J. Geogr. Sci. 2013, 23(5): 871-882
DOI: 10.1007/s11442-013-1050-6

An exploratory analysis of benthic macroinvertebrates as indicators of the ecological status of the Upper Yellow and Yangtze Rivers

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Abstract: This study presents findings of the first systematic analysis of aquatic biotic assemblages in the source region of the Yellow and Yangtze Rivers. It provides an initial basis with which to select representative organisms as indicators to assess the aquatic ecological status of rivers in this region. Macroinvertebrates are considered to be good indicators of long-term environmental changes due to their restricted range and persistence over time. Field investigations of macroinvertebrates were conducted in August 2009 in the source region of the Yellow River, and in July 2010 in the source region of the Yangtze River. Altogether 68 taxa of macroinvertebrates belonging to 29 families and 59 genera were identified. Among them were 8 annelids, 5 mollusks, 54 arthropods and 1 other animal. In the source region of the Yellow River, taxa number, density and biomass of macroinvertebrates were 50, 329 individuals m^{-2} and 0.3966 g dry weight m^{-2}, respectively. Equivalent figures for the source region of the Yangtze River were 29, 59 individuals m^{-2} and 0.0307 g dry weight m^{-2}. The lower benthic animal resources in the source region of the Yangtze River are ascribed to higher altitude, higher sediment concentration and wetland degradation. Preliminary findings of this exploratory study indicate that hydroelectric power stations had a weak impact on benthic dwellers but wetland degradation caused by a series of human activities had a catastrophic impact on survival of macroinvertebrates. Ecological protection measures such as conservative grazing and vegetation management are required to minimize grassland degradation and desertification, and reduce soil erosion rate and river sediment discharge.

Keywords: macroinvertebrate; biodiversity; standing crops; functional feeding group; Yellow River source zone; Yangtze River source zone

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Received: 2012-05-30 **Accepted:** 2013-03-28
Foundation: National Natural Science Foundation of China, No.51209010; No.41001008; International Science & Technology Cooperation Program of China, No.2011DFA20820; 2011DFG93160; Fund from Tsinghua University, No.20121080027

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1 Introduction

The source regions of the Yellow River and the Yangtze River atop the Qinghai-Tibet plateau are important water conservation areas of China. They play a key role in maintaining the unique biota and ecological security for the whole river basins. However, the natural environment in the river source regions is very harsh, and the ecosystem is considered to be very fragile (Tang, 2003; Chen *et al*., 2007). Analysis of the ecological status of these regions is a prerequisite for precautionary environmental management (see Li *et al*., 2012).

In recent years a significant body of research has documented changing environmental conditions in the source region of the Yellow and Yangtze River basins. This has included work on climate (e.g. Li *et al.*, 2006; Hu *et al.*, 2007; Zhang *et al.*, 2011), hydrology (e.g. Li *et al.*, 2004; Zhang *et al.*, 2004; Shi *et al.*, 2007) and terrestrial ecosystems (especially grassland ecosystems, including research on grassland plant productivity (Sun *et al.*, 2005; Guo *et al.*, 2008), degradation and stress factors (Liu *et al.*, 2008; Feng *et al.*, 2009; Li *et al.*, 2011; Yang *et al.*, 2011), and sustainable utilization of grasslands (Sheng *et al.*, 2007)). Although spatio-temporal changes of habitat conditions for biotic organisms have been well documented (Qian *et al.*, 2006; Wu *et al.*, 2008; Liu *et al.*, 2009), no systematic studies on aquatic biotic assemblages have been completed in the river source regions. Exploratory analyses are required to select representative organisms as indicators of the aquatic ecological status of rivers in this area.

Benthic macroinvertebrates are important components of river ecosystems. They play an important role in trophic dynamics by cycling nutrients and providing food for higher trophic levels such as fish and birds. As such, they are considered to provide good indicators of long-term environmental changes due to their limited range and long-term persistence (Hart and Fuller, 1974; Smith *et al.*, 1999; Pan *et al.*, 2012). A better understanding of macroinvertebrate assemblages is of great significance to river ecological assessment and management.

