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Macrozoobenthic community of Poyang Lake, the largest freshwater lake of China, in the Yangtze floodplain

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Abstract Poyang Lake (Poyang Hu) is located at the junction of the middle and lower reaches of the Yangtze (Changjiang) River, covering an area of 3283 km^2. As one of the few lakes that are still freely connected with the river, it plays an important role in the maintenance of the unique biota of the Yangtze floodplain ecosystem. To promote the conservation of Poyang Lake, an investigation of the macrobenthos in the lake itself and adjoining Yangtze mainstream was conducted in 1997–1999. Altogether 58 benthic taxa, including 22 annelids, 8 mollusks, 26 arthropods, and 2 miscellaneous animals, were identified from quantitative samples. The benthic fauna shows a high diversity and a marine affinity. The standing crops of benthos in the lake were much higher than those in the river, being 659 individuals/m^2 and 187.3 g/m^2 (wet mass) in the main lake, and 549 individuals/m^2 and 116.6 g/m^2 in the lake outlet, but only 129 individuals/m^2 and 0.4 g/m^2 in the river. The dominant group in the lake was Mollusca, comprising 63.4% of the total in density and 99.5% in biomass. An analysis of the functional feeding structure indicated that collector-filterers and scrapers were predominant in the lake, up to 42.2% and 24.7% in density and 70.2% and 29.2% in biomass, respectively, while shredders and collector-gatherers were relatively common in the river. The present study was restricted to the northern outlet and the northeast part of Poyang Lake. A scrutiny is required for the remaining areas.

Key words Macrozoobenthos · River-connected lake · Community structure · Yangtze floodplain

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Introduction

In the shallow lakes of the Yangtze (Changjiang) River floodplain, benthic macroinvertebrates play an important role in material cycling and energy flow. Their production is generally higher than that of zooplankton (YY Chen et al. 1995; Liang and Liu 1995). For the purposes of fisheries utilization and biomonitoring, Chinese benthologists have done noticeable work on zoobenthic abundance, distribution, production, and energetics (e.g., Institute of Hydrobiology Academia Sinica 1965; CY Chen et al. 1975; QY Chen et al. 1980; Liang 1984; Liang and Liu 1995; Yan et al. 1999, 2001). These studies, however, were mainly accomplished in disconnected lakes (i.e., those severed from the Yangtze mainstream by dikes and gates). Little attention has been paid to the benthos in river-connected lakes.

Historically, all the lakes along Yangtze River were connected with the mainstream. At present, only three lakes still retain their free connection. Among them, Poyang Lake (Poyang Hu), the largest freshwater lake in China, is the most significant. As a connected lake located at the junction of middle and lower reaches of the river, it remains more pristine in nature and exhibits greater annual water fluctuation than allied waters. There are six nature reserves inside the lake area for fishes, birds, mollusks, etc. (State Forestry Administration 2000). Obviously, Poyang Lake is of great value in the maintenance of the unique aquatic biota of the Yangtze Basin. To implement lake conservation more effectively, comprehensive studies of benthos as well as other ecological groups are required. In fact, our hydrobiological knowledge of Poyang Lake is still far from complete (Zhang et al. 1988; Zhu et al. 1997). Previous macrobenthic works conducted there were largely concentrated on molluscan fauna (Lin 1962; Tchang and Li 1965; YG Chen 1988; Liu and Wu 1991; XP Wu et al. 1994, 2000). No previous research has included the entire benthic community.

In 1997–1999, an investigation of macrobenthos in Poyang Lake and adjoining Yangtze mainstream was carried out by us as a part of a larger project on the biological limnology of this region. To date, only some faunistic findings have been reported (Wang et al. 1999; JH Wu et al. 2000; Wang and Liang 2001; Gibson and Wang 2002). In this article, we present an overview of the zoobenthic community, mainly the aspects of standing crop and functional feeding groups.

