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Impacts of small bypass plants on water chemical characteristics and macroinvertebrate communities in the Lancang River basin of southwest China

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ABSTRACT

In order to explore the effects of the cascade bypass small hydropower stations (SHSs) on the water chemical characteristics and macroinvertebrate communities, three SHSs in Jingguhe stream of Lancang River basin have been investigated. A total of 50 species were recorded, including 4 mollusks, 5 Oligochaetas, and 41 aquatic insects, and the *Polypedilum* spp. was the dominant species. The results indicated that the construction and operation of SHSs had a significant impact on water velocity and depth but the water chemical characteristics. Some differences in Shannon–Wiener index and species richness were found between the dewatered reaches and the recovered-water reaches. Moreover, in these three SHSs, the density and biomass in recovered-water reaches were higher than in dewatered reaches. The relative abundances of filter collecters, predators, and scraper, as the different functional feeding groups, in mixed discharge sections were significantly higher than in reduced discharge sections for all SHSs. The macroinvertebrates community in dewatered reaches had been subjected to a certain external disturbances.

Keywords: Small bypass hydropower plants; Macroinvertebrate community structure; Water chemical characteristics; Lancang River basin

1. Introduction

Small hydropower (with installed capacity of less than 50 MW), as an important part of the clean energy in China, has provided an important foundation and strong power for the economic and social development in rural areas and played an important role in meeting the demand of national economic increasing energy supply, improving energy structure, and protecting the ecological environment. The technically exploitable capacity of small hydropower in China is estimated as 128 GW, with an average energy generation of 450 TWh/y, which are widely distributed in more than 1,600 mountainous counties around the country. West China accounts for 67.6% of the total capacity, while for Central China and East China, the shares are 16.8% and 15.6%, respectively [1,2]. By the end of 2014, small hydropower stations (SHSs) had possessed an installed capacity of 73 million KW and an annual average generation of more than 2,200 TWh. More than 47,000 small hydropower plants had been built, and more than 700 rural counties

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(about 300 million rural population) had achieved preliminary electrification having departed from the "live without electricity" [3].

Human disturbances, such as river dams and water conservancy dispatches, not only change the hydrological and hydraulic characteristics of rivers, but also have a serious impact on the basic ecological discharge that is a basic guarantee to maintain the normal structure and function of the river/stream ecosystems, and could affect the material transport and energy flow between the upper and lower reaches [4,5]. Hydropower station construction, especially the development of cascade hydropower stations, has caused the fragmentation of river habitats, seriously the destruction of continuity and the integrity of river ecosystems, which would further affect the health of river ecosystems [6]. The construction of the hydropower station will have a certain impact on the entire river basin system, such as river dehydration, vegetation damage, soil erosion, etc., and change the transportation mode of sediments, aquatic organisms, and nutrient salts, which lead to different sediment, shore habitats, and bio-community structures between the upper area and lower area of the dam [7,8]. It has been believed that the drastic changes in river flow caused by the operation of hydropower plants will have a very negative impact on the water ecological environment [9].

Benthic macroinvertebrates, as an important part of aquatic ecosystems, are characteristics of abundant species, wide ecological amplitude, weak avoidance to unfavorable factors [10,11], and reflecting the spatial heterogeneity of environmental factors in river ecosystems [12]. Some studies have shown that changes in river morphology and hydrodynamics could affect benthic community structure [13], and the SHSs construction had a certain influence on the functional groups and community composition of macroinvertebrates and to some extent affected the substance transport and the energy flow under natural conditions in the river systems [14,15]. In addition, SHSs often have been constructed and operated in the form of cascaded hydropower plants, and this might result in water flow reducing or even flow cutoff from the upstream to the downstream of these developed rivers, especially in the non-flood season, which has a great impact on the river's ecological environment. However, there were fewer studies on the effect of cascade hydropower plants on macroinvertebrates. This paper takes the Jingguhe stream in Yunnan province as an example to find out the effects of long-term operation of cascaded small bypass plants on the water chemical characteristics and abundance, biomass, diversity index, and feeding functional groups of macroinvertebrates.

