Internat. Rev. Hydrobiol.	**93**	2008	3	297–311

DOI: 10.1002/iroh.200711038

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Research Paper

Impacts of a Small Dam on Riverine Zooplankton

key words: small hydropower plant, in-channel dam, Xiangxi River

Abstract

In order to explore the temporal impacts of a small dam on riverine zooplankton, monthly samples were conducted from November 2005 to June 2006 in a reach of Xiangxi River, China, which is affected by a small hydropower plant. A total of 56 taxa of zooplankton were recorded during the study and rotifers were the most abundant group, accounting for 97% of total taxa, while the others were copepod nauplii and copepod adults. This study indicated that: (1) the small dam in the Xiangxi River study area created distinct physical and ecological conditions relative to free-flowing lotic reaches despite the constrained channel and small size of the dam; (2) the existence of the plant's small dam had a significant effect on the zooplankton community. In long periods of drought or dry seasons the effect of the dam on potamoplankton was more pronounced (*e.g.*, November, February, March, and May). But the downfall or the connectivity of channel appeared to decrease the effect of small hydropower plants on riverine zooplankton (*e.g.*, April). The present observation underscores the need for additional studies that provide more basic data on riverine zooplankton communities and quantify ecological responses to dam construction over longer time spans.

1. Introduction

Zooplankton are commonly referred to as 'passive drifters' based on the accepted notion that they are unable to swim against water currents and are thus transported passively in the horizontal plane by the flow field (WIAFE and FRID, 1996). In comparison to lentic systems, much less is known about the factors structuring zooplankton communities in lotic systems (streams and rivers) (JACK and THORP, 2002). Possible factors regulating plankton biomass in rivers may be physical (light), chemical (nutrient concentrations), hydrological, and biotic. The main factors regulating zooplankton biomass or abundance in lotic water are hydrological factors such as discharge or water residence time and suspended sediment (BASU and PICK, 1996; THORP and CASPER, 2003). Plankton in rivers is only important when residence time allows enough time for growth and reproduction (LAIR and REYES-MARCHANT, 1997). However, several studies suggest that zooplankton in river systems occupy an important status in food webs, contributing to secondary production and enabling flow of energy from algal primary producers to higher trophic levels (*e.g.*, MWEBAZA-NDAWULA *et al.*, 2005).

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1434-2944/08/306-297

All parts of a river ecosystem are inter-connected. Any disturbance to one part will create a greater or lesser response over much of the system. For instance, an in-channel dam can disrupt the river's natural course and flow, alter the water temperature, redirect the river channel, stop the migration of fish to spawning grounds, cut the circulation of organic matter and nutrients, increase the fragmentation of habitat with associated isolation of populations (WINSTON *et al.*, 1991), and ultimately disrupt the composition of the river continuity. Ecological connectivity underpins the transfer of materials and products of ecological functions and processes. In aquatic ecosystems, the connectivity is mediated by flows and hydrological linkages (JENKINS and BOULTON, 2003). The flow regime is probably one of the most important factors associated with the abundance of riverine zooplankton (KOBAYASHI *et al.*, 1998). A change in flow regime would theoretically have significant effects on riverine zooplankton.

Hydropower construction and operation are associated with a number of serious environmental problems: water diversion, interruption of fish migration, hydropeaking, reservoir flushing, inundation of landscapes, and alterations in bio-geochemical cycling (TRUFFER *et al.*, 2003). As a consequence, the impact of dam construction and flow diversion are receiving increasing attention (BENSTEAD *et al.*, 1999). More and more effort has been directed towards research on the impacts of dams on aquatic systems. However, most studies have focused on aquatic plants, macroinvertebrates, fish and stream chemistry (OŤAHEĽOVÁ and VALACHOVIČ, 2002; CUMMING, 2004; SHARMA *et al.*, 2005; THOMSON *et al.*, 2005; VELINSKY *et al.*, 2006) and studies on riverine zooplankton are few. Zooplankton is sensitive to environmental changes and is an important bioindicator (SLÁDEČEK 1983). The present study aims to examine: (1) the species composition and the seasonal variation in zooplankton community in a stream that is heavily fragmented by a small hydropower dam and water abstraction for electricity production, and (2) whether there were any negative or positive downstream effects of a small hydropower plant on riverine zooplankton communities.

2. Materials and Methods

2.1. Study Area and Sites

Xiangxi River, a sixth-order river, originating from the Shennongjia Forest Region, is an important tributary of the Yangtze River, China. It has a length of 94 km, with a catchment area of 3,099 km^2, and a natural fall of 1540 m from the headwaters to its confluence with the Yangtze River at Xiangxi River Mouth. Therefore, many small hydropower stations were built within the watershed.

When water discharge is low, from October to June, the flow regime of this river is changed by the small drawing dams of small hydropower plant and some segments of the river dry up. During this period the upstream of the dams is a lotic habitat but the downstream of the dam becomes a small lentic pool. Therefore, riverine zooplankton is segregated by the dam. However, during high flows, river water flows over the dam and the downstream of the dam shifts from a lentic to lotic habitat and riverine plankton is connected again.

