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RESEARCH ARTICLE

Macroinvertebrate distribution and aquatic ecology in the Ruoergai (Zoige) Wetland, the Yellow River source region

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Abstract The Ruoergai (Zoige) Wetland, the largest plateau peatland in the world, is located in the Yellow River source region. The discharge of the Yellow River increases greatly after flowing through the Ruoergai Wetland. The aquatic ecosystem of the Ruoergai Wetland is crucial to the whole Yellow River basin. The Ruoergai wetland has three main kinds of water bodies: rivers, oxbow lakes, and marsh wetlands. In this study, macroinvertebrates were used as indicators to assess the aquatic ecological status because their assemblage structures indicate long-term changes in environments with high sensitivity. Field investigations were conducted in July, 2012 and in July, 2013. A total of 72 taxa of macroinvertebrates belonging to 35 families and 67 genera were sampled and identified. Insecta was the dominant group in the Ruoergai Basin. The alpha diversity of macroinvertebrates at any single sampling site was low, while the alpha diversity on a basin-wide scale was much higher. Macroinvertebrate assemblages in rivers, oxbow lakes, and marsh wetlands differ markedly. Hydrological connectivity was a primary factor causing the variance of the bio-community. The river channels had the highest alpha diversity of macroinvertebrates, followed by marsh wetlands and oxbow lakes. The density and biomass of Gastropoda, collector filterers, and scrapers increased from rivers to oxbow lakes and then to marsh wetlands. The river ecology was particular in the Ruoergai Wetland with the high beta diversity of macroinvertebrates, the low alpha diversity of macroinvertebrates, and the low taxa richness, density, and biomass of EPT (Ephemeroptera, Plecoptera, Trichoptera). To maintain high alpha diversity of macroinvertebrates in the Ruoergai Wetland, moderate connectivity of oxbow lakes and marsh wetlands with rivers and measures to control headwater erosion are both crucial.

Keywords macroinvertebrates, aquatic ecology, hydrological connectivity, Ruoergai Wetland, Yellow River source

1 Introduction

The headwater region of a river system is crucial to the entire ecosystem, influencing flow conditions and contributing significantly to biodiversity. The Ruoergai (Zoige) Wetland, the largest plateau peatland in the world, is located in the Yellow River source region. It is well-known as the “kidney” of the Qinghai-Tibet Plateau because the Yellow River flow volume increases by 30% after flowing through Ruoergai (Zhang et al., 2005). The Ruoergai Wetland plays a pivotal role in biodiversity conservation and ecological security for the whole Yellow River basin. Studies on the ecological state in this area are of great importance to the integrated management of the Yellow River.

In recent years many studies have documented changing environmental conditions in the Ruoergai Wetland. These include works on climate change (Zhou et al., 2002; Dai et al., 2010), land use (Xiao et al., 2010; Hu et al., 2012; Bai et al., 2013), aeolian desertification (Qiu et al., 2009; Dong et al., 2010), and wetland shrinkage (Zhang et al., 2011b; Huo et al., 2013; Li et al., 2014). Other studies have described the bio-communities in the Ruoergai Wetland and their responses to environmental changes (Tang et al., 2011; Wu and Yang, 2011; Zhang et al., 2011a). However, systematic studies on the ecological state of aquatic communities in the Ruoergai Wetland are lacking.

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Benthic macroinvertebrates (organisms larger than 500 μm) are important components of freshwater ecosystems, playing a crucial role in trophic dynamics by cycling nutrients and providing food for the higher trophic levels. Macroinvertebrates are generally viewed as good indicators of long-term changes in the environment since they are confined to the river bed, have limited movement capabilities, often possess relatively long life cycles, and are sensitive to environmental changes (Smith et al., 1999; Pan et al., 2012; Xu et al., 2014; Zhao et al., 2015). Research on macroinvertebrate assemblages is thus of great significance to aquatic ecological assessment.

Natural disturbances brought about by (often periodic) flooding strengthen nutrient exchange and ecological connectivity between different water units in a floodplain (Salo et al., 1986; Amoros and Roux, 1988; Ward and Stanford, 1995). Such lateral exchanges and the consequent nutrition cycling directly influence organisms dwelling in flood-prone regions (Vannote et al., 1980; Junk et al., 1989), and are among the primary factors determining benthic animal community structures (Reckendorfer et al., 2006; Obolewski, 2011). Flooding is one among several riverine processes influencing hydrological connectivity. Hydrological connectivity is defined as the ratio of the flux exchange to the mainstream flow, which indicates the degree of isolation of a water unit from the mainstream (Gallardo et al., 2008). Previous studies indicated that hydrological connectivity has an important impact on the development of the floodplain ecological pattern of meandering rivers (Pringle, 2003).

According to Gallardo et al. (2008), hydrological connectivity was the primary factor that influenced macroinvertebrate assemblages (accounting for 28% of the variance), followed by physical and chemical factors (accounting for 10%), and nutrition factors (accounting for 7%). Obolewski (2011) obtained similar results for a meandering river and associated oxbow lakes in Poland, and pointed out that the abundance and density of macroinvertebrates were positively correlated with hydrological connectivity. Pan et al. (2011) identified river-lake isolation as an important factor leading to decreases in benthic macroinvertebrate populations in abandoned channels of the middle Yangtze River. However, these studies were all focused on low-altitude aquatic ecosystems. There is a lack of studies on the headwater region with high altitude, such as Qinghai-Tibet Plateau.