Potential threats of human activities upon aquatic ecology in the river source regions include the construction of hydroelectric power stations and wetland degradation. To date, there are no reservoir power stations that store significant volumes of water, with major impact upon flow regulation, in the source regions of the Yellow and Yangtze Rivers. Rather, impacts are restricted to run-off hydroelectric power stations that have limited storage. These features exert a negligible impact upon the flow regime. However, the region has been subjected to significant wetland and grassland degradation, through overstocking, trenching and draining, illegal mining and so on (Jiao *et al*., 2007; Wang *et al*., 2009).

This paper presents a summary of systematic investigations of macroinvertebrates in the source regions of the Yellow River and the Yangtze River completed in 2009–2010. The purpose of this study is threefold: to describe the overall characteristics of macroinvertebrate assemblages in the river source regions; to explore the impact of human activities on macroinvertebrate assemblages; and to put forward strategies of aquatic conservation and management for the river source regions.

2 Study area and methods

2.1 Study area

Fluvial morphology, river patterns and controls on their development in the source region of the Yellow and Yangtze River differ markedly (see Yu *et al.*, 2013). The relief of the source region of the Yellow River is of lower elevation and much more varied than the source region of the Yangtze River. The elevation of the main channel decreases from 4600 to 2500 m. Variation in gradient is also more marked than it is in the source region of the Yangtze River. As a result, the source region of the Yellow River exhibits greater morphological diversity, with the range of river planforms along its trunk stream and tributaries including braided, anabranching, anastomosing, meandering and straight patterns (see Blue and Brierley, 2013; Li *et al.*, 2013; Yu *et al.*, 2013). By contrast, the middle reach of the source region of the Yangtze River is relatively flat (with elevation of 4300–4800 m), divided by quasi-parallel low mountains or ridges, and the elevation gradually lowers from the northwest to the southeast. Hence, wide and shallow valleys and braided channel patterns dominate in the source region of the Yangtze River, with sinuous or straight reaches in laterally-confined sections.

2.2 Methods

Field investigations of benthic macroinvertebrates in the source regions of the Yellow River and the Yangtze River were carried out in August 2009 and July 2010, respectively. The study locations of the source region of the Yellow River (33°46′01″–36°33′16″N, 97°45′22″–101°33′40″E) and the source region of the Yangtze River (33°43′56″–35°34′57″N, 92°07′05″–94°01′27″E) are shown in Figure 1.

