3
Win/05	*Polypedilum scalaenum*	44.3	Win/10	*Stictochironomus* sp.	67.1
	N. inflata	32.1	Spr/10	*N. inflata*	88.4
Spr/05	*N. inflata*	93.8	Sum/10	*Chironominae* sp.2	33.3
Sum/05	*L. hoffmeisteri*	46.7	Aut/10	*Chironominae* sp.2	100
Aut/05	*Polypedilum scalaenum*	64.7	Win/11	*N. inflata*	71.9
Win/06	*Polypedilum scalaenum*	44.9	Spr/11	*N. inflata*	86.0
Spr/06	*N. inflata*	97.7	Sum/11	*Procladius* sp.	66.7
Sum/06	*Procladius* sp.	52.9	Aut/11	*Procladius* sp.	53.1
Aut/06	*Procladius* sp.	68.8		*B. sowerbyi*	30.5
Win/07	*Polypedilum scalaenum*	64.4	Win/12	*Stictochironomus* sp.	42.1
Spr/07	*N. inflata*	91.1		*B. sowerbyi*	21.1
Sum/07	Nematoda spp.	47.1		*Polypedilum scalaenum*	21.1
Aut/07	*Procladius* sp.	100	Spr/12	*N. inflata*	69.9
Win/08	*N. inflata*	90.6		*Polypedilum scalaenum*	19.4
Spr/08	*N. inflata*	96.3	Aut/12	*T. tubifex*	76.9
Sum/08	*Procladius* sp.	81.8	Win/13	*N. inflata*	47.4
Aut/08	*Procladius* sp.	100		Nematoda spp.	24.1
Win/09	*N. inflata*	71.4	Spr/13	*N. inflata*	91.9

In the third impounding year, density and richness of macroinvertebrates achieved a peak in spring, and reached their lowest level in autumn. Seasonal ordination of density and richness was: spring > winter > summer > autumn. This stable seasonal pattern was similar to that of the preceding two impounding stages and was supported by two-way ANOVA and multiple comparisons. All

Please cite this article in press as: Li, B., et al., Macroinvertebrate community succession in the Three-Gorges Reservoir ten years after impoundment, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.06.017

Table 2
Multiple comparisons between variables in Two-Way ANOVA.

		WRT	D	TD	R	H'	C%	T%	N%
Stage one	Stage two	**−11.639**[b]	−0.005	0.244	**0.285**[b]	**0.147**[a]	0.121	0.553	0.148
	Stage three	**−27.697**[b]	0.020	0.392	**0.272**[b]	0.064	0.174	0.184	−0.114
Stage two	Stage three	**−16.058**[b]	0.025	0.148	−0.013	−0.083	0.053	−0.369	−0.262
Winter	Spring	0.793	0.071	**−1.197**[b]	**−0.188**[a]	**0.166**[b]	**0.821**[b]	**0.741**[b]	−0.707
	Summer	**−40.986**[b]	**−0.393**[b]	**0.911**[b]	**0.279**[b]	0.046	0.108	−0.224	**1.038**[a]
	Autumn	**−40.236**[b]	**−0.432**[b]	**0.919**[b]	**0.349**[b]	**0.145**[a]	−0.121	0.079	**1.168**[b]
Spring	Summer	**40.193**[b]	**−0.463**[b]	**2.108**[b]	**0.467**[b]	**−0.120**[a]	**−0.713**[a]	**−0.965**[a]	**1.745**[b]
	Autumn	**39.443**[b]	**−0.503**[b]	**2.116**[b]	**0.537**[a]	−0.021	**−0.942**[b]	−0.662	**1.874**[b]
Summer	Autumn	−0.002	−0.040	0.008	0.070	0.099	−0.229	0.302	0.130

WRT: water retention time (day); D: discharge (10^3 m^3/s); TD: total density (ind./m^2); R: richness; H': Shannon–Wiener diversity index; %C: relative abundance of Chironomidae; %T: relative abundance of Tubificidae; %N: relative abundance of Naididae.
[a] Indicates difference is significant at 0.05 level.
[b] Indicates difference is significant at 0.01 level.