The study reported herein was based upon field investigations and samplings done in 2012 and 2013. Habitats in the Ruoergai Wetlands were classified into three types: rivers, oxbow lakes, and marsh wetlands. Macroinvertebrate assemblages in these different water bodies were analyzed. The main objectives were to: (i) describe the characteristics of macroinvertebrate assemblages in the Ruoergai Wetland; (ii) analyze the environmental factors influencing macroinvertebrate communities in the different water bodies; (iii) analyze the river ecological characteristics in the Ruoergai Wetland.

2 Study area and methods

2.1 Study area

Figure 1 shows the locations of the study area and the sampling sites. The Ruoergai Wetland is located at the northeastern edge of the Qinghai-Tibet Plateau. The total area of the wetland is about 16,000 km^2 (Li et al., 2014). The landform is hilly, with altitudes of 3400–3900 m. The annual mean temperature is approximately 1°C, and the annual mean precipitation is approximately 650 mm. It includes Ruoergai, Hongyuan, and Aba Counties in Sichuan Province and Maqu and Luqu Counties in Gansu Province. The Hei River and the Bai River are the two main rivers flowing through the Ruoergai Basin. The wide valley and dense grasses in the Ruoergai Basin have provided favorable conditions for river meander development. Oxbow lakes and marsh wetlands develop along the river channels. Field investigations and macroinvertebrate samplings in the rivers, oxbow lakes, and marsh wetlands of the Ruoergai Basin were carried out in July, 2012 and in July, 2013. Altogether 23 sampling sites were selected. Sites S1–S6, S7–S12, S13–S18, and S19–S23 are located in the Bai River and its tributaries, in the Hei River and its tributaries, in the oxbow lakes adjacent to rivers, and in the marsh wetlands, respectively. The hydrological connectivity decreases from rivers to oxbow lakes and then to marsh wetlands.

2.2 Study methods

Macroinvertebrates in the rivers were collected using a kick net (1 m × 1 m area, 420 μm mesh). At each sampling site three replicate samplings were conducted with a sampling area of 1/3 m^2. Macroinvertebrates in the oxbow lakes and marsh wetlands were collected using a kick net and a 1/16 m^2 Peterson dredge. Specimens were manually picked out from the sediment on a white porcelain plate and preserved in 75% ethanol. Later in the laboratory, macroinvertebrates were identified and counted using a stereoscopic microscope. The wet weight of the macroinvertebrates was measured using an electronic balance, and then the dry weight was calculated according to dry-wet weight ratios reported by Yan and Liang (1999). All taxa were assigned to functional feeding groups (shredders, collector filterers, collector gatherers, scrapers, and predators) according to related literatures (Barbour et al., 1999; Duan et al., 2010). If a taxon had several possible feeding activities, its functional designations were equally proportioned into the corresponding functional feeding groups.