2. Material and methods

2.1. Description of the sites

Jingguhe stream, as one branch of Lancang River basin, originates from Daguangshan mountain, Zhenyuan County, Pu'er City, Yunnan province, with a total length of 85.6 km, a catchment area of 634 km^2, the average annual flow of 2.15 m^3/s, the natural fall of 285 m and flows through the Zhentai country and Jinggu country and then into the Weiyuanjiang River. Eight SHSs have been built and operated in the Jingguhe stream with a total capacity of 0.03 million KW. According to the magnitude of discharge and the water level, the river could be divided into three different sections, a retained-water reaches (RRs), a dewatered reaches (DRs), and a recovered-water reaches (CRs) (Fig. 1). From the upper to the lower reach of Jingguhe stream, I-grade station (I-S), III-grade station (III-S), and V-grade station (V-S) were selected as our research object. The macroinvertebrates were sampled and analyzed in the DRs and CRs of each station, named IS-DRs and IS-CRs, IIIS-DRs and IIIS-CRs, VS-DRs, and VS-CRs, respectively (Fig. 2).

2.2. Sampling programme

Collections of invertebrates were made during the spring 2012, the dry season (from November to April) of Jingguhe stream. In each SHSs, including the I-degrade station, III-degrade station, and V-degrade station, 2–3 samples were taken from the RRs, DRs, and CRs, separately (Fig. 2). For this purpose, we used a Sauber net (S=0.09 m^2, mesh size=500 μm) to quantitatively sample, and each standard sample of biological quality consisted of 2–3 replications. The collected animals were fixed together with sieving residues (debris, sand, and pebbles) in 95% ethanol and quickly transported to the laboratory to sort the live macroinvertebrates. Wherever possible, organisms were identified to species or genus level (the main exceptions being the *Diptera* and *Oligochaeta* groups, which were differentiated only to family or subfamily level) [16,17]. Moreover, water depth and velocity were obtained by means of field monitoring, and water samples were also collected at each sample site and transported to the laboratory to test.

2.3. Statistical analysis

Statistical analyses were executed with SPSS 13.0 (SPSS Inc., Chicago, IL, USA). The data were analyzed through a nonparametric test to detect the effect of the bypass plant on removal efficiencies taking P<0.05 as a significant difference.

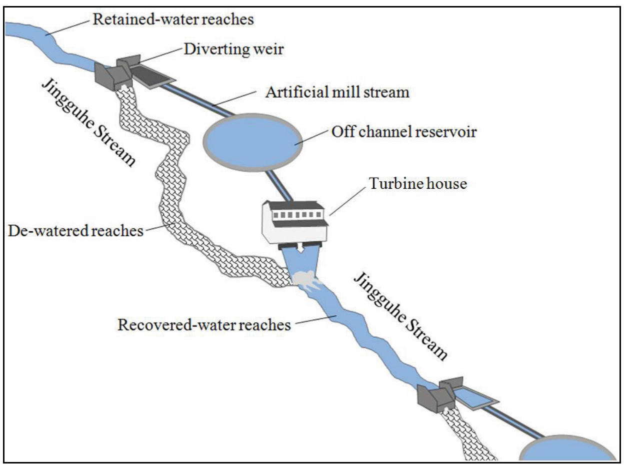

Fig. 1. Scheme of typical bypass-type hydropower stations.

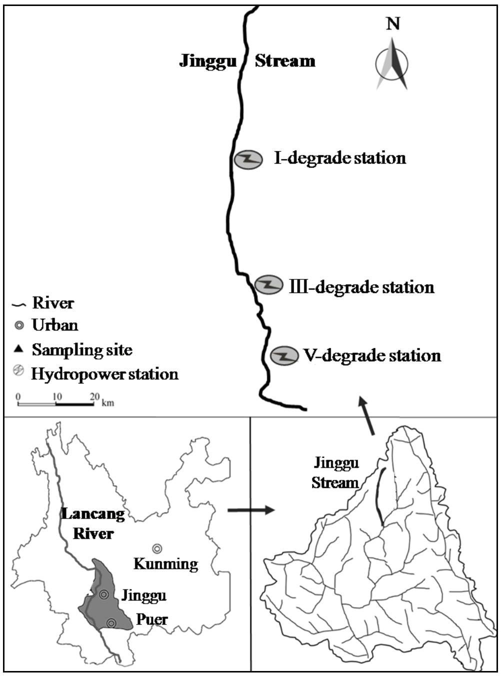

Fig. 2. Location of the sampling sites.