Communities in winter and spring were clearly segregated from those of summer and autumn on the CCA axes (Fig. 5). Macroinvertebrate communities were principally regulated by inflow discharge in summer and autumn, and intensely correlated with WRT in winter and spring. Moreover, the NMS ordination demonstrated that macroinvertebrate community could be grouped by seasons in the third impoundment stage. Taking the three stages into consideration, MRPP analysis demonstrated extremely low but not significant similarity between summer and autumn ($A = -0.0165$, $P = 0.773$), which may be an indicator of stochastic dynamics of macroinvertebrate communities in these two seasons. In sharp contrast, the other between-season differences were all highly significant ($A<0.3$, $P < 0.01$) (Fig. 6).

4. Discussion

4.1. Succession

At the initial stage of reservoir formation that includes sediment and nutrient loading, organic substances in sediment accumulate and provide an abundance of high quality habitat and food for macroinvertebrate biomass (Popp and Hoagland, 1995). Pioneer colonists of a new reservoir are primarily facultative species from streams and ponds inundated by impoundment. Subsequent succession is related to limnophilic species probably from other nearby waters (Voshell and Simmons, 1984; Bass, 1992). *Polypedilum scalaenum* was the pioneer species of the TGR, while *Nais inflata* was dominant in spring and winter, commencing in the second year. Borutsky et al. (1959) reported *N. inflata* as common in the creeks of the TGR, which provided compelling evidence for why *N. inflata* could be prevalent in the macroinvertebrate community before flooding seasons. Generally, after the colonization of pioneer fauna, autochthonous factors begin to regulate succession, and the dominant species shift to other colonizers (Voshell and Simmons, 1984; Bass, 1992). Profiting from the fact that TGR is an almost lotic water system during the flooding season and a lentic water system in the non-flooding season, the facultative species *Polypedilum scalaenum* could be dominant for a long time. Statistical analyses demonstrated a greater variation among seasons than among years since the second year, which indicated that a seasonal

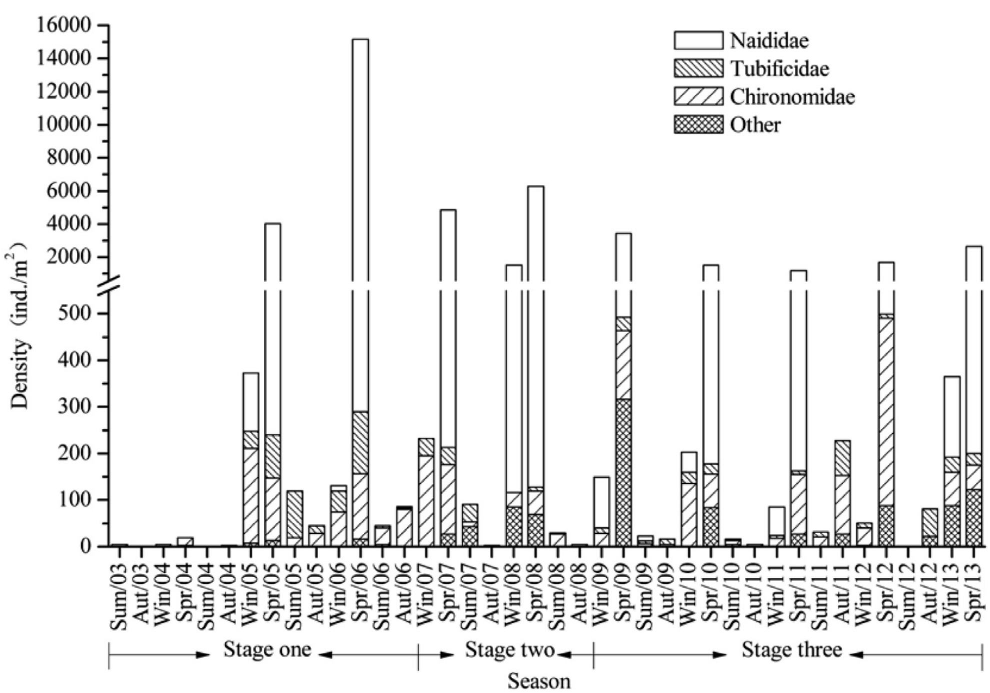

Fig. 4. Density of macroinvertebrate in each season.