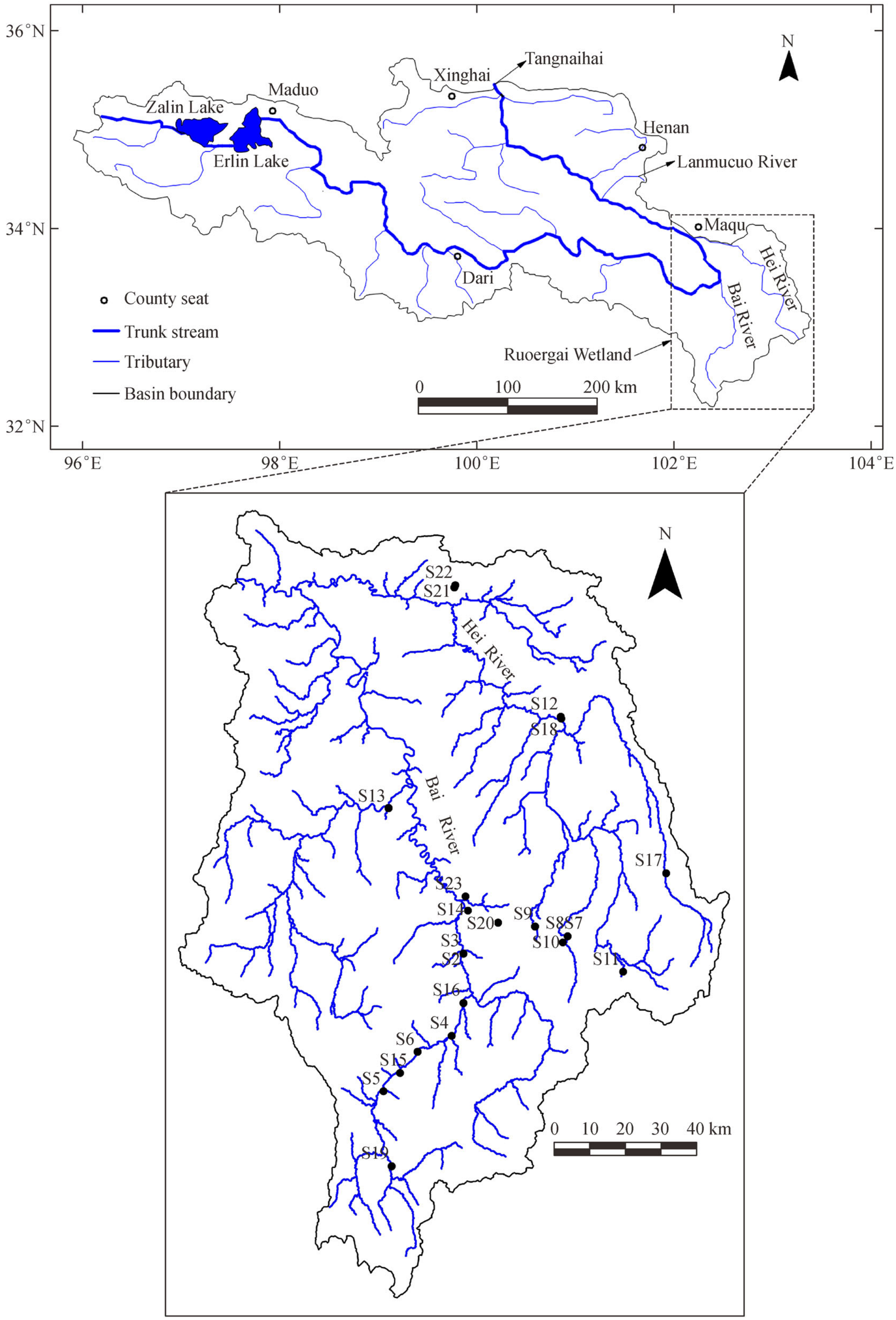

Fig. 1 Locations of the study area and the sampling sites.

Water depth was measured with a steel ruler, water transparency was measured with a Secchi Disc, water velocity was measured with a propeller velocimeter (Global Water FP111), and dissolved oxygen and water conductivity were measured using a hand-held oxygen meter (HACH HQd-40) with probe LBOD10101 and CDC40101, respectively. pH value and water temperature were measured with a pen-type pH meter (Hanna HI98128). Water samples taken near the surface and at the bottom were combined and taken to the laboratory, where they were analyzed for total nitrogen, total phosphorus, and total organic carbon contents. All parameters were analyzed according to Standard Methods for Water and Wastewater Monitoring and Analysis (WWWMAMC, 2002). Macrophytes were sampled with a scissor, then cleaned, superfluous water removed, and weighed to determine the wet weight.

2.3 Data analysis

Taxa richness S, the Shannon-Wiener index H', and the improved Shannon-Wiener index B were used to evaluate alpha diversity of macroinvertebrates. Taxa richness S is defined as the number of species in an assemblage.

The Shannon-Wiener index H' is defined as (Shannon and Weaver, 1948)

$$H' = -\sum_{i=1}^{S}(n_i/N)\ln(n_i/N). \tag{1}$$

The improved Shannon-Wiener index B is defined as (Wang et al., 2009)

$$B = -\ln N\sum_{i=1}^{S}(n_i/N)\ln(n_i/N), \tag{2}$$

where n_i is the number of macroinvertebrates of the i^{th} species, and N is the total number of individuals at each site. The higher the value of H', the higher the alpha diversity of the macroinvertebrate assemblage. The index B takes into account density factors in the sample. The higher the value of B, the higher the alpha diversity of the assemblage.

Beta diversity β was used for assessment of the regional diversity of macroinvertebrates for the whole basin. It is defined as (Wang et al., 2012)

$$\beta = \frac{M}{\frac{1}{S}\sum_{i=1}^{S} m_i}, \tag{3}$$

where M is the number of the selected sampling sites and m_i is the number of sites at which the i^{th} taxon occurred. This index value is related with the number of selected sites. In order to compare the beta diversity of two regions, the number of sites selected in each region should be the same. For a given M, the higher the value of β, the higher the heterogeneity of the assemblage.

Taxonomic distribution along the main environmental gradients was determined using Detrended Correspondence Analysis (DCA). DCA, by which similarity relations amongst analytical objects are shown in a 2D diagram, is an indirect ordination method (Braak and Smilauer, 2002). Relationships between macroinvertebrate communities and environmental factors can be well illustrated by a DCA diagram. CANOCO 4.53 software for Windows was used for the DCA. The input data for the DCA is the macroinvertebrates' density matrix of species × samples. To reduce heterogeneity of variances, the macroinvertebrate densities were log $(x + 1)$ transformed.

3 Results and discussion

3.1 Environmental parameters

Table 1 lists the environmental parameters in the Ruoergai Wetland. Water temperatures were relatively low. The pH values of all sites were greater than 7. Differences in dissolved oxygen, water transparency, and water depth between rivers, oxbow lakes, and marsh wetlands were little. The mean water conductivity and TOC increased from rivers to oxbow lakes and then to marsh wetlands. The TN and TP of rivers were lower than those of oxbow lakes and marsh wetlands. The substrate of most rivers was mainly gravel. The substrate of the small tributary through the swamps was humus whose main component was decayed root material. The substrate of the oxbow lakes and marsh wetlands was mainly silt and peat. There were no macrophytes living in the river sampling sites. However, there were macrophytes living in the oxbow lakes and marsh wetlands.