In this article, we quantitatively assess whether there were any negative or positive downstream effects of a small in-channel dam on riverine zooplankton. We selected a section of Xiangxi River for the research, where five sampling sites were selected: two sites (S1 and S2) located upstream of the abstraction for a small hydropower plant; the third site (S3) was just below the dam which became a billabong because of the water abstraction in case of low flows; but it could be inundated again in the rainy season (*e.g.*, in April sampling); the fourth site (S4) was just at the upstream of the inflow of used water back into stream, while the fifth site (S5) was mounted below the inflow of used water back into stream (Fig. 1). Here, the distance between S1 and S2 is about 50 m; the distance between S2 and S3 is about 30 m, the distance between S3 and S4 is about 4 km; the distance between S4 and S5 is about 80 m. We hypothesized that the structure and composition of zooplankton communities at S1 and S2

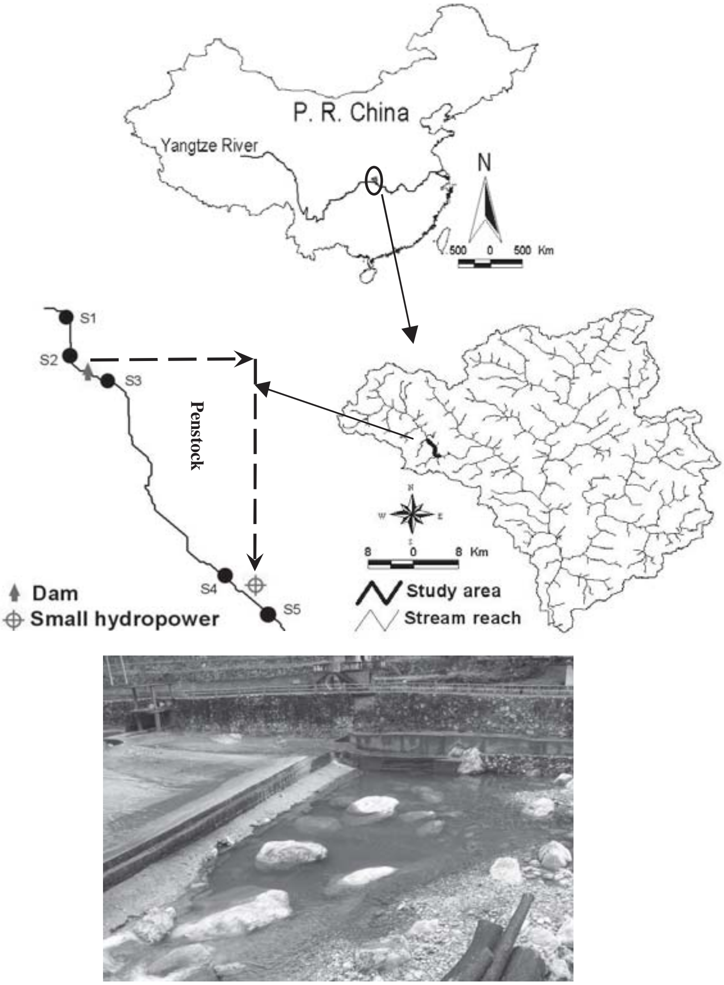


Figure 1. The location of Xiangxi River in China (top), the small hydropower plant and the sampling sites in Xiangxi River (middle) and the picture of S3 (bottom).

would be similar or the same; and the zooplankton community in S3 would similar to those at S1 and S2 because of the short distance between them if there was no dam (Fig. 1).

2.2. Sampling Methods

From November 2005 to June 2006, monthly zooplankton samples at the five sites were collected. At each site and on every sampling date, three replicate samples of 20 L stream water were taken with a 5 L sample bottle. Immediately after sampling, the water was filtered through a 30 μm mesh netting and the retained organisms were fixed in non-acetic Lugol's iodine solution. Forty eight hours later, the undisturbed water samples were concentrated to about 50 mL and preserved with 4% formalin. Concurrently, the following parameters including water temperature (WT), conductivity (Cond), turbidity (Turb), dissolved oxygen (DO), and total dissolved solid (TDS) were measured *in situ* with a Horiba multimeter (U23), while the current velocity was measured by a LJD water current meter. For chlorophyll *a* determinations, three replicate samples of 1.5 L surface water were filtered through WHATMAN GF/C glass-fiber filters and in the laboratory, chlorophyll *a* was determined spectrophotometrically after acetone extraction according to APHA (1992). In addition, live rotifers were examined to obtain qualitative information about the soft-bodied species which are difficult to identify and easily overlooked in preserved samples. Because of the low abundance of riverine zooplankton, all individuals of each zooplankton species in each sample were enumerated.

Predominant species were defined as follows: the species whose numbers (biomass) amounts to 20% or more of the total zooplankton (HABERMAN, 1983).