Please cite this article in press as: Li, B., et al., Macroinvertebrate community succession in the Three-Gorges Reservoir ten years after impoundment, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.06.017

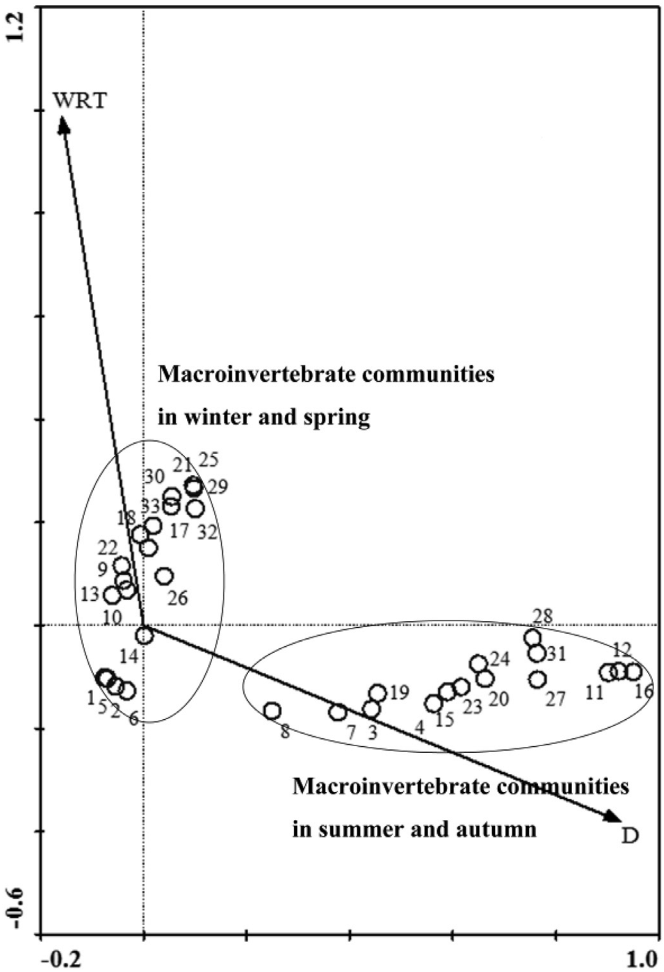

Fig. 5. Distribution of macroinvertebrate communities and hydrological variables on the CCA axes.

pattern was formed in the macroinvertebrate community of the TGR. Hydrological stability and sedimentation are significant factors regulating the secondary succession of macroinvertebrate community in a reservoir (Popp and Hoagland, 1995; Ruhí et al., 2010). Collectively, our results lead to the assumption that water-level fluctuation and sedimentation may be the key factors controlling macroinvertebrate community succession of the TGR.

4.2. Water-level fluctuation

Water-level fluctuation has always been thought to have a considerable effect on macroinvertebrates (Richardson et al., 2002; Wantzen et al., 2008; McEwen and Butler, 2010). Moderate fluctuation can be beneficial to the development of macroinvertebrate communities, whereas intense and sustaining fluctuation may reduce diversity and even destroy the structure of a macroinvertebrate community (Valdovinos et al., 2007; Aroviita and Hämäläinen, 2008; Bond et al., 2008). Water-level fluctuations of the TGR are mainly of two kinds: periodic variation caused by reservoir regulation; and drastic fluctuation within a short time caused by flooding (Figs. 1 and 7). Based on the conclusions of Shao et al. (2008b) and Zhang et al. (2010), along with our results, we outlined the general insights that steady seasonal pattern had been formed since the second impounding year for the macroinvertebrate community in the TGR. In the third impoundment stage, water-level fluctuation range rose by 173% from 11 m to 30 m. Nevertheless, differences among the three stages were not obvious. Periodic fluctuation did not significantly affect the macroinvertebrate community in the TGR. It had previously been confirmed that water-level fluctuation induced by flood in summer had no statistical effect on the macroinvertebrate community in the estuary area of Xiangxi Bay (Zhang, 2012). Intensely influenced by the mainstream of Yangtze River, the macroinvertebrate community in the estuary area of Xiangxi Bay is similar to that in the mainstream of the TGR (Shao et al., 2010). Therefore, these surveys demonstrate that the effects of the drastic fluctuation caused by flooding in summer to the macroinvertebrate community in the TGR were also finite.