3. Results and discussion

3.1. Effect of SHSs on hydrological and water chemical characteristics

As shown in Fig. 3, due to a small amount of water discharge from RRs, the DRs of IS had a low velocity of 0.42±0.04 m/s. The water velocity and depth of DRs were all lower than those of CRs in all the other degrade stations and the DRs of III-S and V-S have been shrinking and dry ups occurred, which was directly related to the interception of the dam and the sampling season (e.g., lacking of runoff supply in the dry season). The CRs were made up by the effluent of the power station and the discharge from RRs, usually with the characteristics of greater discharge and flow rate. The hydrological characteristics of the river including the flow velocity and water depth have changed because of the construction of SHSs, and this may have an influence on the species, composition, and distribution of the macroinvertebrates. However, the water chemical characteristics of DRs and CRs from different SHSs, including the indexes of total nitrogen (TN), total phosphorus (TP), chemical oxygen demand (COD_{Mn}), and dissolved oxygen (DO), had not been affected significantly by the interception of the dam as listed in Table 1.

3.2. Effect of SHSs on macroinvertebrates community

3.2.1. Predominant species

Altogether 38 taxa of macroinvertebrates were found, including 1 species of mollusks accounted for 2.63%, 2 species of oligochaete accounted for 5.26%, and 35 species of *Arthropoda* (aquatic insects) accounted for 92.1%. The macroinvertebrates of Jingguhe stream were mainly composed by aquatic insects, which were found at every sample site and had higher relative abundance. Among them, the species of aquatic dipteral insects were the most abundant, accounting for 40.0% of all the aquatic insects, followed by *Ephemeroptera*. With the relative abundance ≥5% as the reference for the dominant species, the *Heptagenia* spp. species were the dominant populations with the most frequencies, followed by *Choroterpides* spp. and *Hydropsyche* spp.

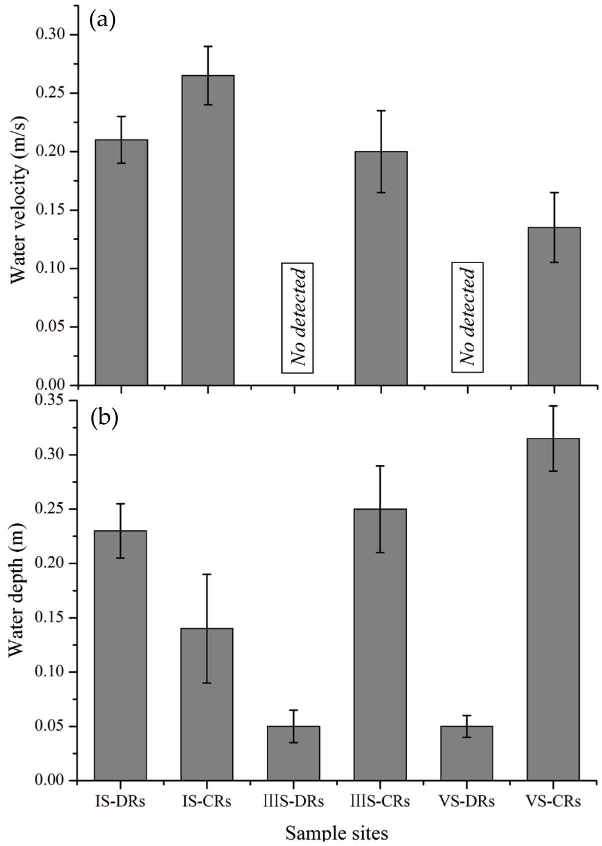

Fig. 3. The water depth and velocity of each sample site.

3.2.2. Biodiversity and taxa

As shown in Table 2, the maximum value of macroinvertebrates species number and Shannon–Wiener diversity index (H') appeared in VS-CRs, with a mean value of 15 and 1.91, respectively. The species number in VS-DRs was as many as that in CRs, yet with a lower diversity. The minimum value of species number and H' appeared in the IS-CRs, 9 and 1.39 on average, respectively. The Kruskal–Wallis test showed that there was no significant difference in species number between DRs and CRs, except that in VS-DRs was significantly higher than in IIIS-DRs ($P<0.05$). In addition, the H' in IS-DRs was significantly higher than that in IS-CRs ($P<0.05$), but there was no significant difference among other reaches. In this survey, it is found that the habitat state in IS-DRs was closer to the natural state where the amount of water was sufficient and the species diversity was also higher. Fu et al. [14] found that SHS construction had not significant influence on the abundance and H' of macroinvertebrates. This could be explained as follows: (i) most kinds of macroinvertebrates have a certain adaptability to the external disturbance [18] and most of them would not disappear in a short timescale under the confined pressure by SHSs and (ii) most DRs were with little flow quantity in the dry season, but there were still some appropriate survival niches for some species as a result of the slope runoff supply (no thoroughly drying up).