2.3. Data Analyses

Percent similarity index (PSI) was used to compare the community composition of zooplankton between the sampling sites.

$$PSI = 100 - 0.5 \sum [P_{ik} - P_{jk}]$$

Where PSI represents the similarity between communities i and j, and varies from 0.0 to 100, with 100 meaning the two communities have identical composition. P_{ik} and P_{jk} are the proportions of individuals present in communities i and j, respectively, that comprise the k-th species.

PSI is strongly influenced by the most abundant species (REBSTOCK, 2001) and from our study zooplankton was dominated by several categories. Therefore, it was appropriate to apply this index. Unfortunately, there is no statistical method available to test the significance of PSI, so some authors considered the community as similar when PSI was >60% (UCHIKAWA *et al.*, 2002; SCHAEFER *et al.*, 2005).

Rotifers were divided into two categories according to habitat preference as lotic species (benthic species) and lentic species (planktonic species). The Notommatidae, Philodinidae, Colurellidae, Lecanidae and Proalidae were consistently present in the lotic meiobenthos (RICCI and BALSAMO, 2000), while Brachionidae, Synchaetidae, *Trichocerca pusilla* (LAUTERBORN, 1898) and *Filinia minuta* (SMIRNOV, 1928), which were the dominant categories in the downstream Three-Gorge Reservoir (ZHOU *et al.*, 2006; ZHOU *et al.*, 2007), prevailed in the lentic habitat. To detect the species shift of zooplankton community because of the small dam we introduced a P/R index. Here, P presented percent of lentic species (pelagic species) out of total density and R presented percent of lotic species (riverine species) out of total density. If P/R equals 1, it means the lentic and the lotic species were equally important. If $P/R > 1$ lentic species dominated the community and conversely if $P/R < 1$ lotic species dominated the community.

The relative abundance matrix of zooplankton community was used to calculate a distance matrix using Euclidean distances. A dendrogram comparing samples was obtained by Unweighted Pair-Group Method with Arithmetic averages (UPGMA) in cluster analysis (ZÖLLNER *et al.*, 2003). The cluster analysis was conducted by STATISTICA 6.0. In our study, we used parametric analysis of variance and if the parametric analysis assumption was rejected we used nonparametric analysis of variance. All the analysis was conducted by SPSS 11.5. The level of significance was set at $P < 0.05$.

3. Results

3.1. Environmental Factors

From November 2005 to June 2006, the environmental factors changed significantly through time (Friedman test; $df = 7$, $P < 0.05$) (Table 1) and the spatial differences of environmental factors among the five sampling sites were significant as well (Friedman test; $df = 4$, $P < 0.05$). There was significant change of WT, DO and current velocity from S1 and S2 to S3 (Wilcoxon Signed Ranks test; $P < 0.05$), while the other stations were not statistically different (Wilcoxon Signed Ranks test; $P > 0.05$).

Table 1. The temporal variation of the *in situ* environmental factors at the five sites.

	Sites	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
WT (°C)	S1	9.78	9.12	8.09	9.55	11.40	13.40	12.78	17.20
	S2	9.81	9.22	8.14	9.65	11.24	13.57	13.98	17.21
	S3	10.89	9.05	8.46	9.87	12.95	14.11	19.10	18.87
	S4	11.00	9.38	7.60	10.73	11.92	13.51	20.99	22.24
	S5	10.32	9.28	8.59	10.06	11.06	12.25	14.01	17.84
Cond (ms/m)	S1	20.50	25.90	17.90	21.10	28.60	20.40	39.60	17.30
	S2	20.47	24.78	18.40	21.10	20.10	18.70	22.70	16.90
	S3	21.07	25.00	18.60	21.40	21.60	17.60	26.80	17.60
	S4	26.13	30.00	22.20	24.80	25.40	17.90	37.40	20.60
	S5	20.97	24.80	19.00	21.20	20.60	19.10	25.70	17.00
Turb (NTU)	S1	17.97	16.20	10.70	31.30	86.60	171.00	170.00	136.00
	S2	17.33	15.50	11.30	27.00	76.50	160.00	114.00	45.60
	S3	16.97	17.70	10.00	27.60	94.70	57.90	54.60	54.70
	S4	16.17	17.90	–	25.10	10.40	74.30	0.00	15.90
	S5	16.93	14.00	9.60	27.60	–	219.00	14.50	89.30
DO (mg/l)	S1	11.94	11.28	9.51	11.64	10.11	9.09	11.16	10.48
	S2	12.06	11.27	9.83	10.80	10.33	9.08	10.28	10.11
	S3	11.63	10.86	9.30	10.38	10.08	8.62	10.25	8.59
	S4	11.89	11.88	9.33	11.65	9.47	9.47	8.95	7.42
	S5	11.97	11.10	9.27	11.35	9.92	10.04	9.80	9.27
TDS (g/l)	S1	0.13	0.17	0.12	0.14	0.19	0.13	0.26	0.11
	S2	0.13	0.16	0.12	0.14	0.13	0.12	0.15	0.11
	S3	0.14	0.16	0.12	0.14	0.14	0.11	0.18	0.11
	S4	0.17	0.20	0.15	0.16	0.17	0.12	0.24	0.13
	S5	0.14	0.16	0.12	0.14	0.13	0.12	0.17	0.11
Velocity (m/s)	S1	0.62	0.34	0.43	0.44	0.52	0.64	0.54	0.35
	S2	0.51	0.31	0.68	1.05	0.87	1.47	0.82	0.80
	S3	0.00	0.00	0.00	0.00	0.00	1.01	0.00	0.00
	S4	0.22	0.15	0.30	0.47	0.39	0.73	0.56	0.15
	S5	0.58	0.42	0.45	0.79	0.61	0.89	0.65	0.69