3.2 Taxa of macroinvertebrates

Table 2 lists the taxa of macroinvertebrates in the Ruoergai Wetland. A total of 72 taxa of macroinvertebrates belonging to 35 families and 67 genera were identified from the 23 sampling sites. Among them were 1 Nematoda, 3 Oligochaeta, 1 Bivalvia, 4 Gastropoda, 4 Crustacea, 1 Arachnida, and 63 Insecta. Samples of Insecta composed greater than 85% of the total, followed by Gastropoda and Crustacea with 5.6%, and Oligochaeta with 4.2%. The proportions of Nematoda, Bivalvia, and Arachnida were only 1.4%. In assemblage composition, aquatic insects dominated.

The alpha diversity of macroinvertebrates at a single sampling site in the Ruoergai Basin was low. The maximum species number of macroinvertebrates at a single sampling site was 19. However, the alpha diversity

Table 1 Environmental parameters (mean±SE) in the Ruoergai Wetland

Parameter		Bai River	Hei River	Oxbow lakes	Marsh wetlands
T/°C	Mean±SE	19.67±1.99	16.43±1.17	22.73±2.64	20.30±2.60
	Min–Max	12.80–25.20	11.00–19.20	15.10–30.50	15.10–27.50
DO/(mg·L^{-1})	Mean±SE	6.42±0.16	6.46±0.28	8.47±0.95	7.86±1.23
	Min–Max	6.11–7.17	5.31–7.40	6.33–12.51	4.74–10.50
pH	Mean±SE	8.42±0.11	8.03±0.10	9.32±0.44	8.99±0.47
	Min–Max	8.20–8.75	7.75–8.28	8.11–10.75	8.02–10.01
$Cond$/(μS·cm^{-1})	Mean±SE	107.1±9.8	98.5±6.5	132±24.1	343.1±128.6
	Min–Max	83.5–137.4	79.7–118.6	66.8–228.0	62.7–628.0
h_{SD}/cm	Mean±SE	33±5	19±7	19±8	17±9
	Min–Max	20–50	4–40	5–50	15–60
h/cm	Mean±SE	25±6	15±4	26±5	15±5
	Min–Max	13–49	7–32	15–40	11–35
v/(m·s^{-1})	Mean±SE	0.41±0.14	0.38±0.14	0.00±0.00	0.00±0.00
	Min–Max	0.10–1.00	0.15–1.00	0.00–0.00	0.00–0.00
B_{Mac}/(g·m^{-2})	Mean±SE	0±0	0±0	1148±743	18,666±9507
	Min–Max	0–0	0–0	120–4800	163–37,000
TOC/(mg·L^{-1})	Mean±SE	5.39±0.10	5.59±0.36	7.86±1.33	11.46±4.72
	Min–Max	5.11–5.82	4.10–6.31	4.23–12.20	3.74–23.66
TN/(mg·L^{-1})	Mean±SE	0.184±0.019	0.257±0.034	0.387±0.087	0.327±0.127
	Min–Max	0.148–0.248	0.127–0.369	0.181–0.680	0.154–0.702
TP/(mg·L^{-1})	Mean±SE	0.037±0.008	0.047±0.017	0.054±0.012	0.069±0.018
	Min–Max	0.023–0.065	0.020–0.130	0.028–0.100	0.020–0.099
Substrate type		Gravel, silt and fine sand	Gravel, humus	Silt	Silt

Note: T: water temperature; DO: dissolved oxygen; pH: pH value of water; $Cond$: water conductivity; h_{SD}: water transparency; h: water depth; v: water velocity; B_{Mac}: wet biomass of submersed macrophytes; TOC: total organic carbon concentration of water (representing the organic matter concentration of water); TN: total nitrogen concentration of water; TP: total phosphorus concentration of water.

of macroinvertebrates on a basin-wide scale was much higher. The total species number at all the 23 sampling sites was 72. The low biodiversity in the single sampling site might be due to a variety of causes including: i) the cold climate and consequent low average water temperature in the Yellow River source region. Water temperature is a critical environmental factor influencing benthic animal assemblages (Lessard and Hayes, 2003); ii) the simple habitat of invertebrates in the Yellow River source region. There are few aquatic plants living in the rivers, and the habitat heterogeneity at any given site is low. Such habitat conditions are very unfavorable to the development of a diverse macroinvertebrate community (Beisel et al., 2000; Downes et al., 2000). In contrast, at the scale of the entire basin, the topographical variations and environmental gradients between water bodies are far more pronounced, and this results in great inter-site changes in macroinvertebrate composition. Consequently, the alpha diversity of macroinvertebrates for the overall basin was much higher than that at any single sampling site.

3.3 Detrended Correspondence Analysis ordination and alpha diversity

Figure 2 shows the DCA diagram of the sampling sites. Eigenvalues of axes 1 and 2 of the DCA were 0.863 and 0.480, respectively. According to the change of environmental parameters in the three water bodies and hydrological connectivity, the first axis denotes changes of the hydrological connectivity, which explains 18.3% of the macroinvertebrate assemblages' variance. The DCA ordination diagram demonstrates that hydrological connectivity was the main factor influencing macroinvertebrate patterns of different water bodies in the floodplain. This is mainly because the hydrological connectivity with the rivers promotes the exchanges of the sediment, organic matter, nutrients, and organisms (Tockner et al., 2000).