3.2.3. Density and biomass

As shown in Table 2, the statistics results indicated that the average density and biomass of macroinvertebrates in CRs were all higher than those in DRs for each SHS, but no significant difference other than that in VS (Kruskal–Wallis test, $P<0.05$). The maximum average biomass of macroinvertebrates was 23.41 g/m^2 in IIIS-CRs, and the lowest was 2.27g/m^2 in VS-DRs. The maximum density of macroinvertebrates was 2,200 ind./m^2 in VS-CRs, and the minimum was 718 ind./m^2 in IIIS-DRs. In addition, the macroinvertebrates biomass presented a decreasing trend from IS to VS. With difference from the variation characteristics of species and diversity mentioned above, the reason for the difference of density and biomass between the two groups could be that (i) the change of macroinvertebrates individuals could be more sensitive to external disturbances than the species number; (ii) the lower reaches of the dam have been shrinking and dried up due to interception by SHS construction, further influencing the habitat features and spatial pattern distribution of macroinvertebrates (flow velocity slowing and the occurrence of the hydrostatic area), which could lead to the transformation of the dominant species from rapid flow type to slow flow type or stagnant water type. For instance, in this study the species enjoying stagnant water, such as *Polypedilum* spp. and *Tanypus* spp. were dominated in the IS-DRs. If the individual size of the dominant species was larger, the biomass of the whole community would be fluctuated.

3.3. Functional feeding groups

The hydropower station construction would affect the species and distribution of available food resources of the macrobenthos and further have an indirect influence on the functional feeding group (FFG) [19]. In order to explore the distribution rule of FFG in different habitats under the influence by SHSs, all the macrobenthos collected from the above samples were divided into six main FFGs, filter collecters (FC), gather collecters(GC), predators (PR), scrapers (SC), shredders (SH), and other groups (OT) based on Barbour et al. [11] and Wetzel [20]. The results (Table 3) showed that GC was predominant group with the abundance of 33.8%, followed by the FC and SH group with the abundance of 27.1% and 23.0%, respectively. The relative abundances of SC, PR, and OT were 11.3%, 4.4%, and 0.5%, respectively.

Comparing the abundance of macrobenthos FFG of different reaches from the same station, the results showed that the SH abundance in CRs was significantly higher than that in DRs but it was opposite for GC, with the abundance in DRs higher than in CRs. For the FC, the abundance of DRs was higher than that of CRs other than I-S. Significant difference of SC abundance between DRs and CRs exsisted in I-S and V-S. It was found that the dam construction could result in a decrease in the abundance of FC and SC in the lower reaches [21], which may be related to the abundance change of *Cinygma* spp, as the major components of the FFG. For the CRs, the PR abundance showed an increased tendency from the upstream

Table 1
Water chemical characteristics of each sample site (mg/L)

Sample sites	TN	TP	COD_{Mn}	DO
IS-DRs	0.14	0.02	1.86	8.40
IS-CRs	0.10	0.02	2.18	5.50
IIIS-DRs	0.16	0.04	2.06	6.60
IIIS-CRs	0.14	0.02	3.47	7.40
VS-DRs	0.18	0.02	1.39	9.40
VS-CRs	0.13	0.03	2.36	7.10

Table 3
The abundance of macroinvertebrate FFG among different sample sites

Sample sites	Relative abundance (%)					
	SC	FC	GC	SH	PR	OT
IS-DRs	12.5	18.1	44.4	21.5	3.5	NF
IS-CRs	3.1	37.0	16.5	42.5	NF	0.8
IIIS-DRs	10.4	65.2	15.6	5.9	3.0	NF
IIIS-CRs	15.9	45.5	8.0	14.8	6.8	9.0
VS-DRs	23.2	14.3	42.9	19.6	NF	NF
VS-CRs	5.5	5.5	37.2	37.2	12.4	2.1

NF, not found.