Note: – means data absent.

3.2. Impacts on Chlorophyll a

The temporal dynamics of Chl *a* concentration were significant (ANOVA; $df = 7$, $P < 0.05$). The maximal mean value was 0.70 μg/l; the minimal mean value was 0.18 μg/l (Fig. 2). The spatial differences of Chl *a* among the 5 sites were significant in November, February, March, and May (ANOVA; $df = 4$, $P < 0.05$); nevertheless it was not significant in December, January, April, and June (ANOVA; $P > 0.05$). In February and May Chl *a* at S1 and S2 were significantly different from that at S3.

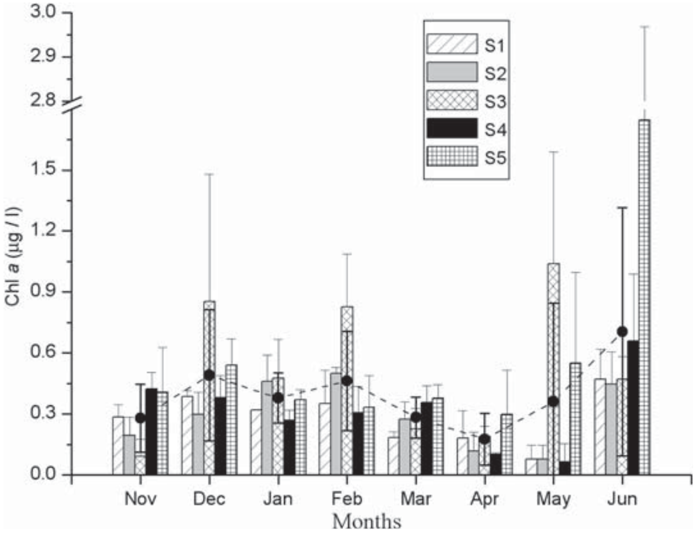


Figure 2. The temporal distribution of Chl *a* concentration among sampling sites, and filled circles were the mean values.

3.3. Taxonomic Composition

A total of 56 taxa of zooplankton were recorded during the study (Table 2). Rotifers were the most diverse group, accounted for 97% of total taxa, the others were copepod nauplii and copepod adults. Although nauplii accounted for no more than 9% of total abundance, they occurred frequently at the sampling sites. As far as the adults were concerned, they belonged to an ephemeral species (a cyclopoid copepod). Most rotifer species were benthic species, belonging to 14 families and 21 genera. Eight predominant species were registered. They were *Philodina erythrophthalma* (EHRENBERG, 1832), *Rotaria tardigrada* (EHRENBERG, 1832), *Colurella adriatica* (EHRENBERG, 1832), *Euchlanis dilatata* (EHRENBERG, 1832), *Cephalodella catellina* (O.F. MüLLER, 1786), *C. intuta* (MYERS, 1924), *Keratella cochlearis* (GOSSE, 1851), and *Polyarthra vulgaris* (CARLIN, 1943). The distributions of various dominant species among the five sites were different: *P. erythrophthalma* occurred at all the sites; except for S3, *R. tardigrada* existed at all the sites; *C. intuta*, *K. cochlearis* and *P. vulgaris* occurred only at S3 (Table 3). The richness of zooplankton at S3 was significantly higher than that found at the other four sites (Friedman test; $df = 4$, $P < 0.05$).

Table 2. Species of zooplankton collected from the five sites in Xiangxi River.