The second axis reflects changes of water conductivity and total organic carbon (TOC), which together explains 10.2% of the macroinvertebrate assemblages' variance. Water conductivity may affect the growth of

Table 2 Taxa list of macroinvertebrates in the Ruoergai Wetland

Phylum	Family	Species (genus) number			
		Bai River	Hei River	Oxbow lakes	Marsh wetlands
Nematoda	Nematoda	u	0	u	0
Annelida	Tubificidae	(1)	(1)	(1)	(2)
	Naididae	1	0	0	0
Mollusca	Planorbidae	1	0	2	1
	Lymnaeidae	1	0	2	2
	Sphaeriidae	0	0	(1)	(1)
Arthropoda	Conchostraca	0	0	0	u
	Cladocera	0	0	u	u
	Calanoida	0	0	u	u
	Gammaridae	(1)	(1)	(1)	0
	Acariformes	u	u	u	u
	Entomobryomorpha	0	0	u	0
	Baetidae	1	1	0	0
	Heptageniidae	(1)	(1)	0	0
	Ephemerellidae	(2)	(1)	0	0
	Perlodidae	1	1	0	0
	Nemouridae	1	1	0	0
	Taeniopterygidae	1	0	0	0
	Limnephilidae	1	1	0	1
	Brachycentridae	2	2	0	0
	Hydropsychidae	(2)	0	0	0
	Dytiscidae	0	0	3	4
	Haliplidae	0	0	(1)	0
	Chrysomelidae	0	0	u	u
	Hydrophilidae	0	u	0	u
	Gomphidae	2	0	0	0
	Lestidae	0	0	(1)	0
	Libellulidae	0	0	0	(1)
	Corixidae	0	0	(1)	(1)
	Veliidae	0	0	0	u
	Tipulidae	(2)	(1)	0	0
	Ephydridae	0	0	(1)	0
	Athericidae	0	1	0	0
	Ceratopogonidae	u	0	0	0
	Chironomidae	(9)	(5)	(10)	(6)

Note: u: taxon unidentified to genus or species. Genus number in parentheses.

macroinvertebrates (Kefford, 1998). In addition, water conductivity may also affect the growth of algae (Tang et al., 2004), which is a food source of benthic animals. As for TOC, the organic matter content of water affects the photosynthesis of algae and macrophytes (Steinberg et al., 2006), and its mineralization also provides nutrition for algae and phytoplankton. These factors in turn influence the availability of invertebrate food sources.

Figure 3 shows the alpha diversity indexes of the three water bodies in the Ruoergai Wetland (taxa richness S, the Shannon-Wiener index H'). The rivers had the highest taxa richness S and Shannon-Wiener index H'. The taxa richness S of oxbow lakes was the same as that of marsh wetlands, while the Shannon-Wiener index H' of oxbow lakes was lower than that of marsh wetlands. This diagram demonstrates that the macroinvertebrate biodiversity of

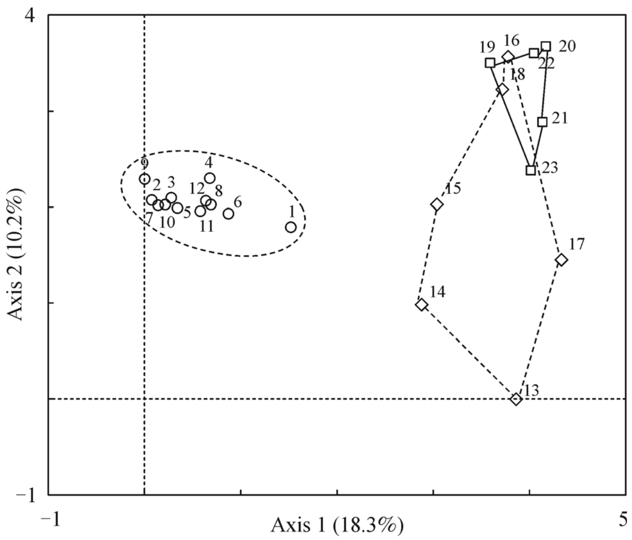

Fig. 2 DCA diagram of the sampling sites (1, 2, 3… represent S1, S2, S3…; ○: rivers, ◇: oxbow lakes, □: marsh wetlands).

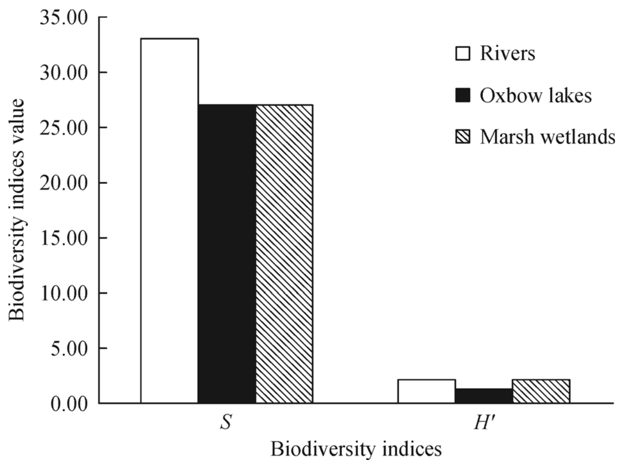

Fig. 3 The alpha diversity indices of the three water bodies in the Ruoergai Wetland.

rivers was the highest, followed by marsh wetlands and oxbow lakes.