4.3. Sedimentation

Sedimentation is also a crucial factor influencing macroinvertebrate communities (Chou et al., 2004; Kaller and Hartman, 2004). Sediment input alters macroinvertebrate habitats, giving rise to changes in community structure (Voshell and Simmons, 1984; Popp and Hoagland, 1995). Sedimentation can severely destroy the macroinvertebrate communities by degrading their food quality (Graham, 1990), impeding their normal ingestion (Cohen et al., 1993; Wood and Armitage, 1997), or even burying organisms (Wood et al., 2005). After impoundment, macroinvertebrate communities of the TGR comprised mainly Chironomidae, Tubificidae, and Naididae (Shao et al., 2008b; Zhang et al., 2010). Owing to their sensitivity to suspended solids, naidids tended to prefer clear water with high transparency and less suspended solids (Shao et al., 2008b; Zhang et al., 2010). Being more tolerant of stress environments (Zhang et al., 2010), tubificids and chironomids have different preferences to habitat. Tubificids can adapt to conditions with fine sediment and rich organic matter (Takamura et al., 2009), while chironomids can accommodate to water disturbance and particle sedimentation (Bazzanti and Seminara, 1987). We suggest that composition and dynamics of macroinvertebrate community in the TGR are closely related to the sedimentation.

Affected by the monsoon precipitation, the runoff within the Yangtze River basin reveals an evident seasonal pattern (Chen et al., 2001; Jiang et al., 2006). Sediment load is strongly correlated with runoff volume in both wet- and dry-seasons (Chen et al., 2001). As a consequence, sedimentation in the Yangtze River shows a significant seasonal pattern with a varying runoff volume (Chen et al., 2008). Chen et al. (2008) reported that about 87% of the sediment transportation took place during May to October. Intercepted by the TGD, a large amount of suspended solid was retained in the TGR (Wang et al., 2007; Ran et al., 2013). Flushed out of the TGR by high velocity currents, the sedimentation attained its maximum in the subsequent two months of the maximal runoff volume period (Chen et al., 2001), which took place during the flooding season (June to August). Consequently, the most severe sedimentation occurred at the end of the flooding season (September to October).

Significant correlations were revealed between inflow discharge and community variables (Zhang et al., 2010). As displayed in the variations of macroinvertebrate community in the TGR, total density and richness always reached their peak in spring, rapidly decreased in summer, degraded to their lowest level in autumn, and rose again in winter (Figs. 3 and 4). In winter and spring, due to inflow discharge and sediment load reducing, with water retention time increasing as well as water disturbance lessening, optimal habitats were formed within the TGR, which resulted in the expansion of the macroinvertebrate community. In summer, exposed to the drastic disturbance caused by the high velocity current carrying a large amount of sediment, the density of Naididae declined dramatically (Shao et al., 2008b; Zhang et al., 2010),