Species	S1	S2	S3	S4	S5
Keratella cochlearis (GOSSE, 1851)			+++	+	+
Anuraeopsis fissa (GOSSE, 1851)			+		
Brachionus angularis GOSSE, 1851			+	+	+
Brachionus urceus (LINNAEUS, 1758)			+		
Brachionus quadridentatus HERMANN, 1783			+		

Table 2. (continued)

Species	S1	S2	S3	S4	S5
Brachionus calyciflorus Pallas, 1766			+		
Euchlanis dilatata Ehrenberg, 1832	++	++	+	+	++
Lecane inermis (Bryce, 1892)	+				+
Lecane curvicornis (Murry, 1913)	+				
Lecane thienemanni (Hauer, 1938)		+		+	
Lecane cornuta (O. F. Müller, 1786)	+	+	+	+	+
Lecane hamata (Stokes, 1896)				+	
Lecane aculeata (Jalubski, 1912)		+	+	+	+
Lecane elachis (Harring and Myers, 1926)	+	+	+	+	+
Lecane sp.		+	+		
Lepadella triptera triptera Ehrenberg, 1930	+				
Lepadella patella (O. F. Müller, 1786)	+		+	+	+
Lepadella ovalis (O. F. Müller, 1786)	+	+	+	+	+
Lepadella acuminata (Ehrenberg, 1834)	+			+	
Colurella uncinata (O. F. Müller, 1773)	+	+	+	+	+
Colurella unicata bicuspidata (Ehrenberg, 1832)		+	+	+	
Colurella obtusa (Gosse, 1886)	+	+	+	+	
Colurella adriatica (Ehrenberg, 1831)	+	+	+	+	+
Colurella obtusa clausa Hauer, 1936	+	+	+	+	+
Trichotria pocillum (O. F. Müller, 1776)			+		
Trichotria tetractis tetractis (Ehrenberg, 1830)	+		+	+	
Wulfertia ornata Donner, 1943	+	+	+		+
Monommata longiseta (O. F. Müller, 1786)		+	+	+	
Notommata cyrtopus Gosse, 1886	+		+		
Metadiaschiza trigona (Rousselet, 1895)				+	
Monommata grandis Tessin, 1890		+	+		
Cephalodella catellina (O. F. Müller, 1786)	+	++	+	+++	+
Cephalodella exigua (Gosse, 1886)	+	+	+	+	+
Cephalodella apocolea Myers, 1924		+	+		
Cephalodella gibba (Ehrenberg, 1838)	+	+	+	+	+
Cephalodella evabroedae De Smet 1988		+			
Cephalodella doryphora Myers, 1934	+	+			
Cephalodella carina Wulfert, 1959		+			
Cephalodella sp.	+	+	+	+	+
Cephalodella megalocephala (Glasscott, 1893)	+	+			
Cephalodella intuta Myers, 1924	+	+	+	+	+
Synchaeta stylata Wierzejski, 1893			+		
Polyarthra vulgaris Carlin, 1943	+		+++		+
Trichocerca insignis (Herrick, 1885)	+				
Trichocerca tigris (O. F. Müller, 1786)	+	+	+		+
Trichocerca similis (Wierzejski, 1893)				+	
Trichocerca porcellus (Gosse, 1886)	+			+	+
Trichocerca pusilla (Lauterborn, 1898)			+		
Trichocerca sp.			+	+	
Scaridium longicaudum (O. F. Müller, 1786)				+	
Filinia minuta (Smirnov, 1928)			+		
Rotaria tardigrada (Ehrenberg, 1832)	++	++	+	+	++
Philodina erythrophthalma (Ehrenberg, 1832)	+++	+++	+	++	+++
Rotaria neptunia (Ehrenberg, 1832)	+				
Nauplius	+	+	+	+	+
Copepod			+	+	+

Note: +: <10%, ++: 10–20%, +++: >20% of the total individuals in the community.

Table 3. The distribution of dominant species and richness.

	S1	S2	S3	S4	S5
P. erythrophthalma	+	+	+	+	+
R. tardigrada	+	+		+	+
C. adriatica		+	+	+	
E. dilatata	+	+			+
C. catellina		+	+	+	
C. intuta			+		
P. vulgaris			+		
K. cochlearis			+		
Mean richness	13.13	12.38	15.63	11.63	10.50

Note: + means dominant species appeared at the site.

Table 4. The temporal dynamics of P/R index in different sampling sites.

Months	S1	S2	S3	S4	S5
Nov	0.00	0.00	0.11	0.00	0.03
Dec	0.00	0.00	0.17	0.00	0.02
Jan	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	3.99	0.07	0.00
Mar	0.09	0.00	1.40	0.00	0.00
Apr	0.00	0.00	0.01	0.07	0.12
May	0.00	0.00	3.02	0.00	0.00
Jun	0.00	0.00	0.04	0.00	0.00

When S3 became a billabong, planktonic species of zooplankton occurred and dominated the community. However, in other sites it still were the riverine species that dominated the zooplankton community (Table 4). From S1 and S2 to S3 there was a strong shift of zooplankton species composition in February, March and May, when planktonic species were a higher proportion at S3 compared to the other sites where riverine species were proportionally more important.

Table 5. The PSI similarity between the sites in different months.