Study area and methods

Located in Jiangxi Province, Poyang Lake (28°25′–29°45′ N, 115°48′–116°44′ E) is a fluvial lake formed about 6000 years ago that receives flows of five rivers in the catchment of 1.62 $\times 10^5$ km^2. It covers an area of 3283 km^2 at 21.7 m a.s.l., with a shore development of 5.9, a maximum depth of 29.2 m, and a mean depth of 5.1 m. The southwest part of the lake basin is shallower, and, thus, wetland vegetation there is well developed. The mean annual water input is 1.50×10^{11} m^3, and the retention time is about 10 days. The water level undergoes great change within a year, up to 17.6 m in July and down to 10.5 m in January on average. In winter, the lake resembles a river, retaining a water area only 5% of its largest area. The mean annual water temperature is 18.0°C, and the mean annual water sediment concentration (inorganic seston) is 66.1 g/m^3. The climate is monsoonal with a mean annual air temperature of 17.2°C, mean annual precipitation of 1482.3 mm (46% falls in April–June), and mean annual evaporation of 1184 mm (Zhu and Zhang 1997).

The sampling stations ST1 and ST3–ST5 were in the Yangtze mainstream, ST6–ST12 in the lake outlet, and ST13–ST18 in the northeastern part of the main lake (Fig. 1). Their physicochemical properties are summarized in Table 1. Macrophytes were not found in any station.

Samplings were carried out in October 1997 (ST1, ST3–ST14 only), April 1998, November 1998, May 1999, and July 1999 with a weighted Petersen grab (1/16 m^2). One quantitative sample was taken from each station at each sampling time. All bottom samples were sieved with a 420-μm sieve. Specimens were manually sorted out from sediment on a white porcelain plate and preserved in 10% formalin.

Animals were mainly identified to species and genus. All taxa were assigned to functional feeding groups (shredders, collector-gatherers, collector-filterers, scrapers, and predators) according to Morse et al. (1994) and Liang and Wang (1999), or by a superficial examination of gut content. When a taxon had several possible feeding activities, its functional designations were equally proportioned. Biomass of larger animals was determined with an electronic balance after being blotted (molluscan shells retained), whereas that of smaller worms was calculated by means of length–mass relationships.

Results

Taxa and abundance

Altogether, 58 taxa belonging to 5 phyla were identified from quantitative samples (Table 2). Because 4 oligochaetes and 4 insects were observed only in the river, there were in total 50 taxa including 18 annelids, 8 mollusks, 22 arthropods, and 2 miscellaneous animals found from the lake. Species richness of the main lake was much higher than that of the lake outlet because there were more oligochaetes and insects, and the low species number in the river resulted mainly from the scarcity of mollusks.

Quantitative aspects of common taxa are given in Table 3. According to abundance, the most predominant taxa in the lake were *Corbicula fluminea*, *Parafossarulu*s, and gammarids, whereas those in the river were *Nephthys polybranchia* and gammarids. *N. polybranchia*, *Teneridrilus mastix*, *Limnoperna lacustris*, and *Bellamya* were also abundant in the lake. Larvae of *Ephemera* occurred frequently in both the lake and the river, where dead mayflies were found floating all over the water in April 1998.

The standing crops of the major taxonomic groups are shown in Fig. 2. Their total quantities in the lake were much higher than those in the river, being 659 individuals/m^2 and 187.3 g/m^2 (wet mass) in the main lake, 549 individuals/m^2 and 116.6 g/m^2 in the lake outlet, but only 129 individuals/m^2 and 0.4 g/m^2 in the river. Mollusks were the dominant group in the lake, comprising 63.4% of the total in density and 99.5% in biomass, but they were rare in the river.

Concerning the qualitative and quantitative pattern of benthos in the investigated water system, there is generally a decreasing tendency from the main lake, through the lake outlet, to the Yangtze River (Table 2, Figs. 2, 3). Thus, the outlet is the transition zone between the main lake and the river trunk.

Functional structure

The main members of each functional feeding group are shown in Table 2, and the standing crops of five groups are shown in Fig. 3. Collector-filterers and scrapers were predominant in the lake, being 42.2% and 24.7% in density and 70.2% and 29.2% in biomass, respectively, but they were rare in the river. Shredders and collector-gatherers were dominant in the river, but their absolute abundance was on the same level with that in the lake. Predators in both habitats were in small proportion, being 2.0%–3.3% in density and 0.02%–0.9% in biomass, although their absolute abundance in the main lake was significantly higher than that in the river.