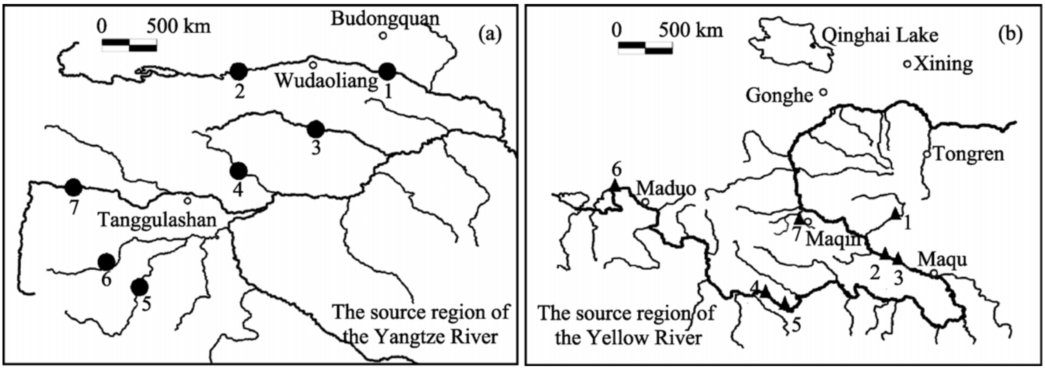

Figure 1 Locations of study areas and sampling sites in the river source regions of the Yangtze River (a) and the Yellow River (b). Sampling sites in the source region of the Yangtze River: 1. Downstream Chuma'er River; 2. Upstream Chuma'er River; 3. Beilu River; 4. Ri'achiqu River; 5. Buqu River; 6. Ganaiqu River; 7. Tuotuo River. Sampling sites in the source region of the Yellow River: 1. Zequ; 2. Gravel bar along meandering Yellow River; 3. Oxbow lake adjacent to the Yellow River; 4. Riparian wetland of the Yellow River; 5. River mainstream with low sediment concentration; 6. Shore of Erling Lake; 7. Jiangrang hydroelectric power station in a tributary of the Qiemuqu River.

Water depth (Z) and Secchi depth (Z_{SD}) were measured with a sounding lead and a Secchi Disc, respectively. Water velocity (U) was measured with a propeller-type current meter (Model LS 1206B). Water samples taken near the surface and at the bottom were combined for laboratory analyses. Suspended sediments (SS) were analyzed following procedures outlined by APHA (2002). Conductivity was measured using a conductivity meter (Model DDS-11A). Total nitrogen (TN) was analyzed using the alkaline potassium persulfate digestion-UV spectrophotometric method. Total phosphorus (TP) was analyzed using the ammonium molybdate method. All parameters were analyzed according to Standard Methods for Water and Wastewater Monitoring and Analysis (APHA, 2002). A summary of the environmental parameters at the study sites in the river source regions is presented in Table 1.

Table 1 Environmental parameters (mean ± SE) of sampling sites in the source regions of the Yellow River and the Yangtze River

Environmental parameters	The source region of the Yellow River	The source region of the Yangtze River
Water depth (m)	0.4±0.2	0.4±0.2
Sechhi depth (m)	0.30±0.1	0.15±0.10
Water velocity (m s^{-1})	0.26±0.15	0.38±0.05
Suspended sediments (mg L^{-1})	59.3±39.3	351.6±84.5
Conductivity (μS cm^{-1})	487±12	2257±838
Total nitrogen (mg m^{-3})	2940±540	1967±347
Total phosphorus (mg m^{-3})	8±1	37±17

Three replicate samples of macroinvertebrates were collected at each sampling site. Each sample was collected at a different place with a sampling area of 1/3 m^2. Macroinvertebrates were collected by a kick-net with mesh spacing of 420 μm. Specimens were manually sorted from sediment on a white porcelain plate and preserved in 75% ethanol. Wet weight of animals was determined with an electronic balance after being blotted, and then dry weight (mollusks without shells) was calculated according to the ratios of dry-wet weight and tissue-shell weight reported by Yan and Liang (1999). All taxa were assigned to functional feeding groups (shredders, collector-gatherers, collector-filterers, scrapers, and predators) (see Morse *et al.*, 1994; Liang and Wang, 1999). When a taxon had several possible feeding activities, its functional designations were equally proportioned (i.e. if a taxon can be both collector-gatherer and scraper, its abundance is divided 50:50 into these groups). The Jaccard similarity coefficient (S_J) was used to compare macroinvertebrate assemblages between the river source regions:

$$S_J = c / (a + b - c) \tag{1}$$

where a is the number of species in assemblage A, b is the number of species in assemblage B, and c is the number of species co-existing in both assemblages.