	Nov	Dec	Jan	Feb	Mar	April	May	Jun
S1 & S2	76.66	81.20	84.86	88.40	68.56	90.48	91.96	71.54
S1 & S3	51.71	28.69	51.16	6.66	15.61	85.17	17.06	38.07
S1 & S4	61.37	45.73	69.96	57.45	51.17	77.33	50.99	36.33
S1 & S5	83.15	75.72	83.58	60.36	65.77	83.92	54.41	81.40
S2 & S3	51.67	26.71	61.24	7.01	1.72	86.90	18.27	54.53
S2 & S4	63.89	42.86	76.92	54.03	79.55	74.76	57.24	47.27
S2 & S5	72.33	86.41	72.91	68.06	89.05	88.59	59.68	72.72
S3 & S4	55.77	48.31	74.49	12.68	1.84	78.93	21.24	49.65
S3 & S5	56.32	29.64	50.00	6.50	1.72	83.18	16.05	41.88
S4 & S5	63.86	43.90	68.05	44.22	74.74	79.73	81.23	37.28

3.4. *Impacts on Riverine Zooplankton*

3.4.1. *Percent Similarity Index (PSI)*

The PSI values between S1 and S2 were high (Table 5), all the values were >60%, which indicated that the zooplankton community was similar between the two stations. Although there was a long distance between S1, S2, and S5 (>4 km), the zooplankton community at S5 was similar to those at S1 and S2. However, the PSI values between S3 and S1, S2 (a short distance among them), respectively, were low, which suggested that the small dam had an important impact on the zooplankton community composition. The PSI values between S4 and the other four sites were intermediate.

3.4.2. *Zooplankton Density*

The difference of zooplankton density among the sampling sites and the sampling months was significant (Fig. 3). In the temporal dynamics of zooplankton community, the densities changed significantly among the eight sampling months (ANOVA; $P < 0.05$). Tukey HSD Post Hoc multiple comparisons indicated that the density in June was significantly higher than those in the previous seven months.

Except for January zooplankton density among the five sites was significantly different (ANOVA; $P < 0.05$). And apart from November and June, zooplankton density at S3 was significantly higher than those at the other four sites. Tukey HSD Post Hoc multiple comparisons indicated that during the study period there was no difference of zooplankton density between S1 and S2. But the difference of zooplankton density between S3 and S1, S2, respectively was significant in December, February, March and May.

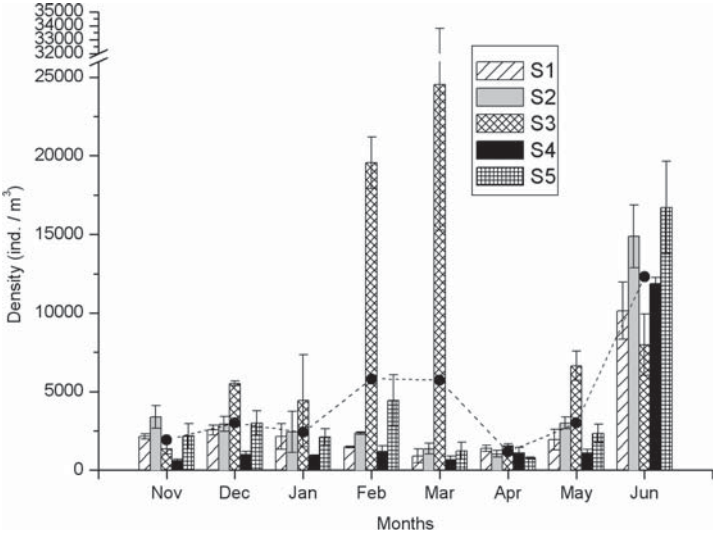
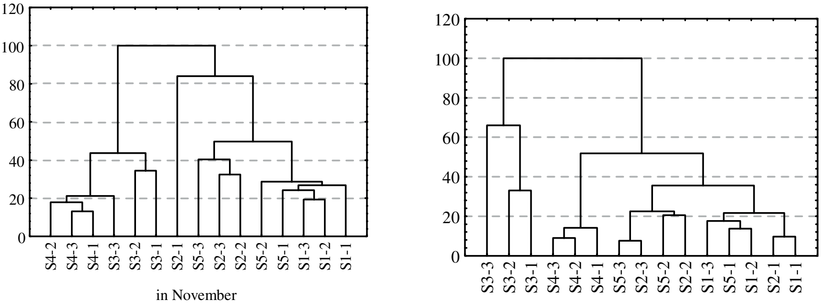
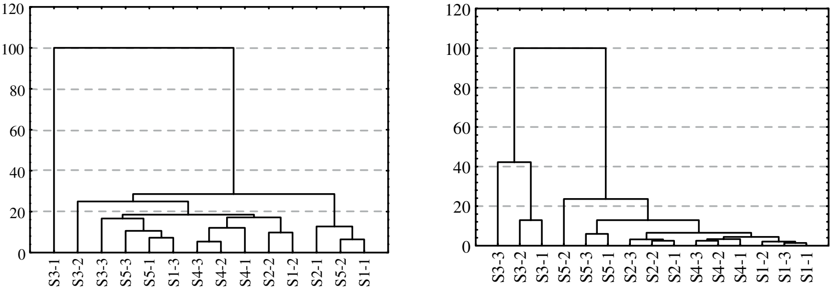


Figure 3. The temporal distribution of zooplankton density among sites, and filled circles were the mean values.



