Original Research

Macroinvertebrate Communities in Recovery Phase in the Middle Reaches of China's Huaihe River

Shi-Yun Chi[1], Jin-Xiu Zheng[1], Gang Yang[2], Ming Li[1], Ju-Xiang Hu[1]*

[1]Key Laboratory of Ecological Impacts of Hydraulic Projects and Restoration of Aquatic Ecosystems, Ministry of Water Resources, Institute of Hydroecology, Ministry of Water Resources, Chinese Academy of Sciences, Wuhan 430079, P.R. China
[2]Huaihe River Water Environmental Monitoring Center; Huaihe River Water Resources Protection Bureau, Bengbu 233000, Anhui, P.R. China

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Abstract

After more than 10 years of treatments against water pollution, the water quality of the Huaihe River has improved considerably. At present, the river is in recovery phase. Two surveys on macro-invertebrates were carried out in the middle reaches in May and October 2010. Fifteen sampling stations were set up along the trunk, including Hongze Lake. Thirty-four species were recorded, and poor species and low biodiversity were the main community characteristics of this river. Significant differences in assemblages were found between the trunk and lake. Collectors were the chief functional feeding group in the trunk, while predators were the chief group in the lake. The species number in Hongze Lake decreased considerably compared to the historical data. Total phosphorus and temperature were important factors affecting the distribution of macroinvertebrates in the trunk, while pH, dissolved oxygen, and chlorophyll were the important factors in the lake. Sand mining, industrial and non-point pollution, and urbanization were the important factors causing degradation of whole aquatic ecosystems in the river basin. Two new alien species from the Yangtze River were first recorded in Hongze Lake, and the previous recorded alien species *Nephthys* sp. has spread into the whole lake and the trunk. Due to having similar histories of water pollution, the Huaihe would experience a process of recovery similar to the Rhine River.

Keywords: macro-invertebrates, species number, biodiversity, recovery phase, Huaihe River, functional feeding groups, alien species

Introduction

The Huaihe River basin in East China, covering 2.7×10^5 km^2 area, is famous for its high population density. As one of the regions short of water resources, the average water consumption in this basin is less than 1/5 of the average countrywide level [1, 2]. The water pollution gradually became serious due to discharges of domestic and industrial wastewater in the 1970s [3]. From 1989 to 2001, five big pollution incidents occurred in the river, resulting in a sharp reduction of population sizes and mass extinction of many riverine organisms [4]. Meanwhile, the water pollution exacerbated the shortage of water resources and became a constraining factor of economic development of the region [5]. In order to control pollution, the State

*e-mail: hujuxiang2005@163.com

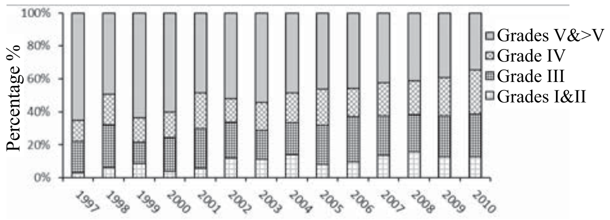

Fig. 1. Comparision of water quality of main monitoring sections in the Huaihe River 1997-2010. In the chart, the percentages of the water quality with different grades were shown in every year. The percentages of grades V& > V had decreased with years, while the percentages of grades I&II had increased steadily with years. Grade > V presents that water quality was worse than grade V. All the grades were classified according to the environmental quality standards for surface water in China. All the data were published by the Huaihe River Water Resources Commission.

Council enacted China's first basin-wide water pollution control law, "Provisional Regulations on the Huaihe River Water Pollution Control," and clearly established the aim of Huaihe water resources management in 1995 [2]. After more than 10 years of treatments against water pollution, Huaihe water quality has improved considerably [6]. The detail data was also seen in Huaihe water resource bulletins from 1997-2010 (Fig. 1).

Macro-invertebrates, with a long life history and weak ability of migration, due to having different sensitivities to several anthropogenic pressures such as water pollution, hydrological, and geomorphological alterations in different species, are often considered a useful bio-indicator tool for monitoring and assessing water quality and aquatic ecosystem health. Moreover, macro-invertebrates constitute an important link between energy sources and top predators in aquatic ecosystems [7]. As an intensively regulated big river, the river is famous for numerous floodgates and dams for food control, navigation, power generation, irrigation, and water supply. For instance, more than 5,700 reservoirs and 5,000 floodgates have been built within the basin [8]. Due to historical reasons, the macro-invertebrate data of the trunk of this river is relatively scarce and insufficient compared with other big rivers in China. However, in past decades Hongze Lake, a river-connected lake, was relative frequently investigated for biological elements for fishery resources, but all these works were mainly conducted before the 1990s [9]. At present, water quality and the aquatic ecosystem have obviously been improved according to chemical analysis data. However, recovery and reconstruction of the impaired ecosystem is a long-term process, the individual chemical data are insufficient to confirm the improvement. Biological data also are required to evaluate the improvement of aquatic ecosystems. The aims of this study are: 1) to describe and evaluate the macro-invertebrate communities in recovery phase, 2) to explore the relationships between macro-invertebrate communities and environmental factors, and 3) to compare with similar rivers and get valuable experiences.

