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RESEARCH PAPER

Impacts of small hydropower plants on macroinvertebrate communities

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Abstract: The influence of small hydropower plants (SHPs) on the spatial distribution of macroinvertebrate assemblages was investigated in 5 cascade SHPs along the Xiangxi River in October 2005. 5 sites were sampled at each SHP. A total of 4656 macroinvertebrates belonging to 69 genera were collected. The characteristics of macroinvertebrate community structures were analyzed by using richness, abundance, dominant species and functional feeding groups. The results suggested that construction of SHPs had no significant impact on water chemistry, but on physical variables (such as current velocity and water depth) which varied significantly among the 5 sites. All the characteristics of the macroinvertebrate community were more or less affected by the construction, especially by the abundance, filter-collector percentage, predator percentage, and the stations. The results also suggested that the sites beneath the dam had the most different community structures, indicating that diverting the water current completely is harmful to the protection of macroinvertebrate diversity of the river.

Key Words: macroinvertebrate; community structure; small hydropower plant; Xiangxi River

The mountain river hydropower, which is widely distributed in China especially in most of the rural and mountain areas, is worthy of exploiting. The exploitation has great potential for future development for the following reasons: first, it will accelerate economic prosperity in the undeveloped area; second, it can solve the difficulty in using electricity for local people; third, it can also make profits for investors. Hydropower as renewable energy resource plays an important role in improving ecological condition and protecting environment. In addition, Small Hydropower Plant (SHP) project with low investment, low risk, constant income and low cost was recommended and supported by the State Planning Commission and the Ministry of Water Resources with lots of preferential policies. After 1980s, the Rural Electrification plan (mainly about SHP) and the hydropower project as fuel alternative were carried out. The scale of the SHP project expanded quickly. Although construction of SHPs has brought in great economic interests for people, it has also caused some environmental problems, such as downstream drought by the dams, deterioration of vegetation, and soil and water loss[1]. It has been reported that dams of SHP projects impede the flux of water, sediments, biota and nutrients, and can strongly alter the structure and dynamics of upstream and downstream aquatic and riparian habitats and biota[2]. At present, research on the impact of hydropower plants on the river ecosystem has been mainly concentrated on large hydraulic engineering[3,4], but less on SHPs[5,6]. Thus, carrying out such studies means significantly maintaining sustainable development of the river ecosystem.

Xingshan County is situated in Xiangxi River Basin, which is rich of hydropower. According to the introduction on the Xingshan government web (http://www.xingshan.gov.cn/xqjj.htm), there are 47 SHPs built in Xiangxi River in Xingshan. The average installed capacity and energy output of Xingshan County rank the first among all counties of China. This paper mainly discussed the impact of SHPs on macroinvertebrate communities in order to consummate the management system of environmental protection and supply reference for wholly

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introducing environmental impact assessment systems in river valley reclamation projects.

1 Materials and methods

1.1 Research area and sites

The Xiangxi River, from the Shennongjia Forest region, is a main tributary of the Three Gorges Reservoir in Hubei Province and has a length of 94 km, a catchment area of 3099 km^2, and a natural fall of 1540 m. Gufu River, Gaolan River and Jiuchong River are its three main tributaries[7]. Along these rivers, lots of cascaded SHPs are distributed. Among them, 5 SHPs (named Xiaodangyang (XDY), Qingfeng (QF), Sanduihe (SDH), Cangpinghe (CPH) and Houzibao (HZB), respectively), located on the main stream, were selected for the study. Based on the impact of SHPs, 5 sites in each SHP were chosen for monitoring (Fig. 1).

Site 1 is located about 50 to 100 m above the dam. The river channels are completely in a natural state without being affected by the dam. The main components of the substrates are cobbles and pebbles.

Site 2 is located just in the upstream of the dam, and the habitats in this site change evidently by the dam compared with those in Site 1, where the river width and depth increase, while current velocity decreases a lot. Sediment storage can be seen in this site.