Discussion

Ecological role of benthos in Poyang Lake

Calculated by the multiplying of biomass and production to biomass (*P/B*) ratio of each taxon (the latter mainly from studies in Yangtze lakes by Yan 1998; see also Liang and Wang 1999), the annual production of benthos in Poyang Lake was estimated to be 373 g/m^2, which was at least three times that of zooplankton in the lake and three to seven times the benthic production in disconnected Yangtze lakes

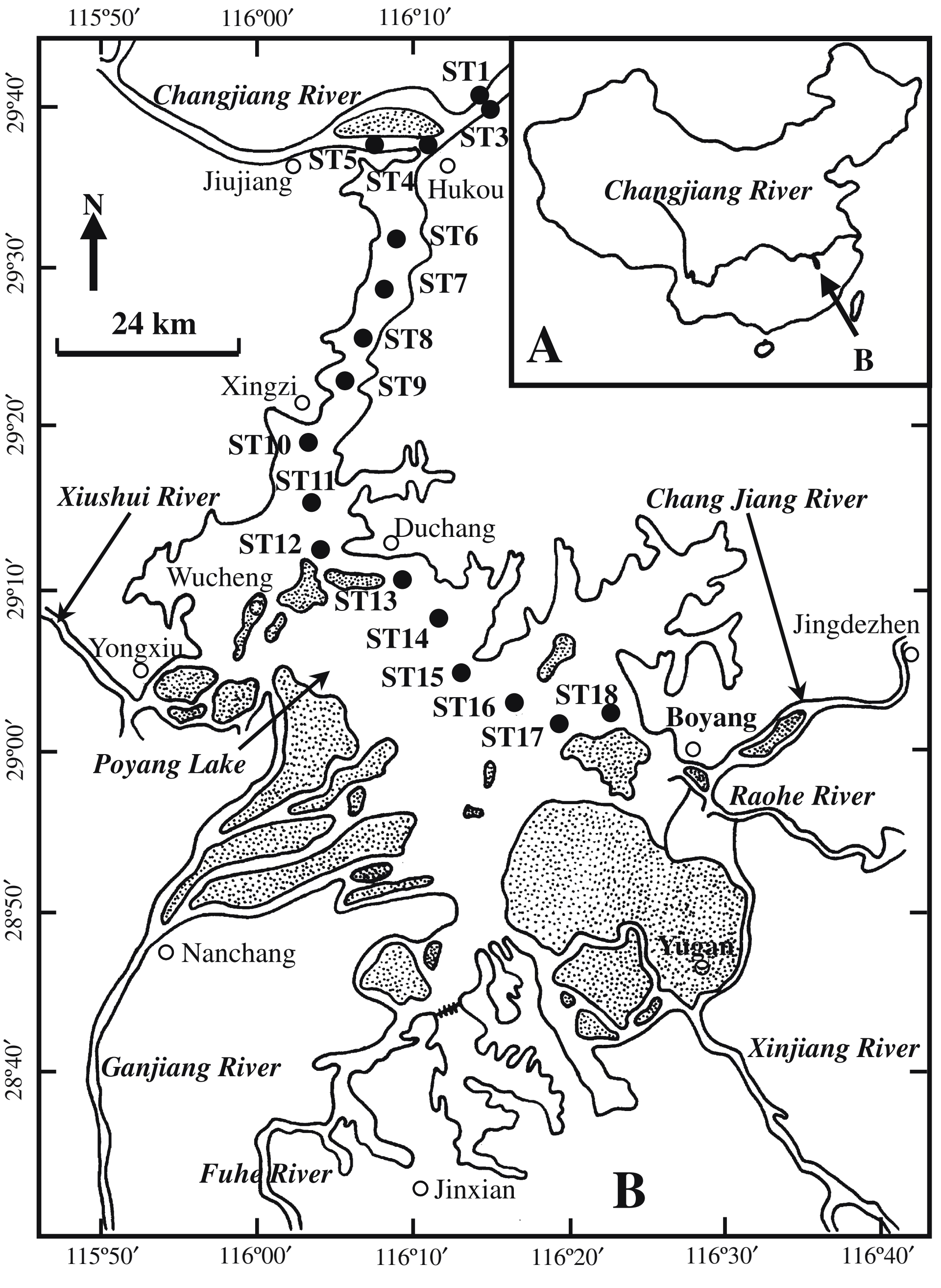

Fig. 1. Sampling stations (ST) in Poyang Lake and adjoining Yangtze River. **A** China (*inset*); **B** Poyang Lake. The *stippled areas* are islands

(Cui and Li 2005). This finding means that the benthic animals are the most important secondary producers in Poyang Lake ecosystem, at least, in the invertebrate community there.