Materials and Methods

Study Area

The Huaihe originates from Tongbai Mountain in Henan Province and flows east across Henan, Anhui, and Jiangsu provinces. As one of the seven biggest rivers in China, the river, with a total length of about 1,000 km, is divided into three reaches: the upper reaches are above

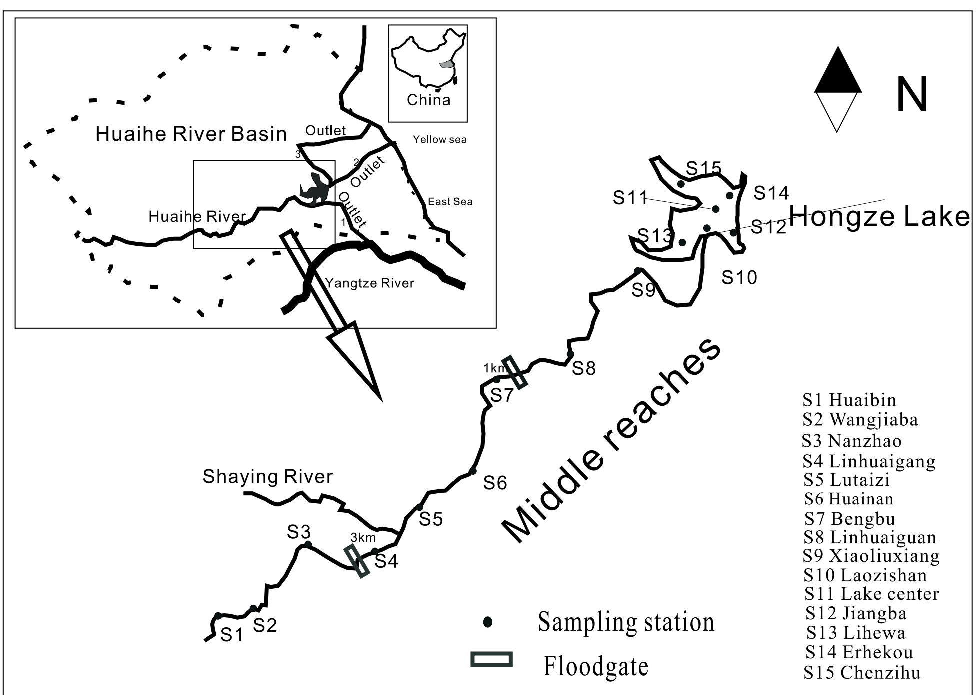

Fig. 2. Locations of sampling stations in Huaihe River of China.

Table 1. Physical and chemical characteristics of water in Huaihe River. Different letters (a, b) represent the differences in parameters between seasons were significant by Mann-Whitney U Test ($p<0.05$), while same letters (a, a) represent the differences were not significant ($p>0.05$)

Parameters	The trunk (Mean±SD)		The lake (Mean±SD)	
	May	October	May	October
Temperature (ºC)	22.51±0.55 (21.70-23.10)^a	17.95±0.92 (16.60-19.80)^b	20.42±0.36 (20-21)^a	14.35±1.24 (13.50-16.70)^b
pH	6.96±0.31 (6.69-7.63)^a	7.18±0.18 (6.90-7.42)^b	7.28±0.19 (7.09-7.63)^a	7.57±0.19 (7.24-7.78)^b
DO (mg/L)	7.20±0.82 (6.33-8.36)^a	8.65±0.56 (7.75-9.35)^b	9.72±0.85 (8.43-10.83)^a	10.88±1.66 (8.86-13.62)^a
COD_{MN} (mg/L)	3.31±0.37 (2.88-3.89)^a	3.34±0.15 (3.18-3.58)^a	3.73±0.54 (3.08-4.70)^a	4.36±1.00 (3.50-5.99)^a
NH_3-N (mg/L)	0.50±0.24 (0.32-1.00)^a	0.18±0.03 (0.14-0.23)^b	0.48±0.08 (0.39-0.58)^a	0.21±0.03 (0.15-0.24)^b
TP (mg/L)	0.11±0.05 (0.07-0.22)^a	0.07±0.03 (0.05-0.15)^b	0.06±0.02 (0.04-0.09)^a	0.06±0.01 (0.04-0.07)^a
F^- (mg/L)	0.53±0.05 (0.50-0.60)^a	0.46±0.05 (0.40-0.50)^a	0.60±0.15 (0.50-0.80)^a	0.60±0.09 (0.50-0.70)^a
TN (mg/L)	2.99±0.67 (2.04-4.05)^a	3.81±0.80 (2.40-4.80)b	2.17±0.87 (0.84-3.09)^a	2.21±0.74 (1.16-2.97)^a
Chl. (µg/L)	1.55±0.23 (1.29-1.96)^a	1.55±0.42 (1.00-2.35)^a	2.79±1.63 (1.18-5.23)^a	4.52±3.04 (2.13-10.17)^a

Honghekou, the middle reaches are from Honghekou to Hongze Lake, and the lower reaches downstream of Hongze Lake. The river has three water outlets to sea in Hongze Lake. Outlet 1 runs across Sanhe Gate, Baoyin Lake, Gaoyou Lake, and finally joins into the Yangtze River at Sanjiangying. Outlet 2 flows across Gaoliangjian Gate and the Subei irrigation drainage into the Yellow Sea at Biandantang Port (Fig. 2). Outlet 3 runs across Erhe Gate along Huaishu River into Haizhou Bay.