Site 3 is located immediately below the dam where an isolated pool has been formed by overflow erosion in rainy seasons. There is no flow in any drought period. A special type of ecosystem has been formed for lacking of outside input in deep depth.

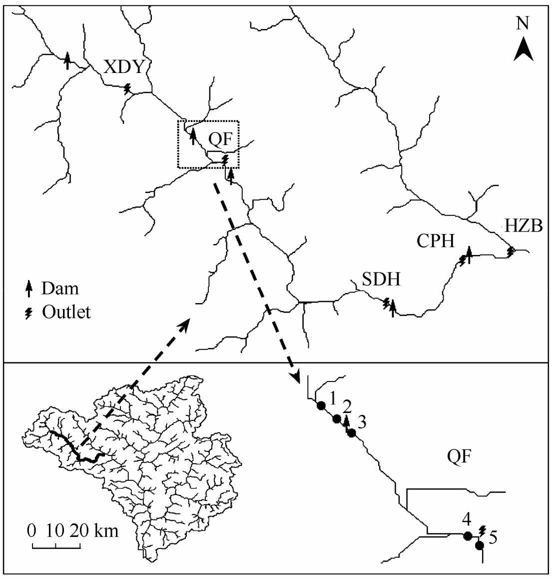

Fig. 1 Location of the sampling sites
XDY, Xiaodangyang station; QF, Qingfeng station; SDH, Sanduihe station; CPH, Cangpinghe station; HZB, Houzibao station

Site 4 is located several kilometers downstream of site 3 and just 50 to 100 m above the outlet of the SHP. Although the dam diverts all the water, the flow is recovered after the water gathers downstream of site 3. Like site 1, site 4 is in a free-flowing state although the discharge decreases because water is transported by the dam at site 2.

Site 5 is located at the outlet of the SHP, where a deep pool is formed by powerful currents discharging from the outlet. The velocity is large and it is deep at the pool center. Around the pool the velocity is much smaller and it is less deep. We mainly sampled in these areas.

1.2 Sampling

Sampling at these 5 sites was carried out in October, 2005. A surber sampler covering 0.09 m^2 area with a net of 250 μm mesh size was used for sampling macroinvertebrates. At each site, 3 replicate samples were taken and combined together in a bottle. All individuals were picked out and kept in 4% formaldehyde in the lab. Then all of them were identified to the lowest identifiable taxon and enumerated. Most of the Insecta, Oligocheata, Gastropoda, Decapoda and Turbellaria were identified to genera or species, while the Hirudinea and Hydracarina were only identified to classes[8,9].

Simultaneously, the physical and electrochemical characteristics of each sampling site were recorded. The site location was set by Turbo-G2 GPS (Topcon). Across each sampling transect, water depth, mean water column velocity (at 0.6× depth from the surface) and substrate composition were recorded. Velocity was measured by an LJD printing current meter. Abiotic factors including pH, DO, temperature (T), conductivity (Cond) and oxidation reduction potential (orp) were measured by HORIBA U-23 (Table 1).

1.3 Data analysis

Similarity analysis among the 5 sites was performed through a hierarchical agglomerative clustering method with the Euclidean distance as the distance measure and with single linkage, based on species composition and individual abundance. All the statistical analysis was carried out by using STATISTICA 6.0.

2 Results and discussion

2.1 Environmental factors

Lots of factors affect distribution of macroinvertebrates such as elevation, velocity, depth, conductivity and pH[10]. The main electrochemical and physical factors are listed in Table 1. More detailed water quality analysis could refer to the study by Ye *et al*[11].

According to Kruskal-Wallis's analysis, it could be found that the entire electrochemical indexes were not significantly different among the 5 sites. However, the same analysis for 3 physical factors showed that except river width, depth (KW-H (4,25) = 11.87, p = 0.02) and velocity (KW-H(4,25) = 16.52, p = 0.002) both had significant difference among the 5 sites.