3.4 Densities, biomass and functional structure

Figure 4 shows the density and dry biomass of each taxonomic group of macroinvertebrates in the Ruoergai Wetland. Insecta was dominant in the rivers, making up 69.9% of the total density and 68.0% of the total biomass. Insecta and Oligochaeta were dominant in the oxbow lakes. Here, Insecta made up 49.6% of the total density and 56.8% of the total biomass. Oligochaeta made up 37.0% of the total density and 32.1% of the total biomass. Insecta and Crustacea were dominant in the marsh wetlands. Insecta made up 35.7% of the total density and 56.3% of the total biomass. Crustacea made up 36.7% of the total

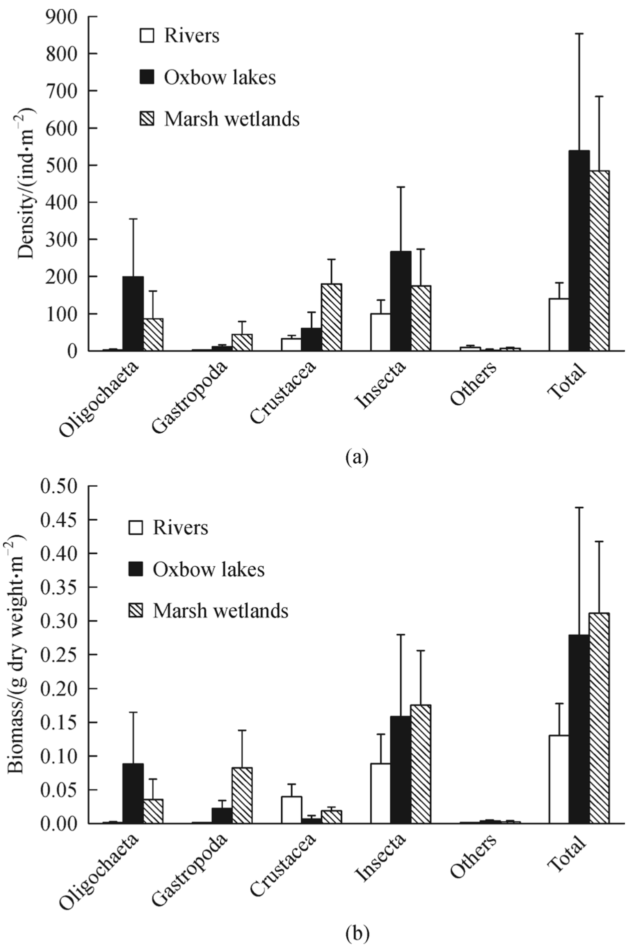

Fig. 4 Density (a) and dry biomass (b) of each taxonomic group of macroinvertebrates in the Ruoergai Wetland.

density and 5.6% of the total biomass. Crustacea was primarily composed of small organisms with low weight such as Conchogtrace, Cladocera, and Calanoida. Therefore, the biomass proportion of Crustacea was low. Since the rivers could not provide suitable living conditions for Gastropoda, there being no aquatic plants for Gastropoda to inhabit and scrape, no Gastropoda appeared in the rivers. The substrate of the rivers was mainly gravel, and could not provide soft habitats for Oligochaeta, so there were few Oligochaeta animals sampled from rivers, making up only 0.02% of the total density and 0.84% of the total biomass. The density and biomass of Gastropoda increased from rivers to oxbow lakes and then to marsh wetlands.

Figure 5 shows the density and dry biomass of each functional feeding group of macroinvertebrates in the Ruoergai Wetland. Collector gatherers and predators were dominant in the rivers, making up 45.0% and 43.4%, respectively, of the total density and 37.3% and 57.3%, respectively, of the total biomass. Collector gatherers were dominant in the oxbow lakes, and made up 58.3% of the total density and 59.5% of the total biomass. Predators were dominant in the marsh wetlands, and made up 34.4%