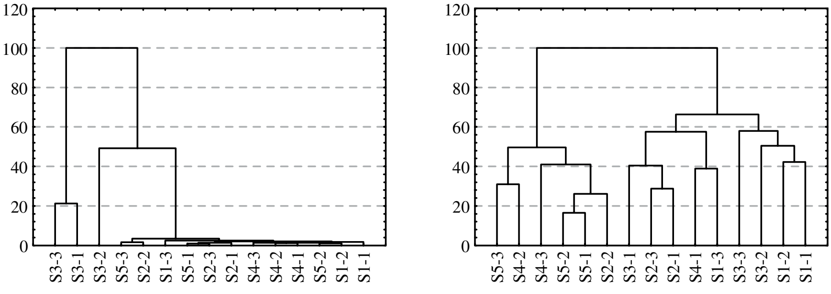
in November

in December



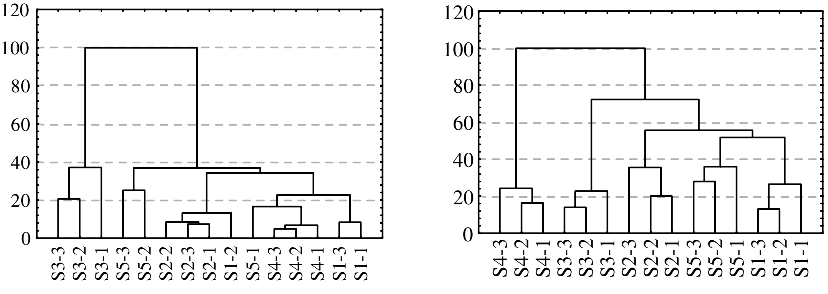
in January

in February



in March

in April



in May

in June

Figure 4. Cluster analyses of the sampling stations (S1–S5) according to month, based on the rotifer species composition and abundance.

3.4.3. *Cluster Analysis*

To explore the distinction among the five sites, cluster analysis was used. Figure 4 presented the graphical results of the cluster analysis based on the species composition and abundance. Except for January and April, S3 was distinct from S1, S2 and S5. S4 was in the midst between group 1 (S1, S2, and S5) and group 2 (S3).

4. Discussion

4.1. *Taxonomic Composition*

Like other studies (Basu and Pick, 1996; Basu and Pick, 1997; Kobayashi *et al.*, 1998; Schmid-Araya, 1998; Reckendorfer *et al.*, 1999; Thorp and Mantovani, 2005), this study showed that in Xiangxi River rotifers species dominated the zooplankton community and benthic rotifers were among the most species rich taxa; large zooplankton taxa (cladocerans and copepods) tended to be much less species rich. As expected the overall density of zooplankton was low: the maximum density was no more than 24,533 ind./m^3, which occurred in the sampling site with no detectable current velocity (S3) and was much lower than the downstream reservoir (Three Gorge Reservoir) (Zhou *et al.*, 2006; Zhou *et al.*, 2007). In Xiangxi River zooplankton was dominated by rotifers, which was likely caused by the short residence time (high current velocity).

One of the most important factors structuring zooplankton community is water residence time. Among rivers, there is often a positive relationship between zooplankton abundance and residence time (Basu and Pick, 1996). Different communities appear to have different responses to water residence times: when water residence time is low to medium, rotifers dominate the zooplankton and when the residence time is long the community is dominated by crustaceans (Baranyi *et al.*, 2002). As residence time is negatively correlated with water discharge or water velocity, potamoplankton biomass has also been inversely correlated with discharge or velocity (Thorp *et al.*, 1994). In Xiangxi River, the current velocity was high – the minimum was 0.15 m/s; the maximum was 1.47 m/s; the mean value was 0.49 m/s (cited from Xingshan Hydrological Survey Station). High current velocities in Xiangxi River were likely the limiting factor for zooplankton reproduction and Ferrari *et al.* (1989) and Reckendorfer *et al.* (1999) also found the same results. According to Rzoska (1978), zooplankton reproduction is unlikely at water velocities >0.4 m/s (Thorp and Casper, 2003). Saunders and Lewis (1989) reported an inverse relationship between egg rations of rotifers and water velocity. The above authors observed no egg-carrying individuals at current velocities >1.5 m/s (Reckndorfer *et al.*, 1999). In Xiangxi River we also found little evidence for offspring of rotifers in samples.

4.2. *Impacts on Hydraulic Changes*

The small dam in the Xiangxi River study area created distinct physical and ecological conditions relative to free-flowing lotic reaches despite the constrained channel and small size of the dam. As expected, dam construction significantly reduced the flow velocity of downstream reach: apart from April when heavy precipitation 1 day before our sampling caused stream discharge to increase to about 12 m^3/s, all the velocities at S3 on other sampling dates were below our limit of detection. These results were consistent with Almodóvar and Nicola (1999) and Parasiewicz *et al.* (1998), and suggest an impact of abstractions on hydraulic changes.