Table 1 Physical and electrochemical factors of the 5 sites (Mean±SD)

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Mean
pH	7.49±0.28	7.56±0.26	7.53±0.16	7.50±0.15	7.64±0.21	7.55±0.21
Cond (ms/m)	18.7±1.52	18.7±1.32	19.5±1.50	20.3±2.49	19.9±1.73	19.4±1.74
Turb (NTU)	44.9±9.95	48.0±2.80	42.8±4.68	38.2±7.66	40.9±7.02	43.0±7.16
DO (mg/L)	10.07±0.44	9.98±0.39	9.37±0.64	9.72±0.34	9.67±0.35	9.76±0.48
WT (°C)	11.97±0.46	11.95±0.49	12.37±0.64	12.94±0.85	12.6±0.41	12.37±0.67
TDS (g/L)	0.120±0.01	0.120±0.01	0.130±0.01	0.130±0.02	0.130±0.01	0.130±0.01
orp	–187±18.56	–191±18.75	–177±16.16	–169±17.27	–181±26.80	–181±19.73
Velocity (m/s)	0.62±0.25	0.17±0.19	0.00±0.00	0.60±0.24	0.36±0.43	0.35±0.34
Width (m)	20.34±5.06	17.81±11.48	23.43±5.13	8.00±1.91	16.72±6.54	17.00±8.14
Depth (m)	0.43±0.17	0.58±0.17	0.79±0.09	0.53±0.29	0.62±0.30	0.59±0.23

Besides, velocity fluctuated with the sites, which came down among sites 1, 2 and 3, and recovered in site 4. Site 5 mainly decreased again because of our sampling areas chosen in the study. Variation of depth was opposite to that of velocity, and river width had no obvious variation pattern.

According to above results, it could be concluded that constructing SHPs caused little impacts on electrochemical indexes, which was in accord with the result in Cortes' study[12]. However, the physical measures changed significantly because of river channels' deformation. It could be inferred that these changes would play an important role in aquatic insects' construction and distribution.

2.2 Composition and abundance

4656 benthic macroinvertebrates, representing 13 orders, 40 families and 69 genera, were recorded in the sampling. Aquatic insects were the most dominant group and constituted about 90.0% of the total taxa. The dominant taxon was *Baetis* spp., which appeared 100% in the sampling points, and had a high density. The other genera *Dugesia japonica, Epeorus* spp., *Heptagenia* spp. and *Cinygmula* spp. were dominant in some sites. The dominant species in every site (relative abundance > 5%) were listed in Table 2.

Abundance analysis showed that macroinvertebrate density was significantly different in the 5 sites ($F = 4.29$, $p = 0.01$). The mean density in site 4 was the highest. The next was in site 1. The site with the lowest density was site 5 (see Fig. 2). The reason for this difference might be that the flow in site 4 gathered from surface water through downstream channels

Table 2 Relative abundance of dominant species

	Site 1	Site 2	Site 3	Site 4	Site 5	Mean
Baetis spp.	51.99%	23.56%	24.84%	40.13%	30.68%	47.72%
Dugesia japonica	8.04%	20.63%	5.28%		7.11%	10.66%
Epeorus spp.	12.18%					5.49%
Heptagenia spp.			9.80%		5.02%	5.33%
Cinygmula spp.			8.75%			

under the dam, where there were constant and gentle current. It was suitable for macroinvertebrates. Besides, multiple comparison also showed that site 1 and site 4 both were significantly different with site 5, possibly because site 5 was frequently affected by the control of SHPs, which made the habitats change frequently. Only could some species stay with strong tolerance, resulting that site 5 had the lowest density.

Total taxa number (Totalt) and biomass were not significantly different in the 5 sites ($p > 0.05$). But the sites unaffected were much better than the ones impacted by SHPs. For example, the sites with the highest Totalt were sites 1 and 4, and the lowest was site 3. The site with the largest biomass appeared in site 1. The next appeared in site 2. The site with the smallest biomass was site 5 just like the density. The possible reason of high biomass for site 2 was that the dam kept most of the organic matter from upstream. This matter supported high biomass here. Site 5, just the opposite, without much substance supply, was frequently affected by torrents, resulting that site 5 had the lowest biomass.