The river basin is located in the climate transition zone between south and north China with moderate climate. The temperature increases gradually along the direction from north to south as well as from coastland to inland. The mean annual temperature ranges from 11 to 16ºC. The mean annual evaporation volume is 900-1,500 mm, and frost-free period is 200-240 days. The river is mainly located in alluvial plains, with slow flow, about 0.1-0.3 m/s, average depth of 3-4 m, and poor drainage, where disaster floods always happen in flood season, historically known as "harm river." In this study, the sampling stations were all located in the middle reaches, including Hongze Lake, the biggest lake in the river basin. The lake covers 1576.9 km^2, with average depth of 1.77 m and maximum of 4.37 m. The lake is made up of three bays, like Chenzihu Bay, Lihewa Bay, and Huaihe Bay.

Sampling Stations

Fifteen sampling stations were set up along the middle reaches (Fig. 2). Among them, 9 stations were located upstream of Hongze Lake, including S1 (distance to Hongze Lake 454 km, river width 154 m, substrate sand), S2 (425 km, 160 m, sand), S3 (369 km, 215 m, sand), S4 (326 km, 227 m, silt), S5 (289 km, 313 m, silt), S6 (237 km, 430 m, silt), S7 (183 km, 712 m, silt), S8 (143 km, 349 m, silt), and S9 (73 km, 377 m, silt); 6 stations were in Hongzehu Lake, including S10 (in the watercourse to lake, silt), S11 (in the center of lake, silt), S12 (in Huaihe Bay, silt), S13 (in Lihewa Bay, silt), S14 (nearby the Erhe gate, silt), and S15 (in Chenzi Bay, silt). Two investigations were conducted in May and October, 2010, respectively. The substrates of upper stations are made up of sand, while in lower stations the substrates are silt. The river width of the trunk varies from upstream to downstream, ranging from 154 m to 712 m.

Data Collection and Treatment

Macro-invertebrate samples with four replications were collected in each sampling station with modified Peterson grab (1/16 m^2) by ship along transection**.** All replicate samples were pooled into a big sample representing the station sample. Biological samples were sieved by 500 µm mesh and washed prior to putting into plastic bags in the field. After simple hand-sorting, the organisms were put into sample bottles, labeled for future check, and fixed with 10% of formalin solution. The organisms were counted and identified to possible level with an Olympus BH-2 microscope and Leica EZ4D dissecting microscope. Wet weights of organisms were measured by electronic balance with accuracy of 0.0001 g. All taxa were categorized into FFGs based on available information [10, 11].

A total of nine physicochemical-water parameters were measured. Four parameters were measured *in situ* with a muti-parameters analyzer (Hydrolab DS5X) at each sampling station, including water temperature, pH, dissolved oxygen (DO), and chlorophyll (Chl.). The remaining five parameters, including chemical oxygen demand (COD_{Mn}), ammonia nitrogen (NH_3-N), total phosphorus (TP), fluoride (F^-) and total nitrogen (TN) were measured after water samples were taken into polypropylene bottles, stored at 4 ºC, and transported into a laboratory. Water samples were collected from the surface layers. Statistical analysis was done using SPSS (v 17.0) software when need.

Table 2. List of macroinvertebrates in the study area.

Species	The trunk (S1-S9)	The lake (S10-S15)
Polychaetes		
Capitella sp.		○
Nephthys sp.	√	○
Terebellides sp.		○
Oligochaetes		
Limnodrilus grandisetosus	√	
Limnodrilus hoffmeisteri	√	
Aulodrilus sp.	√	○
Branchiura sowerbyi	√	
Oligochaeta non det.	√	○
Aquatic insects		
Polypedilum sp.1	√	
Polypedilum sp.2	√	○
Stictochironomus sp.	√	
Cryptochironomus sp.	√	
Demicryptochironomus sp.	√	
Thienemannimyia sp.		○
Chironomus sp.		○
Procladius sp.	√	
Tokunagayusurika sp.	√	
Psychomyiidae non det.	√	
Mollusks		
Novaculina chinensis	√	○
Corbicula fluminea	√	○
Unio douglasiae	√	
Arconaia lanceolata	√	
Limnoperna fortunei	√	*
Semisulcospira cancllata	√	*
Bellamya purificata	*	○
Bellamya aeruginosa	√	*
Stenothyra glabra		○
Alocinma longicornis	*	*
Radix sp.		*
Gyraulus convexiusculus		*
Crustaceas		
Asellus sp.		○
Gammarus sp.	√	○
Others		
Hirudinea non det.	√	
Nematoda non det.	√	

The symbol '√' represents the species collected in May; the symbol '○' represents the occurrence species in October; the sign '*' indicates when the species historically appeared.

Species matrix with quantitative data (ind./m^2) and an environmental matrix with nine parameters were made prior to doing multivariate analysis. NMDS (nonparametric multi-dimensional scaling) and MRPP (pair-wise multi-response permutation procedure) analysis were performed with a Sørensen (Bray-Curtis) distance measure. Environmental data were Box-Cox transformed for approaching normality when needed, and species data were square-root transformed prior to PCA (principal component analysis) and NMDS analyses. In PCA analysis, the first axes with eigenvalues higher than 1 were retained to calculate the synthetic principle component for representing the water pollution gradient. The synthetic principle component was then used to build models between the water pollution gradient and different FFGs. Only linear or quadratic models between them were explored. NMDS, PCA, and MRPP analysis were performed using PC-Ord for Windows (v 5.0).