Characteristics of the macrofauna and community structure

Although our records were derived only from quantitative samples, up to 60 taxa were identified from the Poyang Lake region. Combining our results with other reports (Lin 1962; Tchang and Li 1965; Liu and Wu 1991; YG Chen 1988; XP Wu et al. 1994, 2000; Wang et al. 1999; Gibson and Wang 2002), nearly 130 zoobenthic species have been described there. In comparison with other Chinese lakes (QY Chen et al. 1980; YY Chen et al. 1995; Liang and Liu 1995), Poyang Lake has the highest richness of macroinvertebrates. This result seems attributable to habitat heterogeneity within such a large lotic-to-lentic area. For example, its bottom structure ranges from silt to medium sand (see Study area and methods), but in disconnected Yangtze lakes, sediment is silty in general.

The macrofauna of Poyang Lake is quite characteristic. First, mollusks are very diverse: 37 species of gastropods and 46 species of bivalves have hitherto been recorded from Poyang Lake (XP Wu et al. 2000), comprising 67% and 85% of the total aquatic forms in Yangtze Basin, respectively, and a large proportion of them occur only in large

Table 1. Major physicochemical properties (mean ± SE) of Poyang Lake and adjoining Yangtze River (1997–1999)

Properties	River	Lake outlet	Main lake
Water			
Depth (m)	7.3 ± 0.9 (n = 20)	6.7 ± 0.6 (n = 35)	6.1 ± 0.5 (n = 26)
Surface velocity (m/s)	0.54 ± 0.08 (n = 19)	0.34 ± 0.03 (n = 30)	0.31 ± 0.04 (n = 24)
Secchi depth (cm)	29.2 ± 8.2 (n = 20)	91.0 ± 9.3 (n = 35)	123.1 ± 17.0 (n = 35)
pH	7.6 ± 0.1 (n = 20)	7.5 ± 0.1 (n = 35)	7.7 ± 0.1 (n = 35)
Conductivity (μS/cm)	224.2 ± 19.9 (n = 20)	93.3 ± 2.4 (n = 35)	90.2 ± 4.3 (n = 35)
Total nitrogen (mg/l)	1.36 ± 0.11 (n = 20)	0.93 ± 0.04 (n = 35)	0.99 ± 0.05 (n = 35)
Total phosphorus (mg/l)	0.24 ± 0.06 (n = 20)	0.08 ± 0.01 (n = 35)	0.06 ± 0.01 (n = 35)
Sediment			
Sediment type	Sandy silt to fine sand	Hard clay and fine sand, sometimes silt or medium sand	Similar to that of lake outlet
[a]Total nitrogen (%)	1.12 ± 0.09 (n = 4)	1.23 ± 0.12 (n = 7)	1.51 ± 0.12 (n = 6)
[a]Total phosphorus (%)	0.93 ± 0.09 (n = 4)	0.48 ± 0.08 (n = 7)	0.60 ± 0.04 (n = 6)
[a]Organic matter (%)	0.45 ± 0.15 (n = 4)	0.53 ± 0.08 (n = 7)	0.74 ± 0.04 (n = 6)

Organic matter, ultrafine particulate organic matter (UFPOM) + dissolved organic matter (DOM); measured by the method of Kalemabasa and Jenkins (1973)
[a]Measured in autumn of 1999 only

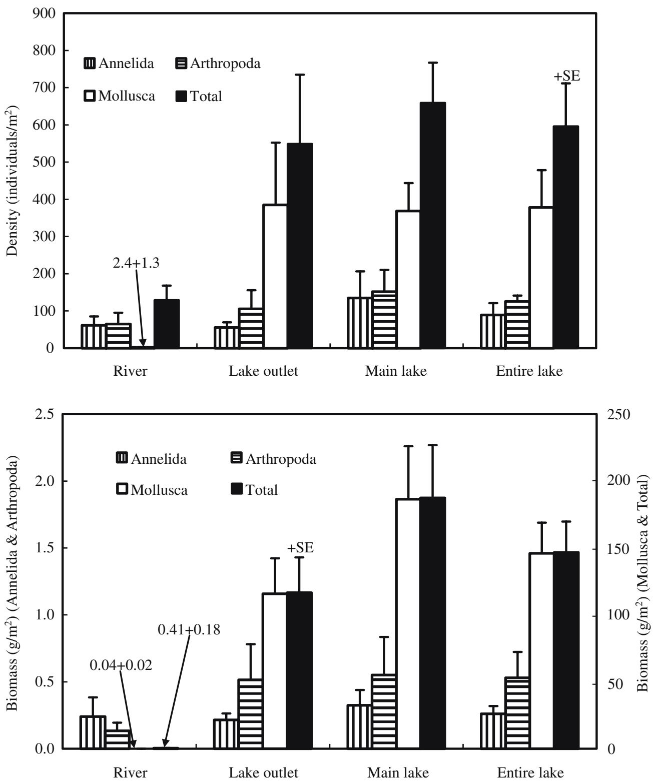

Fig. 2. Density (*top graph*) and biomass (wet mass; *bottom graph*) (means + SE) of macrozoobenthos in Lake Poyang and adjoining Yangtze River. *Entire lake = Lake outlet + Main lake*