Taxa richness, S (the number of species), is the most important characteristic of biodiversity, as it provides a measure of both ecological diversity and habitat conditions of streams. The Shannon-Weaver index, H', integrates taxa richness and evenness of the distribution of animals for different species. It is defined by Krebs (1978) as:

$$H' = -\sum_{i=1}^{S} \frac{n_i}{N} \ln\left(\frac{n_i}{N}\right) \tag{2}$$

where S is the number of species (richness), N is the total number of individual animals, and n_i is the number of individual animal of i-th species. The Shannon-Wiener bio-index reflects the taxon richness and the evenness of number distribution of species. However, the Shannon-Wiener Index provides no information on the total abundance of the bio-community, and sometimes the index provides incorrect results. Numbers of individual animals per unit area vary substantially for habitats with different physical conditions. Considering both abundance and biodiversity, a biocommunity index, B, is used (Wang *et al.*, 2008):

$$B = -\ln N \sum_{i=1}^{S} \frac{n_i}{N} \ln\left(\frac{n_i}{N}\right) \tag{3}$$

3 Results

3.1 Taxa and biodiversity of macroinvertebrates

In summary, a total of 68 taxa of macroinvertebrates belonging to 29 families and 59 genera was identified in the two river source regions (Table 2). Among them were 8 annelids, 5

Table 2 Taxonomic composition of macroinvertebrates in the source regions of the Yellow River and the Yangtze River

Phylum	Class	Family	Species (genus) number	
			The source region of the Yellow River	The source region of the Yangtze River
Nematoda			ud	0
Annelida	Oligochaeta	Naididae	1	0
		Tubificidae	4	4
Mollusca	Gastropoda	Lymnaeidae	3	0
		Planorbidae	2	0
Arthropoda	Crustacea	Gammaridae	ud	ud
	Arachnoida		ud	0
	Insecta	Caenidae	(1)	0
		Baetidae	(1)	(1)
		Heptageniidae	(1)	(1)
		Ephemerellidae	(1)	0
		Leptophlebiidae	0	(1)
		Hydropsychidae	(1)	0
		Leptoceridae	(1)	0
		Brachycentridae	(1)	0
		Nemouridae	0	ud
		Taeniopterygidae	0	ud
		Dytiscidae	ud	0
		Elmidae	ud	ud
		Chrysomelidae	ud	0
		Naucoridae	ud	0
		Corixidae	ud	0
		Pyralidae	ud	0
		Sialidae	0	ud
		Tipulidae	(1)	(1)
		Simuliidae	(1)	0
		Culicidae	ud	0
		Ephydridae	ud	0
		Chironomidae	(20)	(16)
		Total taxa number	50	29

Note: ud, taxon unidentified to genus or species; genus number in parentheses.

mollusks, 54 arthropods and 1 other animal. Altogether, in the source region of the Yellow River, 50 taxa belonging to 25 families and 46 genera were identified. In the source region of the Yangtze River, altogether 29 taxa belonging to 11 families and 24 genera were identified. Only 11 taxa of macroinvertebrates co-existed in the two river source regions. The Jaccard coefficient between the source regions of the Yellow River and the Yangtze River was only 0.16. This indicates that the similarity of macroinvertebrates between the two river source regions was low.

The Shannon-Weaver Index (*H'*) of macroinvertebrates in the source regions of the Yellow River and the Yangtze River was 2.06 and 2.05, respectively. However, biocommunity index (*B*) of macroinvertebrates in the source regions of the Yellow River and the Yangtze River was 11.86 and 8.41, respectively. Species diversity can also be assessed using K-dominant curves, which combine the two aspects of diversity – species richness and evenness. Using this method, dominance patterns can be represented by plotting the accumulative abundance of each species (%) ranked in decreasing order of dominance. Figure 2 shows the K-dominant curve of macroinvertebrates in the river source regions. Biodiversity comparisons indicated that macroinvertebrate diversity in the source region of the Yellow River was higher than in the source region of the Yangtze River.