From the results of Totalt, we could conclude that impacts of SHPs were not significant on the richness of macroinvertebrates. The reasons might be as follows: (1) impacts of SHPs on the river were indeed limited, which could not cause most of the macroinvertebrates to disappear. After all, most of the macroinvertebrates had stronger abilities to fit new habitats[13]. The composition of dominant species in each site and insignificant difference of percentage of dominant species in the 5 sites had also confirmed this point of view. (2) Totalt only considered the total taxa in the site rather than the species composition. Totalt did not vary significantly because when some species disappeared, some other species would also come out. (3) The spatial scale of the study area was not very large and the distances between different sites were even smaller resulting that the different species could diffuse in the whole study area.

Compared with Tatalt, density was more sensitive to environment variation. Most of the species could adapt to a large

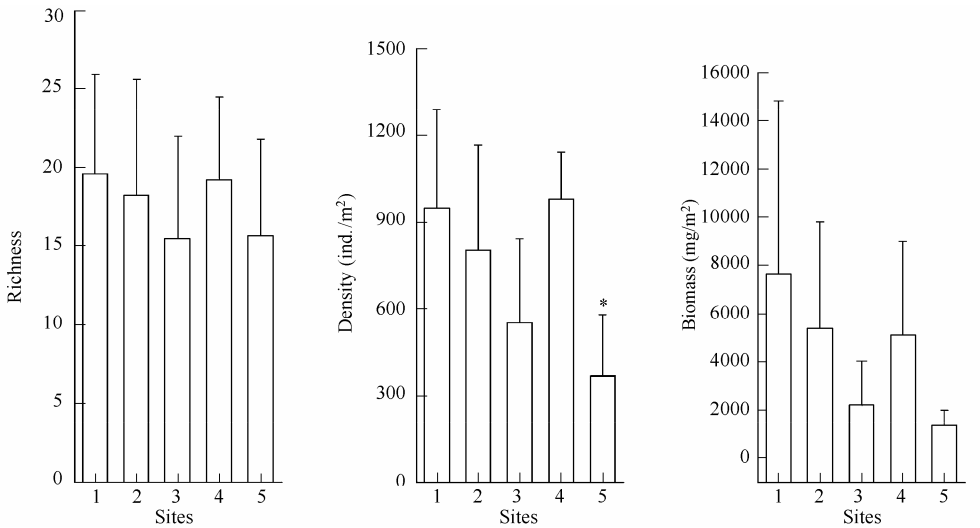

Fig. 2 Richness, density (ind./m²) and biomass (mg/m²) of the 5 sites
* Significantly different from sites 1 and 2.

variety of habitat conditions, such as different velocities, depths and substrates. However, all of them had the most suitable living conditions. For example, Jowett and Richardson's study showed that *Deleatidium* spp. can live in the habitats with a velocity of 1.5 m/s, but the highest density and biomass appear in the habitats with a velocity of 0.7 to 1.0 m/s[14].

These 3 abundance factors (richness, density and biomass) varied in accord with velocity and oppositely with depth, that is to say, Totalt decreased in sites 1, 2, 3, recovered in site 4, but decreased again in site 5 (see Fig. 2). The result could generally infer that the variation of the habitat destruction increased in sites 1, 2, 3, turned back in site 4, but increased again in site 5.

2.3 Function feeding group

Function Feeding Group (FFG) plays an important role in studying composition and function of macroinvertebrate communities[15]. According to the study by Barbour *et al.*[16], macroinvertebrates sampled in these sites could be divided into 5 main FFG groups: Filter-collectors (FC), Gather-collectors (GC), Predators (PR), Scrapers (SC) and Shredders (SH). The dominant FFG was GC and the next was PR.