ARTICLE IN PRESS

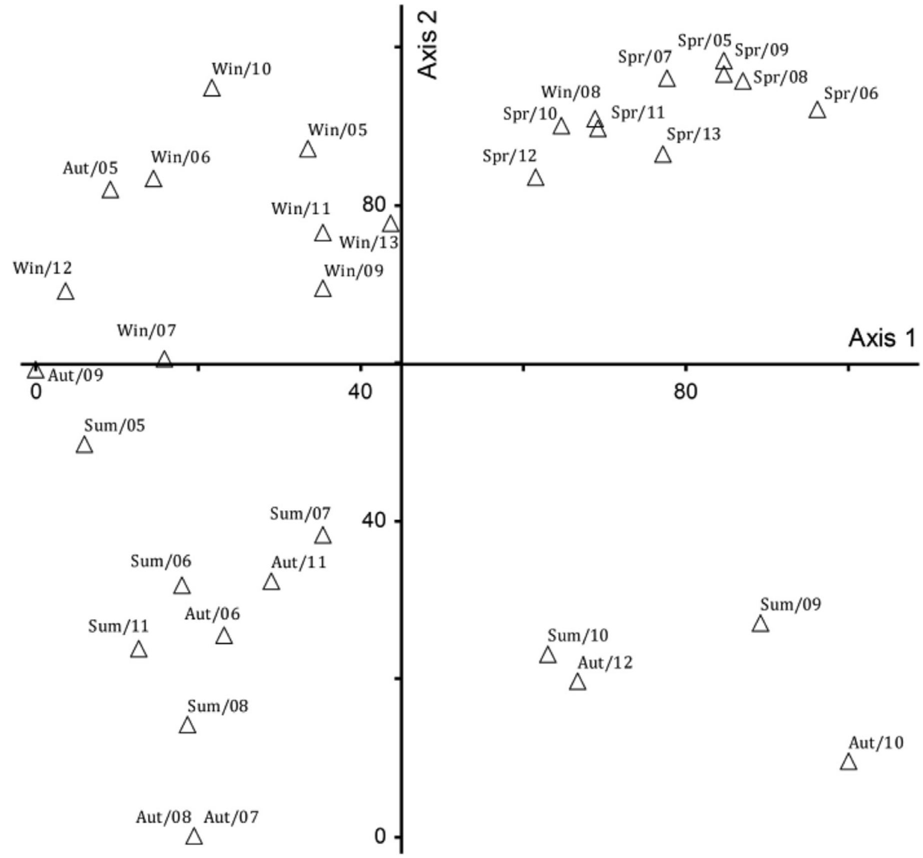

Fig. 6. Results of NMS ordination.

whereas some tolerant tubificids and chironomids survived (Zhang et al., 2010). This explains why richness sustained a relatively high level in spite of the intense decrease of total density. In autumn, total density and richness were lowest, likely due to sedimentation in the TGR. At the end of flooding season, the TGR began to store water. As water-level rose, flow velocity decreased and water retention time became longer. Sedimentation in the TGR was peak in autumn (Chen et al., 2001). The vast sedimentation buried the macroinvertebrates (Wood et al., 2005), and destroyed the community. As a consequence, macroinvertebrate abundance in

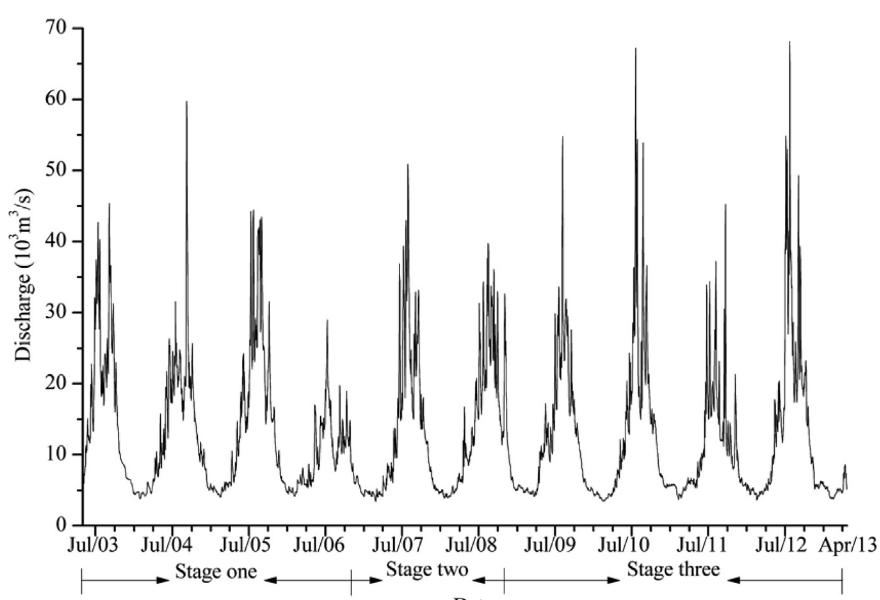

Fig. 7. Inflow discharge of the TGR from May 1st, 2003 to April 23rd, 2013.

Please cite this article in press as: Li, B., et al., Macroinvertebrate community succession in the Three-Gorges Reservoir ten years after impoundment, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.06.017

autumn was rare, and no individuals were found in some sites especially in the middle transects.

5. Conclusion

Affected by the vast inflow discharge in flood season and the intense sedimentation at the end of flood season, the macroinvertebrate community in the TGR will be destroyed every year. The macroinvertebrate community is destroyed in autumn, gradually reconstructed in winter, and then peaks in spring following by drastic decrease in summer. Inflow discharge and sedimentation ultimately are both determined by the subtropical monsoon climate (Chen et al., 2001; Jiang et al., 2006). An and Jones (2002) found that water quality and longitudinal gradients in Asian reservoirs were regulated by the subtropical monsoon, the influence of which was long-term and relatively steady (An and Park, 2002). Based on all these data collected, it is predictable that macroinvertebrate community in the TGR will retain the seasonal pattern in the future. Nevertheless, the sampling period intervals are too long to predict a specific macroinvertebrate community turnover in a year. Consequently, high-frequency sampling will be necessary for an in-depth study.