Results

Physical and Chemical Characteristics

Significant differences in temperature between seasons both in the trunk and the lake were found by Mann-Whitney U Test ($p < 0.05$), as well as in pH and NH_3-N ($p < 0.05$). In the trunk, the values of TP in May were significantly higher than in October, while the values of DO and TN in October were significantly higher than in May ($p < 0.05$). In the lake, no differences in the values of DO, COD_{MN}, TP, F^-, TN, and Chl. between seasons were found ($p > 0.05$). In May, significant differences in temperature, pH, DO, and TP between locations (the trunk versus the lake) were found ($p < 0.05$), while in October, significant differences in temperature, pH, DO, COD_{MN}, F^-, TN, and Chl. between locations were also found ($p < 0.05$) (Table 1).

Macro-Invertebrate Communities

A total of 34 species (12 Mollusks, 10 aquatic insects, 5 oligochaetes, 3 polychaetes, 2 crustaceas, 2 others)

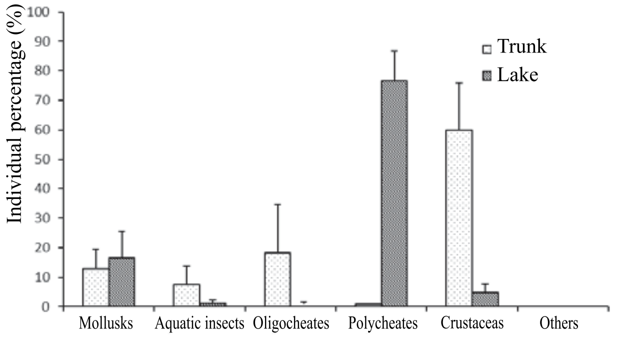

Fig. 3. The composition of different groups in macroinvertebrates.

Table 3. Density, biomass, Shannon-Wienner index and species number of macroinvertebrates at different sampling stations.

Reaches	Station code	Density (ind./m^2)		Biomass (g/m^2)		Shannon-Wienner index		species number
		May	October	May	October	May	October	Both seasons
The trunk	S1	244.4	0	0.40	0	1.97	/	7
	S2	155.6	66.7	2.04	0.02	1.15	1.59	6
	S3	874.1	466.7	0.73	328.60	1.22	0.45	6
	S4	2048.0	9422.2	14.33	203.02	0.79	0.78	8
	S5	266.7	82.4	273.03	0.68	1.46	0.99	5
	S6	222.2	177.8	0.94	0.03	1.37	1.41	5
	S7	/	266.7	/	101.98	/	1.21	4
	S8	222.2	155.6	0.52	0.56	0.97	1.56	5
	S9	111.1	64.0	0.87	50.64	1.37	1.06	6
The lake	S10	266.7	264.0	348.64	49.32	0.92	0.78	5
	S11	88.9	32.0	1.33	36.75	0.00	1.00	3
	S12	533.3	368.0	110.45	60.12	2.12	0.85	6
	S13	266.7	144.0	4.61	8.88	1.00	1.10	5
	S14	400.0	128.0	3.66	1.47	1.75	0.99	4
	S15	177.8	136.0	514.88	0.95	0.81	0.95	6

from 8 classes, 11 orders, 18 families, and 27 genera were recorded by two surveys. Thereinto, 18 and 23 species were collected in May and October, respectively (Table 2). In the trunk, crustaceans accounted for more than 60% of total individuals, in Hongze Lake polychaetes were the dominant group, accounting for more than 70% of individuals (Fig. 3). Mollusks and aquatic insects accounted for relatively low proportions both in the trunk and the lake.

The species number varied from 3 to 8 with 5.4 per station. Species numbers per station in trunk and lake were 5.8±1.1 (5-8) and 4.8±1.1 (3-6), respectively. No significant differences in species number between locations were found (Mann-Whitney test, P=0.224). Shannon-Wienner indexes per station in May and October were 1.21±0.54 (0-2.12) and 1.05±0.31 (0.45-1.59), respectively. Differences in Shannon-Wienner indexes between seasons and locations were not significant either (Mann-Whitney test, $P > 0.05$) (Table 3, Fig. 4). In total, species number and biodiversity per station were very low both in the trunk and the lake.

The total densities in May and October were 419.8±491.6 (88.9-2048.0) and 784.9±2311.7 (32.0-9422.2) ind./m^2 respectively. In the trunk, the densities