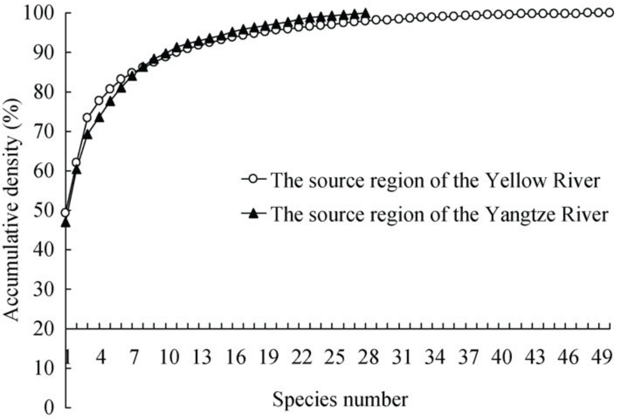

Figure 2 K-dominant curve of macroinvertebrates in the source regions of the Yellow River and the Yangtze River

3.2 Densities, biomass and functional structure

Figure 3 shows densities and biomass of each taxonomic group of macroinvertebrates in the source regions of the Yellow River and the Yangtze River. The densities of total macroinvertebrates were 329 ± 119 (mean ± SE) and 59 ± 32 individuals m^{-2} in the source regions of the Yellow River and the Yangtze River, respectively. The biomass of total macroinvertebrates was 0.3966 ± 0.1763 (mean ± SE) and 0.0307 ± 0.0217 g dry weight m^{-2} in the source regions of the Yellow River and the Yangtze River, respectively. Arthropods were the predominant group in these two river source regions. In the source region of the Yellow River, arthropods made up 85.4% of the total density and 93.5% of the total biomass. In the source region of the Yangtze River, arthropods comprised 86.2% of the total density and 95.8% of the total biomass.

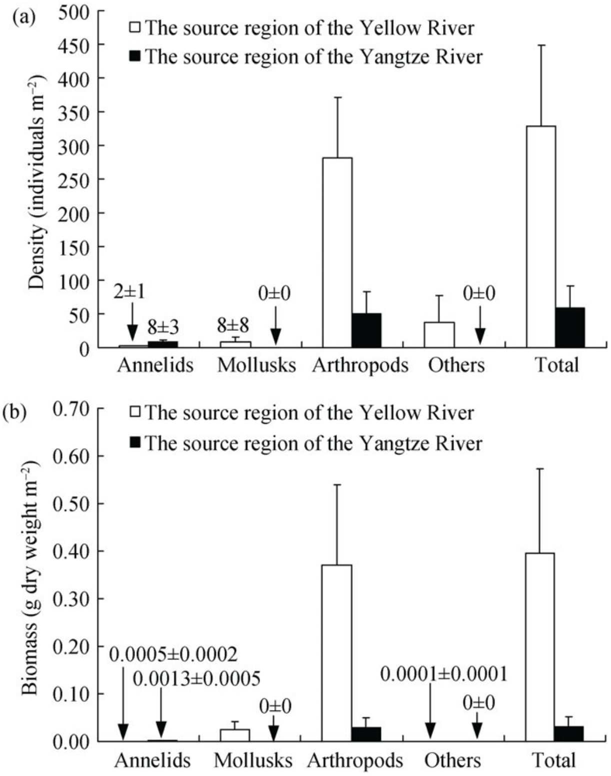

Figure 3 Mean (+ SE) density (a) and biomass (b) of each taxonomic group of macroinvertebrates in the source regions of the Yellow River and the Yangtze River

Figure 4 shows densities and biomass of each functional feeding group of macroinvertebrates in the source regions of the Yellow River and the Yangtze River. With regard to functional groups, shredders were the predominant group in the source region of the Yellow River, being 65.7% of the total in density and 87.1% of the total in biomass. In the source region of the Yangtze River, collector-gatherers and shredders were the dominant groups. Collector-gatherers made up 62.0% of the total density and 50.6% of the total biomass, and shredders made up 28.2% of the total density and 40.7% of the total biomass.

3.3 Macroinvertebrate responses to human disturbance

To assess the impact of hydropower station construction on aquatic ecology, macroinvertebrate assemblages were compared upstream and downstream of Jiangrang run-off hydroelectric power station in Maqin County. Little variance of taxa number, density and biomass of macroinvertebrates was evident upstream and downstream of the hydroelectric power station (Table 3). Macroinvertebrate assemblages in riparian wetland sites were more diverse than in the mainstream of a tributary without macrophytes (Table 3), indicating that the benthic animal resources in the former site were much higher than in the latter. Total density and biomass of macroinvertebrates in riparian wetland were 21 and 27 times higher than in the mainstream of a tributary without macrophytes.