Acknowledgements

This work was supported by the Major S&T Special Project of Water Pollution Controland Management (2012ZX07104-002) and State Key Laboratory FEBL Research Grant (2014FBZ03). We would like to thank Xu, Y. Y., Tan, L., Shen, H. L., Zhang, H. Y., Zhang, C. Q., Qu, Y. M., Gu, Y., He, F. Z., Huang, D., Yan, R., Liu, W., for their assistance in the field sampling, and Rosser Garrison (USA) for reviewing this manuscript.

References

An, K.-G., Jones, J.R., 2002. Reservoir response to the Asian monsoon with an emphasis on longitudinal gradients. Journal of Freshwater Ecology 17, 151–160.
An, K.-G., Park, S.S., 2002. Indirect influence of the summer monsoon on chlorophyll–total phosphorus models in reservoirs: a case study. Ecological Modelling 152, 191–203.
Aroviita, J., Hämäläinen, H., 2008. The impact of water-level regulation on littoral macroinvertebrate assemblages in boreal lakes. Hydrobiologia 613, 45–56.
Bass, D., 1992. Colonization and succession of benthic macroinvertebrates in Arcadia Lake, a South-Central USA reservoir. Hydrobiologia 242, 123–131.
Bazzanti, M., Seminara, M., 1987. Environmental stress in a regulated eutrophic lake indicated by the profundal macrobenthic community. Italian Journal of Zoology 54, 261–266.
Bond, N.R., Lake, P., Arthington, A.H., 2008. The impacts of drought on freshwater ecosystems: an Australian perspective. Hydrobiologia 600, 3–16.
Borutsky, E.B., Wang, Q.L., Chen, S.Z., Wang, S.D., Liu, Q.R., Wu, X.W., Ge, M.S., 1959. Hydrobiological survey of the region of the projected dam-reservoir of Three Gorges with propositions for fisheries management. Acta Hydrobiologica Sinica 1.
Cai, Q., 2007. Protocols for Standard Observation and Measurement on Aquatic Ecosystems. Environmental Science Press of China, Beijing (in Chinese).
Cai, Q., Liu, M., He, Y., Zeng, X., Jiang, T. (Eds.), 2010. China Climate Change Impact Report: Yangtze Three Gorges Area. China Meteorological Press, Beijing (in Chinese).
Cai, Q., Sun, Z., 2012. Water environment and aquatic ecosystem of Three Gorges Reservoir, China: progress and prospects. Journal of Lake Sciences 24, 169–177 (in Chinese).
Cao, M., Cai, Q., Liu, R., Qu, X., Ye, L., 2006. Comparative research on physicochemical factors in the front of Three Gorges Reservoir and after the initiate impounding. Acta Hydrobiologica Sinica 30, 12–19 (in Chinese).
Chen, X., Yan, Y., Fu, R., Dou, X., Zhang, E., 2008. Sediment transport from the Yangtze River, China, into the sea over the Post-Three Gorge Dam Period: a discussion. Quaternary International 186, 55–64.
Chen, Z., Li, J., Shen, H., Zhanghua, W., 2001. Yangtze River of China: historical analysis of discharge variability and sediment flux. Geomorphology 41, 77–91.
Chou, L., Yu, J., Loh, T., 2004. Impacts of sedimentation on soft-bottom benthic communities in the southern islands of Singapore. Hydrobiologia 515, 91–106.
Cohen, A.S., Bills, R., Cocquyt, C.Z., Caljon, A., 1993. The impact of sediment pollution on biodiversity in Lake Tanganyika. Conservation Biology 7, 667–677.
Domingues, R.B., Sobrino, C., Galvão, H., 2007. Impact of reservoir filling on phytoplankton succession and cyanobacteria blooms in a temperate estuary. Estuarine, Coastal and Shelf Science 74, 31–43.
George, D.G., Hurley, M.A., 2003. Using a continuous function for residence time to quantify the impact of climate change on the dynamics of thermally stratified lakes. Journal of Limnology 62, 21–26.
Graham, A., 1990. Siltation of stone-surface periphyton in rivers by clay-sized particles from low concentrations in suspension. Hydrobiologia 199, 107–115.
Hall, R.I., Leavitt, P.R., Dixit, A.S., Quinlan, R., Smol, J.P., 1999. Limnological succession in reservoirs: a paleolimnological comparison of two methods of reservoir formation. Canadian Journal of Fisheries and Aquatic Sciences 56, 1109–1121.
Huang, Z., Li, Y., Chen, Y., Li, J., Xing, Z., Ye, M., Li, J., Lü, P., Li, C., Zhou, X., 2006. Water Quality Prediction and Water Environmental Carrying Capacity Calculation for Three Gorges Reservoir. China Water Power Press, Beijing (in Chinese).
Jiang, T., Zhang, Q., Zhu, D., Wu, Y., 2006. Yangtze floods and droughts (China) and teleconnections with ENSO activities (1470–2003). Quaternary International 144, 29–37.
Jorcin, A., Nogueira, M., Belmont, R., 2009. Spatial and temporal distribution of the zoobenthos community during the filling up period of Porto Primavera Reservoir (Paraná River, Brazil). Brazilian Journal of Biology 69, 19–29.