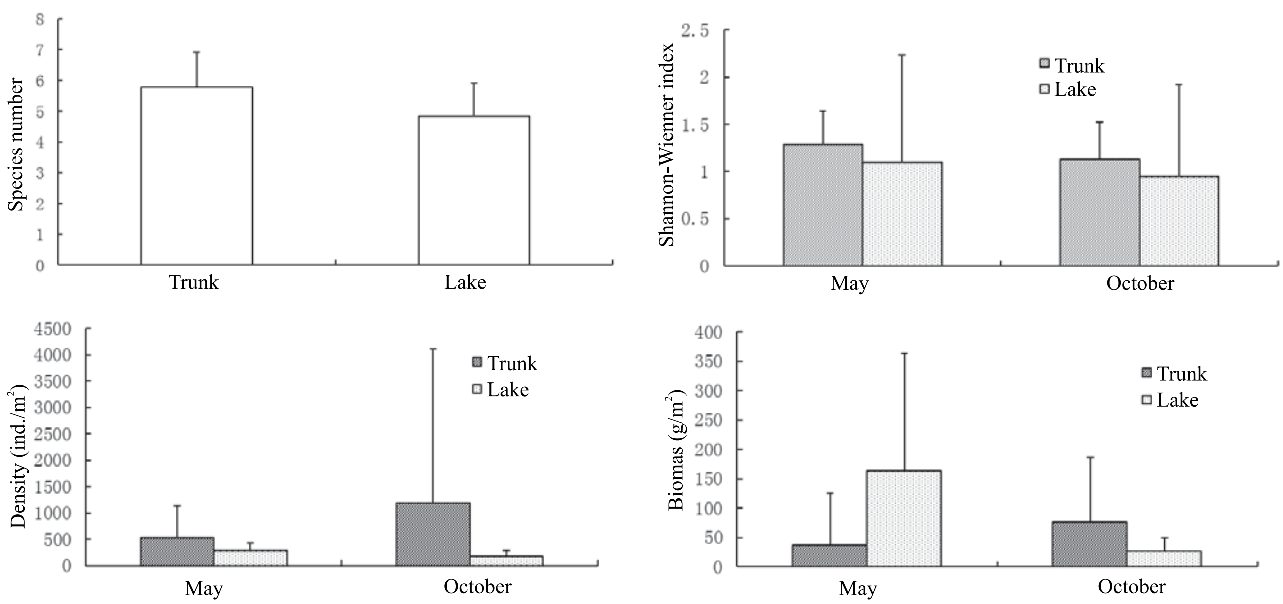

Fig. 4. Species numbers, Shannon-Wienner indexes, densities, and biomass in different locations and seasons.

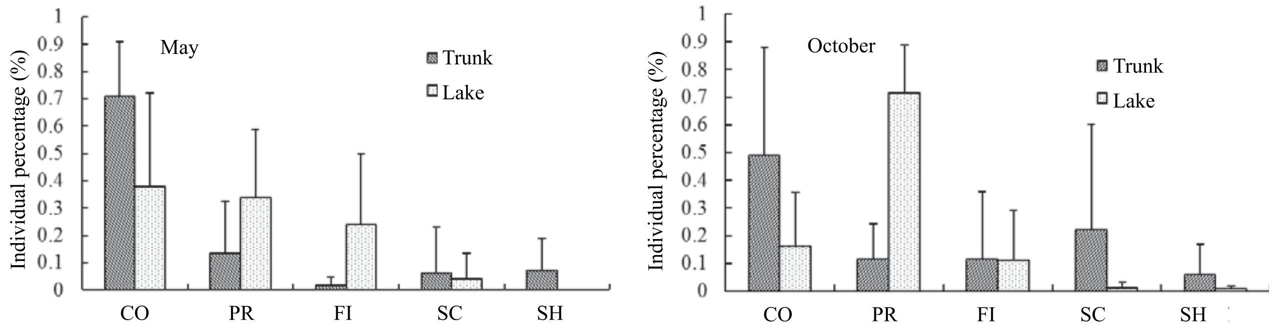

Fig. 5. Individual percentages of different functional feeding groups between seasons and locations. CO = Collectors, PR = Predators, FI = Filters, SC = Scrapers, SH = Shredders.

in May and October were 518.0±620.2 (111.1-2048) and 1189.1±2913.8 (0-9422.2) ind./m^2 respectively. In the lake, the densities in May and October were 288.9±144.6 and 178.7±108.2 ind./m^2 respectively. The total biomass in May and October were 91.17±44.31 (0.40-514.88) and 56.20±24.13 (0-328.60) g/m^2 respectively. In the trunk, the biomass in May and October were 36.61±89.47 (0.4-273.03) and 76.17±110.53 (0-328.6) g/m^2 respectively. In the lake, the biomass in May and October were 163.93±199.02 (1.33-514.88) and 26.25±23.61 (0.95-60.12) g/$m^{2,}$ respectively. There were no significant differences in densities and biomass between seasons (Mann-Whitney test, $p > 0.05$) (Table 3, Fig. 4). Whether in the trunk or in the lake, densities between seasons had no significant differences, as well as biomass. Similarly, whether in May or in October, no significant differences in biomass between locations were found.

Multivariate Analysis Functional Feeding Groups (FFGs) and Distribution

The chief FFGs in the trunk and lake were collectors and predators, respectively. The individual percentages of filters both in the trunk and lake were all low relative to other FFGs (Fig. 5). The collectors were mainly represented by *Limnodrilus grandisetosus*, *Limnodrilus hoffmeisteri*, *Aulodrilus* sp., and *Branchiura sowerbyi*, while the predators were mainly represented by *Nephthys* sp., and the filterers were mainly represented by *Corbicula fluminea*.

In PCA analysis with correlation model, the first two axes had eigenvalues higher than 1 (the first axis, 4.45, the second axis, 2.0), and explained 71.51% of the overall variability. The first axis was highly positively correlated with pH, DO, and COD_{Mn}, and negatively correlated with temperature. Meanwhile, the second axis was negatively correlated with NH_3-N (Table 4). The synthetic principal component (PC_S) was calculated according to the proportions of eigenvalues to represent the water pollution gradient. The individual percentages of collectors increased along the water pollution gradient. However, the individual percentages of predators decreased along the pollution gradient (Fig. 6).