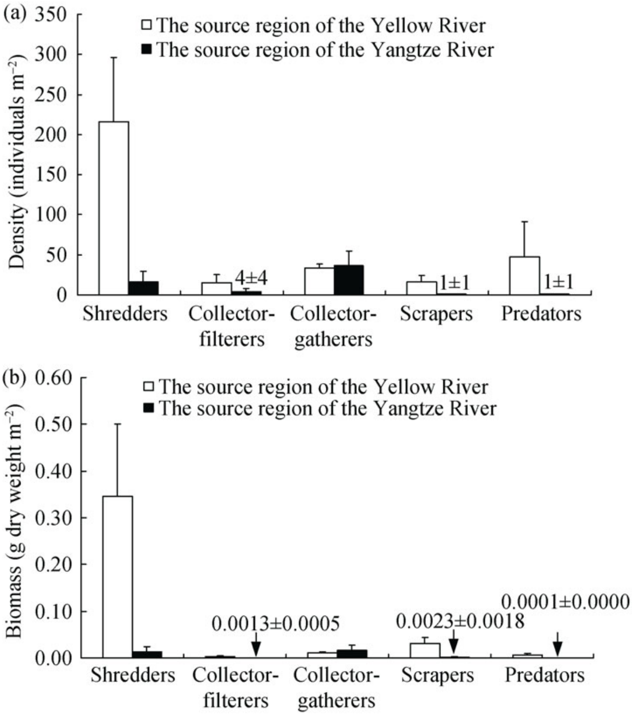

Figure 4 Mean (+SE) density (a) and biomass (b) of each functional feeding group of macroinvertebrates in the source regions of the Yellow River and the Yangtze River

Table 3 Comparisons of taxa number, densities and biomass of macroinvertebrates

Study station	Taxa number	Density (individuals m^{-2})	Biomass (g dry weight m^{-2})
The upstream of Jiangrang hydroelectric power station	10	59 ± 30	0.0100 ± 0.0053
The downstream of Jiangrang hydroelectric power station	8	43 ± 31	0.0075 ± 0.0050
Mainstream of a tributary without macrophytes	7	11 ± 11	0.0051 ± 0.0051
Riparian wetland	14	232 ± 92	0.1374 ± 0.0651

4 Discussion

In terms of macroinvertebrate assemblage structure, aquatic insects were dominant in the source regions of the Yellow and Yangtze Rivers. Similar features have been found in the mid-lower reaches of the trunk streams (Xie *et al.*, 1999; Pan *et al.*, 2011). With regard to species composition, some potamophilic and psychrophilic species occurred in these two river source regions. The potamophilic taxa were Ephemeroptera, Simuliidae, *Rheotanytarsus*, *Stictochironomus*, *Xenochironomus* and so on, and the psychrophilic species were *Stylaria lacustris*, *Limnodrilus grandisetosus*, *Limnodrilus profundicola* and so on. The existence of psychrophilic species can be ascribed to high latitude and low water temperature.

In comparison with the source region of the Yangtze River, higher macroinvertebrate diversity in the source region of the Yellow River can be ascribed to lower altitude and better wetland development. In relative terms, environmental conditions such as climate, oxygen concentration, atmospheric pressure etc. are more amenable at lower elevations. Better wetland development supports more benthic taxa, as these ecological niches play an important role in maintenance of diverse biota.