Kaller, M., Hartman, K., 2004. Evidence of a threshold level of fine sediment accumulation for altering benthic macroinvertebrate communities. Hydrobiologia 518, 95–104.
Kuang, Q., Bi, Y., Zhou, G., Cai, Q., Hu, Z., 2005. Study on the Phytoplankton in the Three Gorges Reservoir before and after sluice and the protection of water quality. Acta Hydrobiologica Sinica 29, 353–358 (in Chinese).
McEwen, D.C., Butler, M.G., 2010. The effects of water-level manipulation on the benthic invertebrates of a managed reservoir. Freshwater Biology 55, 1086–1101.
Popp, A., Hoagland, K.D., 1995. Changes in benthic community composition in response to reservoir aging. Hydrobiologia 306, 159–171.
Ran, X., Yu, Z., Chen, H., Zhang, X., Guo, H., 2013. Silicon and sediment transport of the Changjiang River (Yangtze River): could the Three Gorges Reservoir be a filter? Environmental Earth Sciences 70 (4), 1881–1893.
Richardson, S.M., Hanson, J.M., Locke, A., 2002. Effects of impoundment and water-level fluctuations on macrophyte and macroinvertebrate communities of a dammed tidal river. Aquatic Ecology 36, 493–510.
Ruhí, A., Boix, D., Sala, J., Gascón, S., Quintana, X., 2010. Spatial and Temporal Patterns of Pioneer Macrofauna in Recently Created Ponds: Taxonomic and Functional Approaches, Pond Conservation in Europe. Springer, pp. 293–307.
Scasso, F., Mazzeo, N., Gorga, J., Kruk, C., Lacerot, G., Clemente, J., Fabián, D., Bonilla, S., 2001. Limnological changes in a sub-tropical shallow hypertrophic lake during its restoration: two years of a whole-lake experiment. Aquatic Conservation: Marine and Freshwater Ecosystems 11, 31–44.
Shao, M., He, L., Han, X., Xie, Z., Li, D., Cai, Q., 2008a. Seasonal patterns of sedimentation and their associations with benthic communities in Xiangxi bay of the Three Gorges Reservoir, China. Journal of Freshwater Ecology 23, 151–160.
Shao, M., Xie, Z., Ye, L., Cai, Q., 2006. Changes in the benthic macroinvertebrates in Xiangxi Bay following dam closure to form the Three Gorges Reservoir. Journal of Freshwater Ecology 21, 717–719.
Shao, M., Xu, Y., Cai, Q., 2010. Effects of reservoir mainstream on longitudinal zonation in reservoir bays. Journal of Freshwater Ecology 25, 107–117.
Shao, M.L., Xie, Z.C., Han, X.Q., Cao, M., Cai, Q.H., 2008b. Macroinvertebrate community structure in Three-Gorges reservoir, China. International Review of Hydrobiology 93, 175–187.
Takamura, N., Ito, T., Ueno, R., Ohtaka, A., Wakana, I., Nakagawa, M., Ueno, Y., Nakajima, H., 2009. Environmental gradients determining the distribution of benthic macroinvertebrates in Lake Takkobu, Kushiro wetland, northern Japan. Ecological Research 24, 371–381.
Valdovinos, C., Moya, C., Olmos, V., Parra, O., Karrasch, B., Buettner, O., 2007. The importance of water-level fluctuation for the conservation of shallow water benthic macroinvertebrates: an example in the Andean zone of Chile. Biodiversity and Conservation 16, 3095–3109.
Voshell Jr., J.R., Simmons Jr., G.M., 1984. Colonization and succession of benthic macroinvertebrates in a new reservoir. Hydrobiologia 112, 27–39.
Wang, L., Cai, Q.h., Tan, L., Kong, L.H., 2011. Longitudinal differences of phytoplankton community during a period of small water level fluctuations in a subtropical reservoir bay (Xiangxi Bay, Three Gorges Reservoir, China). International Review of Hydrobiology 96, 381–396.
Wang, R., 2008. The Three Gorges Project and ecological environment protection. South-to-North Water Transfers and Water Science & Technology 6, 83–89 (in Chinese).
Wang, Z.-Y., Li, Y., He, Y., 2007. Sediment budget of the Yangtze River. Water Resources Research 43, W04401.
Wantzen, K.M., Rothhaupt, K.-O., Mörtl, M., Cantonati, M., László, G., Fischer, P., 2008. Ecological Effects of Water-level Fluctuations in Lakes: an Urgent Issue. Springer, Berlin.
Wolfinbarger, W.C., 1999. Influences of biotic and abiotic factors on seasonal succession of zooplankton in Hugo Reservoir, Oklahoma, USA. Hydrobiologia 400, 13–31.
Wood, P., Toone, J., Greenwood, M., Armitage, P., 2005. The response of four lotic macroinvertebrate taxa to burial by sediments. Archiv für Hydrobiologie 163, 145–162.
Wood, P.J., Armitage, P.D., 1997. Biological effects of fine sediment in the lotic environment. Environmental Management 21, 203–217.