Table 4. Correlations of the first two PCA axes and water metrics. The bold words emphasize the correlation coefficients are higher.

Variables	PC1	PC2
Temperature	**-0.77**	-0.46
pH	**0.84**	0.05
DO	**0.84**	0.16
COD_{Mn}	**0.78**	-0.33
NH_3-N	-0.39	**-0.84**
TP	-0.64	-0.40
F^-	0.64	-0.55
TN	-0.49	0.66
Chlorophyll	**0.80**	-0.21

MRPP and NMDS Analysis

The MRPP analysis was used to test differences in assemblages between seasons and locations. There were no significant differences between the May and October assemblages in all stations, but significant differences in the trunk assemblages between seasons were detected except in the lake assemblages. The trunk assemblages were significantly different from the lake assemblages in different seasons, not affected by season variations (Table 5).

In NMDS analysis (stress = 0.155 for 3-dimensional solution), the trunk assemblages were separated from the lake assemblages in the tri-plot, which was confirmed by the MRPP analysis. The scores of the first axis were significantly related to several water metrics like DO, pH, Chl., Temperature, and TP (Cut-off r^2 0.2), indicating the first axis mainly representing the water pollution gradient. In order to find several species for which the distribution was significantly affected by the water pollution gradient, a cut-off r^2 0.3 was set up. In the tri-plot, oligochaetes like *Limnodrilus grandisetosus* and *Limnodrilus hoffmeisteri* frequently occurred in the trunk, where water pollution was always serious, and polychaetes like *capitella* sp. and

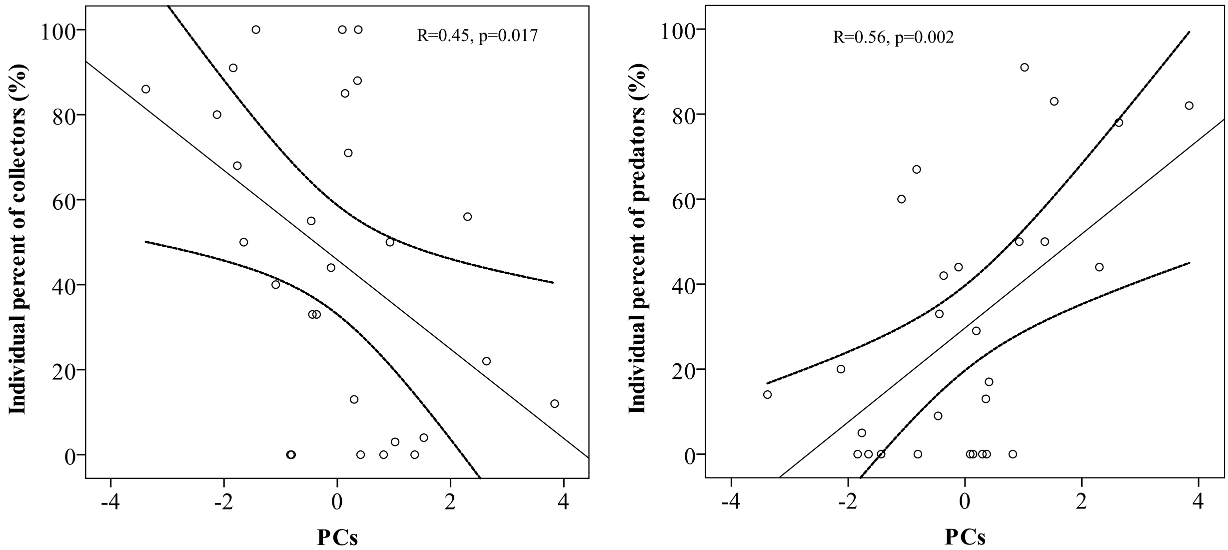

Fig. 6. Collectors and predators in relation to the water pollution gradient (PCs).

Table 5. Results of Multi-Response Permutation Procedure tests (MRPP) among different groups.
The bold words emphasize the p-values <0.05.

Pair-wise comparison	T-statistic	P-value	A-value
May vs. October (in the trunk)	-2.799	**0.011**	0.112
May vs. October (in the lake)	-1.350	0.098	0.059
May vs. October (All stations)	-1.489	0.083	0.033
Station 1-9 vs. station 10-15 (May)	-4.732	**0.0013**	0.244
Station 1-9 vs. station 10-15 (October)	-3.409	**0.0036**	0.117
Station 1-9 vs. station 10-15 (Both seasons)	-6.678	<**0.001**	0.149

nephthys sp. always occurred in the lake where the water pollution was relatively slight (Fig. 7).