FFG percentage analysis showed that FC percentage (Filp: KW-H(4,25) = 10.85, p = 0.03) and PR percentage (Prep: KW-H(4,25) = 9.28, p = 0.05) were significantly different in the 5 sites. GC percentage (Gatp) and SH percentage (Shrp) were not. Filp and Gatp had the same variation trends of decreasing in sites 1, 2, 3, recovering in site 4 and then coming down again in site 5. However, Prep and Shrp were opposite (see Fig. 3). Besides, Filp in site 3 was almost zero. Because FC mainly depended on current flow to get food and the current velocity was almost zero in this site. GC didn't vary much as it mainly depended on the organic substance sedimentation to get food. However, high velocity was good for GC to get more food and then get higher composition percentage. Prep was the highest in site 3 because there was no flow disturbance, which might be suitable for PR to get food. On the other hand, most of macroinvertebrates preferring lotic habitats disappeared in site 3. This also leaded to the highest Prep in site 3. According to the River Continuum Concept (RCC), when going down the river, Shrp gradually drops off and Gatp increases[17]. However, in our study, the variation trends of Shrp and Gatp both changed a lot because of the obstruction of substance and energy by the dam. Tang *et al.* also found that in some disturbed channels, river continuum concept had changed, especially in the first 3 classes of rivers[18].

2.4 Composition similarity

From above analysis, we could get the general compositions and constructions of macroinvertebrate communities in each site. The hierarchical agglomerative clustering gave more clear results in describing similarity of macroinvertebrate compositions. Result showed that site 3 had different taxa composition and the other 4 sites had almost the same composition (see Fig. 4A). As for the relative abundance, these 5 sites could be classed into as follows: site 1 and site 4 which were the most similar, site 2 and site 5, and site 3 with the least similarity (see Fig. 4B). Most of macroinvertebrates had the least request for water velocity. When the velocity was below it, these species could not live normally[19,20]. The velocity in site 3 was almost zero, resulting that site 3 had the most different taxa from the other sites. Besides, site 3, barred by the dam, was almost isolated except the time when the flood flows over the dam. However, the other 4 sites were connected with water and macroinvertebrates could diffuse in these sites by water transport or their own moving abilities. Species abundance in each site is closely related with the habitat suitability of the site[14]. From the result, we could conclude that habitats of