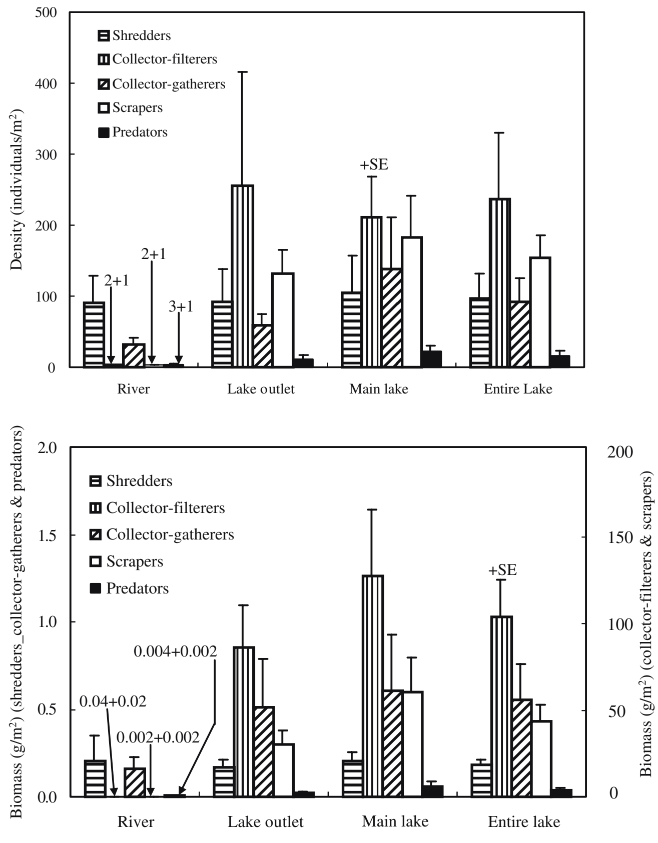

Fig. 3. Density (*top graph*) and biomass (wet mass; *bottom graph*) (means + SE) of functional feeding groups in Lake Poyang and adjoining Yangtze River. *Entire lake = Lake outlet + Main lake*

connected lakes (including Dongting Lake). In contrast, in small to medium disconnected Yangtze lakes (<500 km^2), there are usually no more than 30 gastropod species and 10 bivalves (CY Chen et al. 1975; QY Chen 1979; XP Wu et al. 2000). Even in large disconnected lakes such as Taihu Lake (about 500 km downstream from Poyang; severed from the Yangtze mainstream in 1958), molluscan species, mainly bivalves, were only half the number of those in Poyang Lake (XP Wu et al. 2000). Benthic diversity in the Yangtze mainstream and tributaries is even lower; fewer than 15 molluscan species have been recorded so far (TH Wu and QY Chen 1986; Liang, unpublished data). Second, the fauna of Poyang Lake somewhat reveals a marine affinity. This affinity has been shown by the occurrence of taxa such as *Limnemertes poyangensis* (Nemertea, Tetrastemmatidae) (Gibson and Wang 2002), *Nephtys polybranchia* Southern (Polychaeta, Nephtyidae), and *Parodontophora*

Table 2. Taxonomic composition of zoobenthos in Poyang Lake and adjoining Yangtze River (1997–1999)