Discussion

Macro- Invertebrate Communities and Comparison of Historical Data

In Hongze Lake, polychaete species such as *Nephthys* sp. was the dominant, followed by *Corbicula fluminea,* while gammarus and chironomids occurred infrequently. In the trunk upstream of station S6, oligochaetes and chironomids were the dominant, while polychaetes *Nephthys* sp. no longer appeared. In the lake, although living mollusks *Corbicula fluminea* were collected in most stations, the debris of this species always appeared

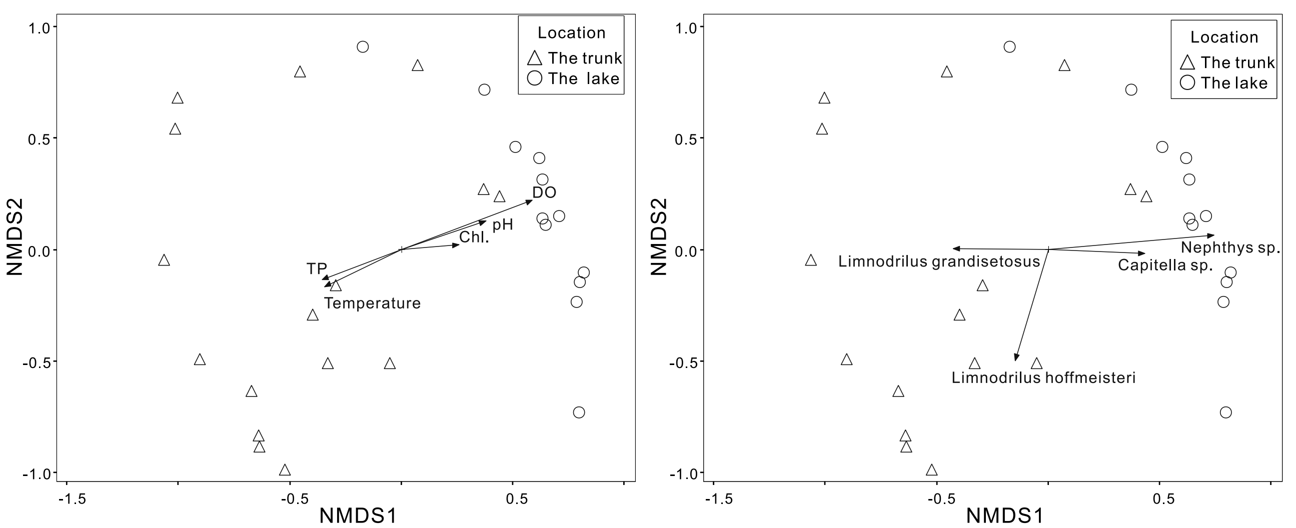

Fig. 7. NMDS of macroinvertebrate community data, showing horizontally the first axis and vertically the second axis. Sampling sites are represented by triangles (the trunk) and circles (the lake). The length of the arrow is a measure of the variable and the arrowhead points in the direction of increasing influence. TP-total phosphorus, DO-dissolved oxygen, Chl.-chlorophyll.

in large amounts. In the trunk, the species *Corbicula fluminea* didn't appear in the trunk upstream of station 9. The relative abundance of mollusks in both the trunk and lake were lower than the other groups. According to our results, only 19 species were collected in the lake. Compared with available historical data, the species number had decreased sharply (from 50-60 species to 19 species) [9]. In the available documents, the polychaetes species *Nephthys* sp. often occurred in the area around station S15 since the 1980s and spread into the whole lake beginning in the 1990s. But no documents reported this species had spread into the trunk. In this study, this species occurred in station S6 in the trunk, with a distance of about 237 km from the lake. The species *Nephthys* sp. was regarded as an invasive alien species from the Yangtze River through the Yangtze River to the Northern Jiangsu Water Transfer Project [9]. Surprisingly, the polychaetes species *Capitella* sp. and *Terebellides* sp., typical euryhaline species occurring in estuary, were first recorded in the lake by our investigations. Maybe it was related to navigation and water diversion projects. Regretfully, the salinity was not measured due to lack of available probes during the investigations. The reason details will be explored in the next study. About 5 mollusk species were distributed ubiquitously in the lake, including *Corbicula fluminea*, *Limnoperna fortune*, *Novaculina chinensis*, *Bellamya aeruginosa*, and *Semisulcospira cancllata* [9]. According to our results, *Corbicula fluminea* still dominated in the lake, but other mollusk species such as *Semisulcospira cancllata, Novaculina chinensis, Alocinma longicornis,* and *Bellamya spp.* occurred infrequently.

Main Factors Affecting the Recovery of Macro-Invertebrates

The assemblages between locations were different, not relating to season variation, which was confirmed by the NMDS and MRPP analysis, indicating the trunk and lake belonged to different aquatic ecosystems, although they were connected to each other. In the trunk, total phosphorus and temperature were important factors affecting the distributions of macroinvertebrates, such as oligochaete species *Limnodrilus grandisetosus* and *Limnodrilus hoffmeisteri*. However, in the lake, relatively high pH, dissolved oxygen, and chlorophyll were the typical symptoms of eutrophication, and these factors affected the distributions of macroinvertebrates, such as polychaete species *Nephthys* sp. and *capitella* sp. In all, our results suggested the ecosystem status of this river system was not good in the recovery phase.