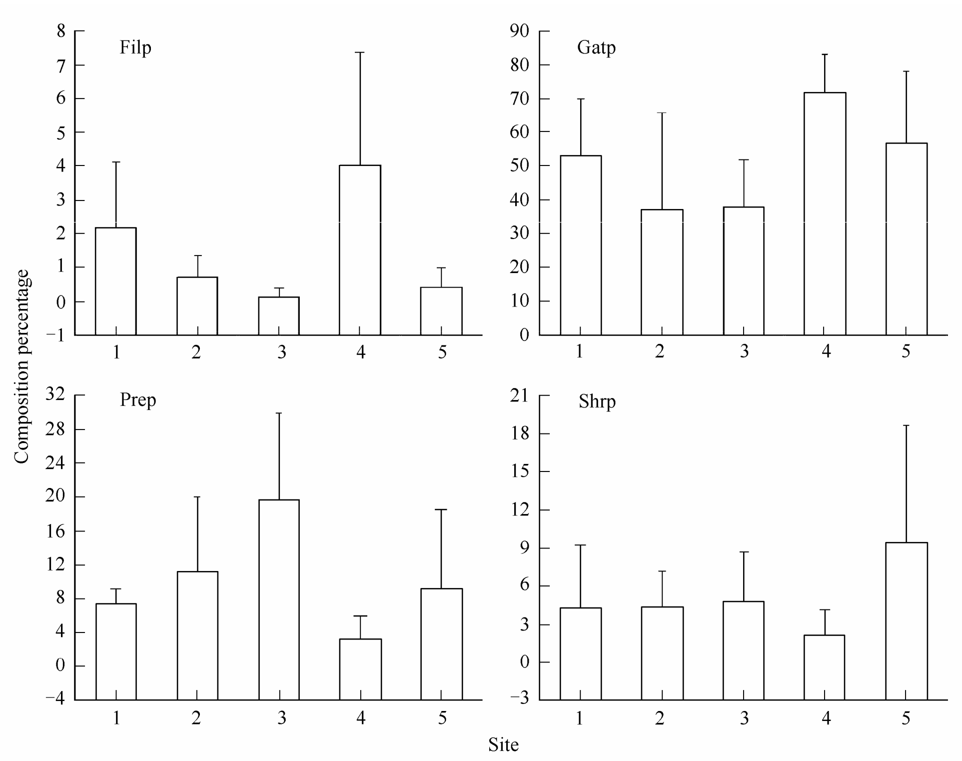

Fig. 3 Composition percentage of FFG among the 5 sites (Filp: Filter-collector percentage; Gatp: Gather-collector percentage; Prep: Predator percentage; Shrp: Shredder percentage)

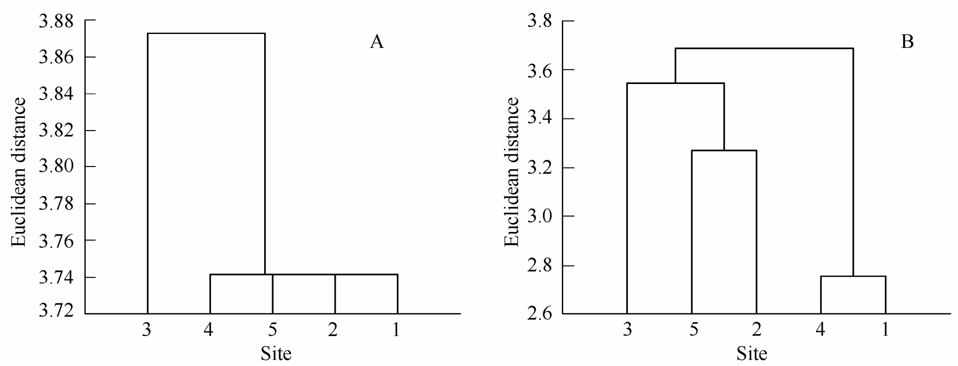

Fig. 4 Hierarchical agglomerative clustering (single linkage) based on taxa composition (A) and average individual abundance (B)

sites 1 and 4 were more suitable than the other sites. These 2 sites were less affected by SHPs and almost kept the natural condition, which were suitable for most of the species sampled in this study, which decided that these two sites had more similar abundance.

At present, there are lots of researches about the minimal ecological water demand[21,22]. From our results on site 3, we were sure that keeping the minimal ecological water demand was important for site 3. It would be the key of future researches. Of course, it should be considered whether this amount of water could keep the lowest destruction on the ecosystem such as the least water velocity so as to make most of the local species here not disappear.

3 Conclusions

This study mainly discussed what the impacts of SHPs were and how they impacted on macroinvertebrates. The results showed that construction of SHPs could have impacts on every aspect of the river ecosystem, especially on the physical factors of rivers because construction of the dam makes river habitats fragmentary. But these impacts on electrochemical factors were not obvious. There were no significant differences in each factor.

As for the variation of macroinvertebrates, its species composition, abundance, dominant taxa and FFG were all more or less disturbed by SHPs. Among them, density and FFG percentage were significantly impacted by SHPs but Totalt and dominant taxa were not.

In view of the sites, impacts of SHPs on each site were not the same. On the basis of community composition and similarity difference, we know that the most impacted site was site 3 and the next was site 5.

This study discussed the negative impacts of SHPs from aspects of river environment and macroinvertebrate community, and provided important information for biological resource protection and rational utilization of water resource. What's more, because macroinvertebrate had obvious temporal pattern, the next step we would consider would be the differences of SHP impacts in different seasons.

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