Phylum	Class	Family	Species (genus) number			
			River	Lake outlet	Main lake	Entire lake
Nemertea	Enopla	Tetrastemmatidae	0	0	1	1
Nematoda			0	ud	ud	ud
	Polychaeta	Nephthydidae	1	1	1	1
		Haplotaxidae	0	0	(1)	(1)
Annelida	Oligochaeta	Enchytraeidae	(1)	0	0	0
		Naididae	2	0	3	3
		Tubificidae	4	6	8	10
	Hirudinea	Glossiphonidae	0	(2)	(1)	(3)
	Copepoda		ud	0	0	0
	Malacostraca	Gammaridae	ud	ud	ud	ud
		Ephemeridae	(1)	(2)	(1)	(2)
		Coenagrionidae	0	0	ud	ud
		Gomphidae	ud	0	0	0
Arthropoda		Corixidae	0	1	0	1
	Insecta	Leptoceridae	0	(1)	(1)	(1)
		Polycentropodidae	(1)	(1)	(1)	(1)
		Ecnomidae	0	(1)	(1)	(1)
		Psychomyiidae	0	0	ud	ud
		Ceratopogonidae	(1)	0	0	0
		Tipulidae	0	ud	0	ud
		Chironomidae	(5)	(4)	(11)	(12)
Mollusca	Gastropoda	Viviparidae	0	(1)	(1)	(1)
		Bithyniidae	0	(1)	(1)	(1)
		Stenothyridae	0	(1)	0	(1)
		Planorbidae	0	0	(1)	(1)
	Bivalvia	Mytilidae	1	1	1	1
		Unionidae	0	(2)	(1)	(2)
		Corbiculidae	1	1	1	1
		Total	21	29	40	50

Entire lake, Lake outlet + Main lake
ud, taxon unidentified to genus or species; genus number in parentheses

limnophila (Nematoda, Axonolaimidae) (JH Wu et al. 2000), most relatives of which are marine inhabitants. Reasonably, this inland lake (about 500 km from the East China Sea) might have had a connection with marine fauna historically.

Referring to the benthic community structure of Poyang Lake, the dominance of bivalve collector-filterers is the most prominent in comparison with other water bodies. As shown in Fig. 3, the collector-filterers in Poyang Lake were 210 individuals/m^2 in density and 126 g/m^2 in biomass, whereas those in small to medium Yangtze lakes were 2–100 individuals/m^2 and 0.01–8 g/m^2, and the dominant groups in those lakes were collector-gatherers (in density) and scrapers (in biomass) (Xu et al. 2003). In a large disconnected lake (Taihu Lake), bivalves only reached half the abundance of those in Poyang Lake (Huang et al. 2001). The great abundance of collector-filterers in Poyang Lake should be attributed to the prevalence of a sandy bottom, which is preferred by the dominant filterer *Corbicula* (Dillon 2000). However, bivalves were few in Yangtze River with similar substrate (see Fig. 3, also TH Wu and QY Chen 1986). This finding may be ascribed to the fact that bivalves cannot adapt well to the turbid, running water in the Yangtze River. It is noteworthy that shredders were richer in Poyang Lake (98 individuals/m^2) than in small to medium lakes (3–61 individuals/m^2) (Xu et al. 2003), probably owing to the richness of allochthonous organic particles.

The present study shares similar results with those in other floodplains such as the Danube and Rhine Rivers. First, the pattern of species richness in Poyang Lake and other waters conforms to the theory that α-diversity of macrobenthos in floodplain waters reaches a maximum at an intermediate level of connectivity (Obrdlik and Fuchs 1991; Tockner et al. 1999; Ward et al. 1999; Amoros and Bornette 2002). As already mentioned, the connected lake Poyang, which has the level of connectivity between disconnected lakes and rivers, is most species rich. Second, collector-filterers dominated in Poyang Lake, as they did in European floodplain waters with high connectivity. In the Dutch Rhine and Meuse, filterers were most numerous in frequently flooded waters (Van Den Brink and Van Der Velde 1991); in a eupotamal lateral channel along the upper Rhine, bivalve filterers reached 281 individuals/m^2 in density, being 30% of the total (Obrdlik and Garcia-Lozano 1992).

Concluding remarks

Benthic macroinvertebrates are very diverse and rather abundant in Poyang Lake. As an invaluable pool of aquatic

Table 3. Density (D, individuals/m^2), biomass (B, g/m^2, wet mass) and percentage of common taxa (D or B > 1% in at least one region) in Poyang Lake and adjoining Yangtze River, with their functional classifications