Intensive sand mining often whirls up the sand sediment, making it unsuitable for macroinvertebrates [12]. Intensive sand mining in the trunk, especially in the reaches from stations S1 to S3, was widespread, leading to the decreasing of the mollusk *Novaculina chinensis,* a common and dominant species historically. This species was only collected in stations S1 and S12 with low density and biomass during two investigations. Literature showed that industrial and non-point pollution were the main factors causing the degression of water quality and aquatic ecosystems [3]. Although the surface water quality in the river has improved considerably in recent years, the sediment pollution, like heavy-metal pollution, could not decline significantly in a short time. Many paper mills along the river had discharged massive heavy metal sewage historically, and the metals were transferred into the sediments of the river, causing serious heavy-metal pollution in Hongze Lake [8]. Fine sediments can accumulate toxics from present and past contamination during a certain period [13]. Although water column toxicity had more adverse effects on macro-invertebrates than sediment toxicity [14], the long-term negative effects of sediments should not be neglected. A species-rich macro-invertebrate com-munity was always observed in the sediment with high food quality and low contaminant concentrations [15]. During the second survey some caddisflies were found in station S4, located in a new riverbed for navigation with relatively good sediment quality. Although significant impacts of toxic contamination on filters, scrapers, shredders, and predators were found [16], their specific effects were different. Studies showed predators were less sensitive than other functional groups to metal conta-mination [17-19]. Our results showed that the percentages of shredders, scrapers, and filters were low in most sampling stations, while the percentage of predators was higher in Hongze Lake than in the trunk. Perhaps the predators were more tolerant to heavy-metal pollution than other FFGs. Water pollution had different effects on different FFGs. For example, collectors were more tolerant than predators to water pollution, especially to organic pollution. In our study, collectors were the main FFGs in the trunk, and the individual percentage increased along the water pollution gradient. In the lake, water pollution declined while eutrophication was still serious. The individual percentage of filters was relatively low, while individual percentages of pre-dators was high, decreasing along the water pollution gradient.

Urbanization is a major disruptive force to degression of river ecosystems when human population density reaches a critical limit within a catchment, resulting in degraded physio-chemical conditions with associated biotic changes [20]. Moreover, river management (e.g. impoundments, water abstraction, channel modifications) can also affect macro-invertebrate assemblages [21-23]. Until 2000, the amount of floodgates and dams in the river basin had already reached up to 1.1×10^4 [24]. In the past 10 years, urbanization along the river has sped up. Due to urbanization, the percentage of urban sewage exceeded that of industrial wastewater in 1999, and the ratio of sewage-to-industry effluents was becoming greater in the following years [3]. Maybe the low species number and low biodiversity per station were related to high urbanization percentages and high population density, bringing high anthropogenic pressures on the river system.

Comparison with Similar Rivers

In the Yangtze River basin the polychaetes species *Nephthys* sp. was also found in Taihu Lake [25], in the section Tonglin city of Anhui Province, Poyang Lake, and some tributaries of the Yangtze river (from own data). According to the data collected, this species can live in freshwater bodies far away from the estuary. Generally, this species is regarded as a typical brackish species, salt water from the estuary can't reach into the section Jiujiang city in Jiangxi Province theoretically. Maybe this species spread into these freshwater bodies by shipping. Unlike the Yangtze, the Huaihe is essentially a semi-closed freshwater body without direct native water outlets into the sea. As several floodgates or dams were built for water regulation, saltwater intrusion can't take place. The species *Nephthys* sp., *Capitella* sp., and *Terebellides* sp. were found in the Huaihe as invaders from the Yangtze. Why do these typical brackish species survive in the Huaihe? Where are their limits of distribution? How do these non-indigenous species impact the native species in the process of river recovery? These are very interesting ecological phenomena for us to explore. Maybe these species can adapt to the freshwater environment and succeed in survival and reproduction.

Compared with the Huaihe, the Rhine has a similar history of water pollution. Water pollution from municipal and industrial wastewater such as organic loads, heavy metals, and pesticides caused a loss of native macro-invertebrates and fish untill the 1970s. Recolonization of native macro-invertebrate species and the appearance of exotic species was observed in the main channel after water quality was improved by sanitation [12]. Prolonged pollution changed the original communities and caused a loss of certain species, simultaneously creating open niches for pollution-tolerant alien species, especially in the process of river recovery and under connectivity between different watersheds [26]. The macroinvertebrate communities of the Rhine were numerically dominated by exotic species [12]. Meanwhile the native species *Ephoron virgo* reappeared in this river after being absent for decades [27]. The water quality of the Rhine has substantially improved, although macro-invertebrate species richness has largely recovered to former numbers, community composition has been substantially altered primarily by invasive species [28]. It seemed that similar recovery process could happen in the Huaihe. For instance, alien species were found in both rivers, and water quality was improved in recent years after measures to control pollution were taken. At present, the effects of invaders on the native species, the original community, and the whole ecosystem are not clear. So it is necessary to carry out continual investigations and research to observe and explain the long-term effects.

Conclusion

Low species numbers and biodiversity of macroinvertebrates were still the typical characteristics of the river system in this stage, although the water quality has improved considerably by means of chemical analysis. In Hongze Lake, the species number decreased considerably compared to historical data, and the whole lake was in the process of eutrophication. The assemblages of macroinvertebrates were significanty different in the trunk and the lake, caused by differences in aquatic systems. According to the PCA results based on water metrics, the water pollution in the trunk was more serious than in the lake. In trunk, total phosphorus and temperature were important factors affecting the distributions of macroinvertebrates. In the lake, pH, dissolved oxygen, and chlorophyll were the important factors. Sand mining, industrial and non-point pollution, and urbanization were the important factors for degradation of the whole aquatic ecosystem in the river basin. In comparison with the Rhine, we thought the river would have similar recovery process.

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