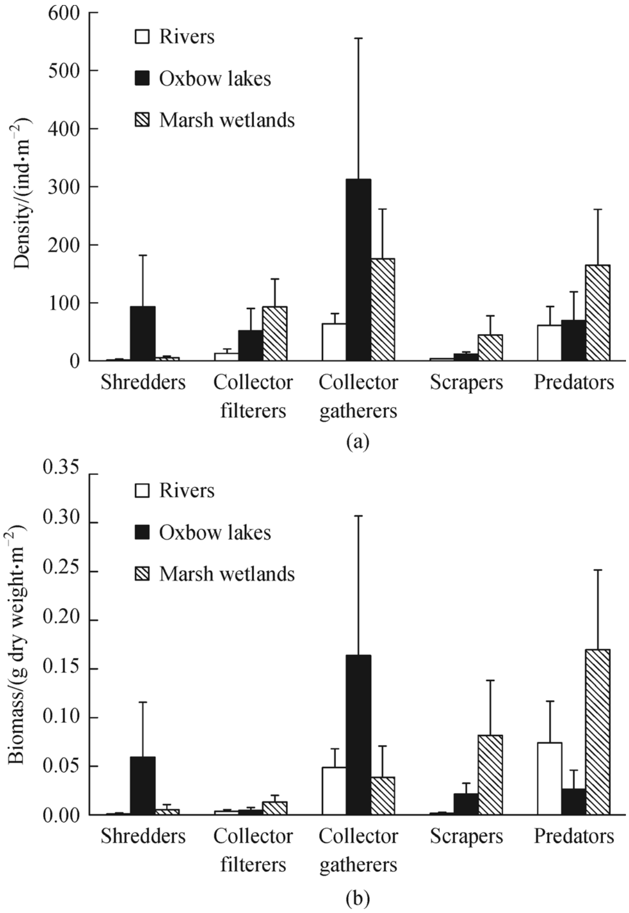

Fig. 5 Density (a) and dry biomass (b) of each functional feeding group of macroinvertebrates in the Ruoergai Wetland.

of the total density and 54.5% of the total biomass. The density and biomass of collector filterers and scrapers increased from rivers to oxbow lakes and then to marsh wetlands.

3.5 River ecology in the Ruoergai Wetland

The special geological conditions and geographic location of the Ruoergai Wetland provide unique habitats for macroinvertebrates. Figure 6 enumerates some factors contributing to the habitat conditions found in the rivers in the Ruoergai Basin. The area is very rich in peat. The river flow carries high concentrations of peat particles while it flows through the peatland. These particles reduce the water transparency, diminishing the amount of light that penetrates underwater which in turn affects the food sources of some macroinvertebrates. Peat particles are also deposited on the substrate, particularly in areas with low flow velocities. This reduces the porosity of the riverbed, and thus affects microhabitat diversity. In addition, some channels in the Ruoergai Basin cut through the peat layer (Fig. 7(a)) due to headwater erosion (Fig. 7(b)). Generally, the peat layer acts to strongly deter riverbed incision. However, once the peat layer is cut through, riverbed incision and the fluvial process will be accelerated, and habitat stability for benthic animals will be reduced. Consequently, the special habitat conditions of the rivers in the Ruoergai Basin may support a unique river ecology.

The Ruoergai Wetland and the Lanmucuo River are both located in the Yellow River source region (Fig. 1) and have similar altitudes (around 3500 m) and climates. To better understand the ecological characteristics of the Ruoergai Wetland's rivers, 8 representative sampling sites were selected in the rivers of Ruoergai Basin and the Lanmucuo River, respectively. Water transparency of the rivers in the Ruoergai Basin was low (Hei River: 19 cm, Bai River: 33 cm), while that of the Lanmucuo River was high (65 cm). Habitat stability and microhabitat diversity of the rivers in the Ruoergai Basin were also lower than those of the Lanmucuo River (reasons for this include factors given in Fig. 6). Figure 8 shows that the alpha diversity of macroinvertebrates in the rivers of Ruoergai Basin was lower than that in the Lanmucuo River.

The beta diversity β of macroinvertebrates in the rivers of the Ruoergai Basin was 3.41, while that in the Lanmucuo River was 2.13. The higher beta-diversity of rivers in the Ruoergai Basin may be attributed to the following reasons: i) the substrates of the rivers in the Ruoergai Basin were varied. There were substrates of gravels, gravels mixed with deposited peat particles, silt and fine sand, and humus. The environmental gradients

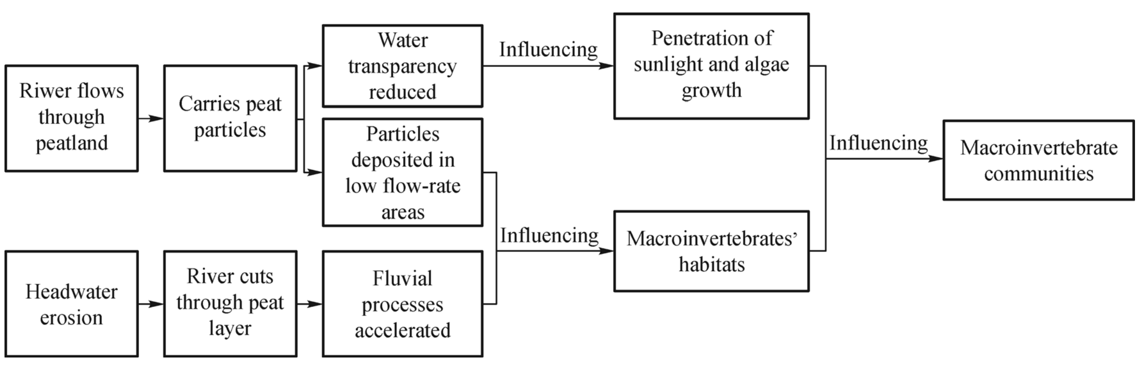

Fig. 6 Habitat conditions of the rivers in the Ruoergai Basin.