Modifications of hydraulic regimes can indirectly alter the composition, structure, or function of aquatic, riparian and wetland ecosystems through their impacts on physical habitat characteristics, including water temperature, oxygen content, water chemistry, and substrate particle sizes (RICHTER *et al.*, 1996).

4.3. Impacts on Zooplankton Community

In the stream, monogonont rotifers (of order Ploima) contrary to bdelloids are not capable of withstanding high current velocities. Monogononts appear to seek sites with reduced current velocities, *e.g.*, stream pools or the hyporheic zone of gravel streams (SCHMID-ARAYA, 1998). Otherwise, bdelloid rotifers exhibit no clear relationship with current velocity either in moss or surrounding mineral substrates (LINHART, 2002). The present study was consistent with these reports. Bdelloid rotifers were dominant at all the sampling sites, whereas monogononts dominated the community only at the site with essentially no current velocity (S3) (Table 2).

Modifications of the hydraulic regime appear to have induced the significant changes of zooplankton composition from S1 and S2 to S3 in Xiangxi River (Table 2). Physical habitat was considered as a primary factor influencing the structure, composition and diversity of stream faunal communities (LAMMERT and ALLAN, 1999; DOWNES *et al.*, 2000). Many stream organisms ranging from algae and aquatic plants to invertebrates and fish have close associations with the physical habitat, which is mainly determined by flow in streams (BUNN and ARTHINGTON, 2002). In Xiangxi River, because of the construction of a small hydropower plant dam, the flow regime changed significantly from S1 and S2 to S3 within a very small distance (Table 1) and induced sharp changes in the dominant zooplankton species, the P/R index, PSI and density.

Environmental shift from a lotic to a lentic will provide opportunity for some species of periphyton, while destroying the habitat for others (ACREMAN *et al.*, 2000). This was the case for pelagic rotifer species in Xiangxi River which obtained higher densities at S3, on the contrary to benthic species. Experiments found that zooplankton prefer low flow areas such as backwaters, pools and in the benthic boundary layer (RICHARDSON, 1992). These low flow areas are preferred because it is easier to reproduce away from the fast flow (VILA, 1989).

4.4. Cluster Analysis

Based on the results of the cluster analysis, the impacts of the dam on overall riverine zooplankton varied depending on the month. For example, except for January and April, S3 was distinct from S1, S2 and S5. S4 was in the midst of Group 1 (S1, S2 and S5) and Group 2 (S3). This can be explained by two main factors (food resource and change of flow velocity).

As the main component of zooplankton, rotifers were significantly depressed by current velocity only when river discharge was high (THORP and MANTOVANI, 2005). In January, water discharge and current velocity was very low (Table 1). Hence, the depressed effect of velocity would not operate during this sampling time. So in January there was no difference of zooplankton community among the five sites.

In April there was also no difference of zooplankton community among the five sites. The potential reason was that the sample was collected just after heavy precipitation. The water discharge and velocity in Xiangxi River were high and thus zooplankton community in channel was flushed evenly from S2 to S3.

In November, February, March, and May phytoplankton (measured by Chl *a*), which was considered as food resource of zooplankton (ZHOU *et al.*, 2007), was significantly different among the five sites (ANOVA; $P < 0.05$). Therefore, the construction of the dam also had significant effect on plant community.

5. Conclusion

The construction of small hydropower plant dams can bring many environmental changes. However, most changes previously described have focused on aquatic plants, macroinvertebrates, and fish (OŤAHEĽOVÁ and VALACHOVIČ, 2002; CUMMING, 2004; SHARMA *et al.*, 2005), fewer on phytoplankton (WU *et al.*, 2007), and the effects on riverine zooplankton have not been as well documented. Our study showed that the construction of a small dam had a significant impact on potamoplankton. It disrupted the connectivity of riverine zooplankton and facilitated pelagic species development. In long periods of drought or dry seasons the effect of the dam on potamoplankton was more pronounced (*e.g.,* November, February, March, and May). But the downfall or the connectivity of channel appeared to decrease the effect of small hydropower plants on riverine zooplankton (*e.g.,* April).

Further development of a complete set of indicators is needed to address the large impact and potential harm of small dam construction. The present observations underscore the need for additional studies that provide more basic data on riverine zooplankton communities and quantify ecological responses to dam construction over longer time spans.

6. Acknowledgements

Special thanks should be expressed to two anonymous reviewers and HAOQI LI of Massachusetts Institute of Technology and HEN QIAN of the Ohio State University for their constructive comments on the manuscript. We thank WANXIANG JIANG and FENGQING LI for assistance with sample collection. This study was supported financially by the National Natural Sciences Foundation of China (No. 30330140), the National Basic Research Priorities Program (973 Program) (No. 2002CD412310), and the Knowledge Innovation Project of CAS (No. KZCX2-YW-427).

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Manuscript received November 5th, 2007; revised January 11th, 2008; accepted February 28th, 2008