Table 2
The species number, Shannon–Wiener index, density, and biomass of macroinvertebrates in different sites

Sample sites	Species number	*H'*	Density (ind./m^2)	Biomass (g/m^2)
IS-DRs	12±1	1.93±0.01[a]	1,050±754	7.76±9.62
IS-CRs	9±1	1.39±0.01[a]	1,743±489	15.35±7.26
IIIS-DRs	11±1[a]	1.62±0.17	718±35	3.30±3.59
IIIS-CRs	10±1	1.81±0.49	820±210	23.41±15.12
VS-DRs	15±1[a]	1.90±0.25	1,380±662	2.27±1.57[a]
VS-CRs	15±5	1.91±0.27	2,200±856	8.82±1.16[a]

[a]Significant level at 5% with Kruskal–Wallis test.

to downstream and this might be in connection with the lower reaches having a narrower path and higher flow speed, comparing the upper reaches, which was more favorable to PR predation and survival [22]. For the river/stream, the litter input from the riparian of upper reaches was the main components of energy sources. Thus, the SC relative abundance in the upper reaches was higher than that in the downstream generally and achieved the minimum value in the largest level river [23]. However, in this study, the SC relative abundance from the upstream to downstream of the river (i.e., from I-S to V-S) have not shown a gradual decline, which could be related to the litter input on both riparian zones and the smaller spatial scale of the field investigation.

In order to further investigate the effects of two different habitats, DRs and CRs, on the FFGs of macroinvertebrate, the abundance of FFGs from three DRs and CRs was taken as two independent samples, respectively, to execute the independent sample *T*-test (Table 4). The results showed that the relative abundances of the FC, SH, and PR in CRs were significantly higher than those in DRs ($P<0.05$), while the relative abundances of the GC and SC were lower than in DRs, but the difference was not significant ($P>0.05$). In DRs, the flow rates and velocities were smaller than that in CRs, even drying out, and this could promote to the organic debris depositing, which was beneficial to the food intake and survival of GC. Thus, the abundances of GC in DRs were higher than that in CRs. The food source of SC was mainly derived from the periphyton in substrate-surface habitats, and sufficient illumination and the appropriate water depth could provide appropriate conditions for periphyton growth [24]. Therefore, the higher SC abundances in DRs might be related to its low velocity and high water transparency. However, the FC abundances were mainly dependent on the role of water flow to obtain food, and its abundance was mainly influenced by the flow rate and the availability of food. Consequently, the habitat of CRs could be more suitable for FC to feed and survive.

In summary, the construction of SHSs have blocked the originally natural continuity of the river and led to the fragmentation, especially the emergence of DRs, which have changed various characteristics of the river, such as the flow rate, water depth, composition of the substrate, and distribution and transport of nutrients. Furthermore, the interception by the dam has resulted in the formation of DRs and the FFG in this reaches being different from that in CRs. In the southern region, being rainy and rich in vegetation, the input of organic debris and abundant runoff recharge could undermine the cumulative effect of cascade SHSs on the community structure of macroinvertebrates.

Table 4
The abundance of macroinvertebrate FFG between the DRs and CRs

Sample sites	Relative abundance (%, mean±SD)				
	SC	FC	GC	SH	PR
DRs	15.4±6.9	16.2±2.7[a]	43.7±1.1	20.6±1.3[a]	3.2±0.4[a]
CRs	10.7±7.3	41.2±6.0[a]	26.9±14.6	39.9±3.7[a]	9.6±4.0[a]

[a]Differences were significant at 5% level.

4. Conclusion

In this study, the construction of SHSs has influenced dramatically the hydrological characteristics of river channel but no significant influence on the water chemical characteristics. The rivers/streams have been separated into RRs, DRs, and CRs by the dam interception, resulting in habitat fragmentation and having influence on species composition, biomass, and individual numbers of the benthic fauna to different extent. The macrobenthos community in DRs had been subjected to a certain external disturbances and significantly different from the CRs on the FFG characteristics.