Taxa	Functional	River				Lake outlet				Main lake			
	group	D	%	B	%	D	%	B	%	D	%	B	%
Annelida													
Nephthys polybranchia	Shredder	**43**	**33.5**	**0.17**	**42.2**	**40**	**7.3**	0.15	0.1	**20**	**3.0**	0.13	0.1
Aulodrilus pluriseta	Collector-gatherer	–	–	–	–	–	–	–	–	**7**	**1.0**	0.00	0.0
Branchiura sowerbyi	Collector-gatherer	**3**	**2.5**	**0.02**	**4.2**	**8**	**1.5**	0.05	0.0	**8**	**1.2**	0.06	0.0
Limnodrilus grandisetosus	Collector-gatherer	**2**	**1.2**	0.00	0.8	–	–	–	–	1	0.2	0.00	0.0
Limnodrilus paramblysetus	Collector-gatherer	**10**	**8.1**	**0.04**	**10.0**	–	–	–	–	–	–	–	–
Spirosperma nikolskyi	Collector-gatherer	–	–	–	–	–	–	–	–	**21**	**3.2**	0.09	0.0
Teneridrilus mastix	Collector-gatherer	**2**	**1.2**	0.00	0.1	4	0.8	0.01	0.0	**49**	**7.4**	0.02	0.0
Tubifex	Collector-gatherer	–	–	–	–	0	0.1	0.00	0.0	**18**	**2.8**	0.00	0.0
Arthropoda													
Harpacticoida	Scraper	**2**	**1.2**	0.00	0.2	–	–	–	–	–	–	–	–
Gammaridae	Shredder	**46**	**36.0**	**0.03**	**7.1**	**47**	**8.6**	0.03	0.0	**85**	**12.9**	0.06	0.0
Ephemera	Collector-gatherer	**8**	**6.2**	**0.09**	**22.3**	**28**	**5.2**	0.42	0.4	**10**	**1.5**	0.40	0.2
Polycentropus	Shredder, collector-gatherer, predator	1	0.6	0.00	0.9	**11**	**2.1**	0.02	0.0	1	0.1	0.00	0.0
Clinotanypus	Predator	–	–	–	–	2	0.4	0.00	0.0	**12**	**1.8**	0.02	0.0
Glyptotendipes	Collector-gatherer, collector-filterer, scraper	–	–	–	–	–	–	–	–	**23**	**3.5**	0.01	0.0
Orthocladius	Collector-gatherer	**2**	**1.9**	**0.01**	**1.4**	–	–	–	–	–	–	–	–
Polypedilum	Collector-gatherer	**2**	**1.2**	0.00	0.1	3	0.6	0.00	0.0	2	0.3	0.00	0.0
Microchironomus	Collector-gatherer	**2**	**1.2**	0.00	0.1	–	–	–	–	1	0.1	0.00	0.0
Mollusca													
Bellamya	Scraper	–	–	–	–	1	0.2	0.28	0.2	4	0.6	**8.25**	**4.4**
Parafossarulus	Scraper	–	–	–	–	**128**	**23.3**	**29.95**	**25.7**	**159**	**24.2**	**51.66**	**27.6**
Anodonta	Collector-filterer	–	–	–	–	1	0.3	0.01	0.0	4	0.7	**3.20**	**1.7**
Corbicula fluminea	Collector-filterer	**2**	**1.2**	**0.02**	**5.8**	**229**	**41.8**	**80.22**	**68.8**	**156**	**23.7**	**118.13**	**63.1**
Lamprotula	Collector-filterer	–	–	–	–	0.4	0.1	**3.66**	**3.1**	–	–	–	–
Limnoperna lacustris	Collector-filterer	1	0.6	**0.01**	**3.4**	**25**	**4.5**	**1.71**	**1.5**	**40**	**6.1**	**5.12**	**2.7**

Bold letters denote relative abundance >1%; –, absent from samples

organisms of the Yangtze floodplain, Poyang Lake should be well preserved, and any attempt of damming around its outlet should be rejected.

Our study was restricted to the northern outlet and the northeast part of the lake, and a large proportion of this huge shallow water body is still uninvestigated. Further studies of benthos as well as other limnological aspects are required for the remaining region. In addition, the other two connected lakes, viz. Dongting Lake (28°44′–29°35′ N, 111°53′–113°05′ E; 2432 km^2) of Hunan Province and Shijiu Lake (31°23′–33′ N, 118°46′–56′ E; 210 km^2) on the border between Anhui and Jiangsu Provinces, also need ecological scrutiny. On the basis of sound scientific knowledge, we hope to highlight the crucial role of connected lakes in the formation of the biodiversity and environment of the Yangtze Basin, and we also hope to promote the conservation of these lake treasures by joint efforts of the decision makers and the public.

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