Please cite this article in press as: Li, B., et al., Macroinvertebrate community succession in the Three-Gorges Reservoir ten years after impoundment, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.06.017

Wu, J., Huang, J., Han, X., Xie, Z., Gao, X., 2003. Three-gorges Dam—Experiment in habitat Fragmentation? Science 300, 1239.
Xu, Y., 2010. Researches on Eutrophication and Spring Phytoplankton Bloom in a Large Reservoir Based on the Concept of Ecological Synchrony — a Case Study from Three-Gorges Reservoir. Institute of Hyrobiology, Chinese Academy of Sciences, Wuhan (in Chinese).
Xu, Y., Cai, Q., Shao, M., Han, X., Cao, M., 2009a. Seasonal dynamics of suspended solids in a giant subtropical reservoir (China) in relation to internal processes and hydrological features. Quaternary International 208, 138–144.
Xu, Y., Shao, M., Han, X., Cai, Q., 2011. Temporal asynchrony of trophic status between mainstream and tributary bay within a giant dendritic reservoir: the role of local-scale regulators. Water, Air, & Soil Pollution 219, 271–284.
Xu, Y., Wang, L., Cai, Q., Ye, L., 2009b. Temporal coherence of chlorophyll a during a Spring phytoplankton bloom in xiangxi Bay of three-Gorges reservoir, China. International Review of Hydrobiology 94, 3656–3672.
Xue, J., Ye, L., Cai, Q., Liu, J., 2006. Variation of Cladocerans from Maoping to Guizhou in the Three Gorges Reservoir before and after impoundment. Acta Hydrobiologica Sinica 30, 58–63 (in Chinese).
Ye, L., Cai, Q., Liu, R., Cao, M., 2009. The influence of topography and land use on water quality of Xiangxi River in Three Gorges Reservoir region. Environmental Geology 58, 937–942.
Ye, L., Han, X., Xu, Y., Cai, Q., 2007. Spatial analysis for spring bloom and nutrient limitation in Xiangxi bay of three Gorges Reservoir. Environmental Monitoring and Assessment 127, 135–145.
Youngman, R., Johnson, D., Farley, M., 1976. Factors influencing phytoplankton growth and succession in Farmoor Reservoir. Freshwater Biology 6, 253–263.
Zhang, M., 2012. Patterns of the Macroinvertebrate Community and the Driving Forces in a Large and Deep Reservoir – a Case Study of the Three Gorges Reservoir. Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan (in Chinese).
Zhang, M., Shao, M., Xu, Y., Cai, Q., 2010. Effect of hydrological regime on the macroinvertebrate community in Three-Gorges Reservoir, China. Quaternary International 226, 129–135.
Zhou, S., Tang, T., Wu, N., Fu, X., Cai, Q., 2008. Impacts of a small dam on riverine zooplankton. International Review of Hydrobiology 93, 297–311.

Please cite this article in press as: Li, B., et al., Macroinvertebrate community succession in the Three-Gorges Reservoir ten years after impoundment, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.06.017