In areas of limited human disturbance, macroinvertebrate assemblages are influenced primarily by habitat conditions such as water velocity (Brooks *et al.*, 2005), substrate size (Jowett and Richardson, 1990; Quinn and Hickey, 1990), bank morphology and other geomorphological considerations (Armitage *et al.*, 2001; Chessman *et al.*, 2006) and so on. Variance of macroinvertebrate assemblages in the Upper Yellow and Yangtze Rivers is considered to reflect different habitat conditions. Among all measured parameters in these two river source regions, the difference of sediment concentration was particularly prominent. The sediment concentration of the source region of the Yangtze River was six times that of the source region of the Yellow River (Table 1). To a large extent, lower animal resources in the source region of the Yangtze River can be ascribed to high sediment concentration. High concentration of sediment causes light limitation on algal growth, and sand pellets may spoil cell walls of phytoplankton (Allan and Castillo, 2007; Pan *et al.*, 2009), resulting in food shortage for benthic animals. High concentration of sediment also inhibits macrophyte growth by light limitation, impacting upon benthic dwellers as macrophytes can support a large number of epiphytic animals (Brönmark, 1989; Newman, 1991; Jeppesen *et al.*, 1998; Wang *et al.*, 2006). Macrophytes create significant horizontal and vertical heterogeneities that provide a physical template for distinct niches (Rosine, 1955; Rooke, 1984), and serve as a refuge against predators (Pan *et al.*, 2011). Moreover, macrophytes can serve as a site for oviposition (Rooke, 1984; Scheffer, 2004), and provide chances for snails to crawl on the air-water interface (particularly for pulmonates) (Brönmark, 1989; Wang *et al.*, 2006).

Flow regulation impacts in the two river source regions are restricted to a few run-off hydroelectric power stations, one of which is shown here to have a weak impact on benthic dwellers (Table 3). Elsewhere, aquatic ecology upstream and downstream of reservoir power stations may vary greatly due to the altered hydrological regime (Friedl and Wüest, 2002; Godlewska *et al.*, 2003; Jorcin and Nagueira, 2005; Allan and Castillo, 2007). Limited impact noted in this instance reflects the fact that run-off hydroelectric power stations have a less adverse impact on the natural flow regime compared than reservoir power stations. For instance, the investigated Jiangrang run-off hydroelectric power station raises the water head by less than 1 m, and its storage capacity is very limited. Thus, the run-off hydroelectric power stations have a weak impact on the flow regime. Besides the construction of run-off hydroelectric power stations, aquatic ecosystems in the river source regions face the threat of wetland degradation caused by human activities. As noted in many other studies (e.g. Hillman and Quinn, 2002; Tarr *et al.*, 2005; Sharma and Rawat, 2009), wetlands are able to support a far greater abundance of benthic individuals than habitats without vegetation (Table 3).

Spatial comparisons of benthic assemblages and environments in the two river source regions indicate that macroinvertebrates were mainly influenced by sediment concentration and aquatic vegetation. In recent years, grassland degradation and erosion has led to serious soil loss, increasing sediment concentration in the region (Luo and Tang, 2003). Conservative grazing and vegetation management can support efforts to minimize grassland and wetland degradation and desertification, and reduce soil erosion rate and river sediment discharge. In the past 40 years, wetland areas in the source regions of the Yellow River and the Yangtze River have decreased by 13.6% and 28.9% respectively (Wang *et al.*, 2009). Degradation of wetlands is due to not only human activities but also reduced rainfall as a result of climate change.

5 Conclusions

Taxa number, density and biomass of macroinvertebrates in the source region of the Yellow River were 1.7, 5.6 and 12.9 times those in the source region of the Yangtze River. Compared with the source region of the Yellow River, lower benthic animal resources in the source region of the Yangtze River were ascribed to higher altitude, higher sediment concentration and wetland degradation. With regards to the impact of human activities on macroinvertebrate assemblages, run-off hydroelectric power stations have a weak impact on benthic animals, while wetland degradation has a catastrophic impact on survival of macroinvertebrates. Vegetation management and reinstigation of wetlands in efforts to reduce soil erosion and maintain water supply are key considerations in the ecological protection of these source regions, supporting efforts to improve ecological conditions across the whole basin.

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