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References

[1] F.S. Hao, Almanac of China's Water Power-2005, China Electric Power Press, Beijing, 2007.
[2] S.C. Zhou, Z.W. Tian, China's hydro resources are the richest in the world—summary of the national countercheck of hydro resources, China Three Gorges Constr., 6 (2005) 68–73.
[3] W.J. Yu, Experts explain the hotspots of small hydropower development: is the small hydropower overdeveloped in China?, Guangxi Electr. Power, 9 (2015) 84–85.
[4] H.H. Li, C.Q. Liu, F.S. Wang, Change characteristics of phosphorus in cascade reservoirs on Maotiao river system in summer, Resour. Environ. Yangtze Basin, 18 (2009) 368–372.
[5] L.J. Li, H.X. Zheng, Environmental and ecological water consumption of river systems in Haihe-Luanhe basins, Acta Geog. Sin., 55 (2000) 495–500.
[6] Y.C. Luo, Z.X. Zhou, Y. Sun, Assessment methods of watershed ecosystem health, Acta Ecol. Sin., 55 (2000) 495–500.
[7] J.H. Fan, Q. Liu, Z.L. Ma, Environmental impact of hydropower development in the upper reaches of Minjiang River, Sichuan Environ., 25 (2006) 23–27.
[8] J.R. Thomson, D.D. Hart, D.F. Charles, Effects of removal of a small dam on downstream macroinvertebrate and algal assemblages in a Pennsylvania stream, J. North Am. Benthol. Soc., 24 (2005) 192–207.
[9] O.M. Bragg, A.R. Black, R.W. Duck, Approaching the physical-biological interface in rivers: a review of methods for ecological evaluation of flow regimes, Prog. Phys. Geogr., 29 (2005) 506–531.
[10] Y.L. Liang, H.Z. Wang, Advanced Hydrobiology, Chapter10: Macroinvertebrate, Science Press, Beijing, 1999, pp. 241–259.
[11] M.T. Barbour, J. Gerritsen, B.D. Snyder, Eds., Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Vol. 339, US Environmental Protection Agency, Office of Water, Washington, D.C., 1999.
[12] J. Heino, P. Louhi, T. Muotka, Identifying the scales of variability in stream macroinvertebrate abundance, functional composition and assemblage structure, Freshwater Biol., 49 (2004) 1230–1239.
[13] A. Sundermann, C. Antons, N. Cron, Hydro morphological restoration of running waters: effects on benthic invertebrate assemblages, Freshwater Biol., 56 (2011) 1689–1702.

[14] X.C. Fu, T. Tang, W.X. Jiang, Impacts of small hydropower plants on macro invertebrate communities, Acta Ecol. Sin., 28 (2008) 45–52.
[15] X.D. Qu, Studies on the Spatial-temporal Variation and Biological Integrity of Macroinvertebrate in the Xiangxi River, and the Impact of Small Hydro Power on Its Communities, PhD Dissertation, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan, 2006.
[16] J.C. Morse, L.F. Yang, L.X. Tian, Aquatic Insects of China Useful for Monitoring Water Quality (No. 13), Hohai University Press, Nanjing, 1994.
[17] J.H. Epler, "Identification Manual for the Larval *Chironomidae* (*Diptera*) of North and South Carolina." A Guide to the Taxonomy of the Midges of the Southeastern United States, Including Florida, Special Publication SJ2001-SP13, North Carolina Department of Environment and Natural Resources, Raleigh, NC, and St. Johns River Water Management District, Palatka, FL, 2001, p. 526.
[18] E. Castella, M. Bickerton, P.D. Armitage, The effects of water abstractions on invertebrate communities in UK streams, Hydrobiologia, 308 (1995) 167–182.
[19] H. Chester, R. Norris, Dams and flow in the Cotter River, Australia: effects on instream trophic structure and benthic metabolism, Hydrobiologia, 572 (2006) 275–286.
[20] R.G. Wetzel, Limnology, 2nd ed., Saunders College Publishing, Philadelphia, PA, USA, 1983, 860 p.
[21] A. Vallania, M. Corigliano, The effect of regulation caused by a dam on the distribution of the functional feeding groups of the benthos in the sub Basin of the Grande River (San Luis, Argentina), Environ. Monit. Assess., 124 (2007) 201–209.
[22] W.X. Jiang, Q.H. Cai, T. Tang, The functional feeding group ecology of macroinvertebrate in Xiangxi River system, Acta Ecol. Sin., 16 (2007) 738–743.
[23] X.D. Qu, Q.H. Cai, Z.C. Xie, Research of functional feeding groups of macroinvertebrates in the stony habitat of the Xiangxi River system, Resour. Environ. Yangtze Basin, 16 (2007) 738–743.
[24] T. Tang, Studies on Characteristics of Epilithic Algae and Ecosystem Management of Xiangxi River, PhD Dissertation, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan, 2003.