(a) (b)

Fig. 7 (a) The peat layer of the Mai River (a Hei River's tributary) was cut through (32°57′0.9″N, 103°5′0″E) (July 2013); (b) The headwater erosion in the Ruoergai Wetland (33°5′6.7″N, 102°50′10.6″E) (July 2013).

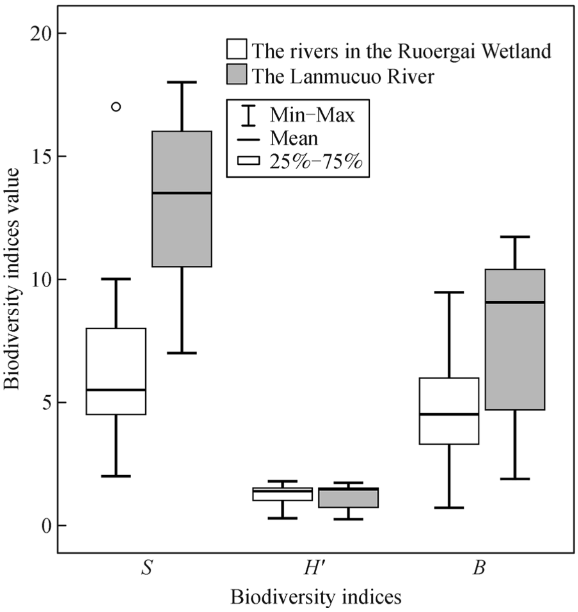

Fig. 8 The alpha diversity of macroinvertebrates.

between different sampling sites were great in the rivers of the Ruoergai Basin; ii) in contrast, the substrate at sites in the Lanmucuo River was mainly gravel.

EPT refers to Ephemeroptera, Plecoptera, and Trichoptera. These three kinds of invertebrates are sensitive to environmental change. EPT population differences between Rivers in different regions may thus be expected to be indicative of environmental differences in these ecosystems. Table 3 lists the EPT taxa richness, density, and biomass in the rivers of the Ruoergai Wetland and the Lanmucuo River. All three characteristics were much lower in the rivers of the Ruoergai Basin than in the Lanmucuo River.

3.6 Management of the Ruoergai Wetland

The results presented herein show that hydrological connectivity was the main factor influencing macroinvertebrate patterns of different water bodies in the floodplain of the Ruoergai Wetland. Previous research also found that the alpha diversity of macroinvertebrates peaks at moderate connectivity with rivers (Ward et al., 1999; Amoros and Bornette, 2002). The oxbow lakes and marsh wetlands, two common water bodies in the Ruoergai Wetland, contribute a lot to the biodiversity of macroinvertebrates in the Ruoergai. To maintain high alpha diversity of macroinvertebrates in oxbow lakes and marsh wetlands, moderate connectivity with rivers is crucial. In addition, to maintain high alpha diversity of macroinverte-

Table 3 EPT taxa richness, density, and biomass at selected sites

River	Item	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Mean value
Rivers of the Ruoergai Wetland	Taxa richness	1	8	3	1	1	5	0	2	3
	Density/(ind·m^{-2})	2	94	7	4	24	18	0	2	19
	Biomass /(g dry weight·m^{-2})	0.001	0.145	0.004	0.002	0.020	0.010	0.000	0.0004	0.023
The Lanmucuo River	Taxa richness	8	9	9	5	6	7	6	4	7
	Density/(ind·m^{-2})	660	765	492	492	51	262	39	46	351
	Biomass /(g dry weight·m^{-2})	0.253	0.293	0.356	0.136	0.027	0.307	0.023	0.065	0.182

brates in the rivers of the Ruoergai Wetland, it is advisable that some measures are implemented to control headwater erosion.

4 Conclusions

The alpha diversity of macroinvertebrates at a single sampling site in the Ruoergai Wetland was low, owing to the cold weather and the simple habitat. In contrast, topographical variation and large environmental gradients between water bodies in the Ruoergai leads to a much higher macroinvertebrate alpha diversity on a basin-wide scale. There are various water bodies in the floodplain of the Ruoergai Basin. Macroinvertebrate assemblages in the different water bodies were significantly different. Hydrological connectivity was the key factor causing the variance of the bio-community. The river channels had the highest alpha diversity of macroinvertebrates, followed by the marsh wetlands and the oxbow lakes. The density and biomass of Gastropoda, collector filterers, and scrapers increased from rivers to oxbow lakes and then to marsh wetlands. Overall, the special geological and geographic conditions in the Ruoergai Wetland provide unique habitats for macroinvertebrates. The river ecology was particular in the Ruoergai Wetland. Compared with the Lanmucuo River close to the Ruoergai Basin, which has a similar climate as the Ruoergai Wetland, the beta diversity of macroinvertebrates in the rivers of the Ruoergai Basin was higher than that of the Lanmucuo River. Nevertheless, the alpha diversity indices of macroinvertebrates, the taxa richness, density, and biomass of EPT (Ephemeroptera, Plecoptera, Trichoptera) in the rivers of Ruoergai Basin were much lower than those in the Lanmucuo River. To maintain a high alpha diversity of macroinvertebrates in the Ruoergai Wetland, moderate connectivity of oxbow lakes and marsh wetlands with rivers and measures to control headwater erosion are crucial.

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