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Short-term effects of drawing water for connectivity of rivers and lakes on zooplankton community structure

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Abstract

During 28–29, September 2005, water was drawn from Hanjiang River and Houguan Lake to the Yangzi River via Sanjiao Lake and Nantaizi Lake in Wuhan in order to provide favorable conditions for ecosystem restoration. To evaluate the feasibility and validity of drawing water as a means of ecosystem restoration, zooplankton populations were studied 3 times (before, immediately after finishing and a month after drawing water) at seven locations from 27 Sept. 2005 to 2 Nov. 2005. Water quality in the lakes was mostly improved and zooplankton species richness decreased as soon as drawing water had finished but increased a month after drawing water. Zooplankton density and biomass was reduced in the lakes by drawing water but was increased at the entrance to Sanjiao Lake because of landform geometry change. Before drawing water, most species in Sanjiao Lake e.g., *Brachionus* sp. and *Keratella* sp. were tolerant of contamination. After drawing water oligotrophic-prone species such as *Lecane ludwigii* and *Gastropus stylifer* emerged. We conclude that drawing water could be important for improving water quality and favour ecosystem restoration. Dilution of nutrient concentrations may be an important role in the effect.

Key words: drawing water; connectivity; zooplankton; species richness

Introduction

Connectivity of lakes and rivers, especially some urban lakes, were separated from each other because of the reconstructive activities of human such as enclosing lakes for aquaculture or impoldering lakes for building (Aoyagui and Bonecker, 2004; Cottenie and De Meester, 2003; Knösche, 2006). These obstructed lakes were usually eutrophicated for the input of sewage water, industrial wastewater or aquaculture water (Daniel *et al*., 1998; Correll, 1998). Re-connecting these eutrophic lakes was considered as an important issue and necessary engineering to improve water safety and environment health.

Connectivity of water-bodies can enhance their spatial heterogeneity and biocomplexity (Amoros and Bornette, 2002). Recent modeling by Loreau and Mouquet (1999) showed that immigration can increase local species diversity in competitive communities open to interactions with other communities. In similar but isolated communities without immigration, competition for space can lead to the exclusion of all but one species. Havel *et al*. (2000) found a positive relation between connectivity of scour basins with the Missouri River and species richness, and then illustrated the importance for local diversity of connections with immigration sources. Shurin *et al*. (2000) found that local species richness was positively related to the number of species in the surrounding area, a result that may suggest a large role for dispersal limitation.

The status of a lake can be assessed by analyzing the structure of its biological communities. In particular zooplankton, are excellent indicators of the trophic status of a lake, due to their pivotal position in food web and top-down feedback mechanisms (Beaver and Havens, 1996; Jeppesen *et al*., 1999; Scheffer, 1999; Pereira *et al*., 2002). Zooplankton abundance can indicate the variation in trophic status, so it is regarded as a sensitive tool for monitoring eutrophication (Whitman *et al*., 2004; Pereira *et al*., 2002; Silva *et al*., 1997; Magadza, 1994).

The objective of this study was to investigate the changes on zooplankton community structure and water quality parameters resulting from drawing water, and, using zooplankton community structure, evaluate the feasibility and validity of the route and plan for drawing water.

1 Materials and methods

Moshui Lake, Longyang Lake, Sanjiao Lake and Nantaizi Lake belong to the same water-shed in Hanyang City. With the development of the city and aquaculture, the lakes became separated from each other and eutrophic. In order to improve the water quality and restore the ecosystem, a

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project to connect the lakes and rivers was carried out.

1.1 Sampling

The routes for drawing water were:

Hanjiang River → Qinduan Stream → Zhuhulaogang → Zhujiaxingang → Dangshan Canal→Sanjiao Lake
Houguan Lake→Dagudu Stream ——↑
→Nantaizi Lake→Yangzi River

Water was draw out by the pump from Hanjiang River at Qinduankou Brake from 09:00 on 27 Sept. to 10:00 on 29 Sept., 2005, from 9:00 on 28 Sept. to 10:00 on 29 Sept., 2005, and from Houguan Lake from 10:00 on 28 Sept. to 16:00 on 29 Sept., 2005.

The quantities were ca. 120×10^4 m^3 at Qinduankou Brake (10–100 m^3/s); ca. 10×10^4–13×10^4 m^3 from Hanjiang River (1–6 m^3/s) and ca. 20×10^4 m^3 from Houguan Lake (8–12 m^3/s).

1.2 Sample collection and analysis

The samples were collected at the same time on 27 Sep., 29 Sep. and 2 Nov., 2005. The sampling sites are indicated in Fig.1. Zooplankton samples were concentrated by filtration through a 64-μm-mesh screen. Macrozooplankton was collected by concentrating 10 L of filtered water sample and completely counted. For microzooplankton, a 1-L water sample was concentrated to 30 ml using sedimentation chambers and sub-samples were used to quantify under microscope. Each sample was immediately placed in sucrose-saturated 4% formalin for zooplankton preservation.

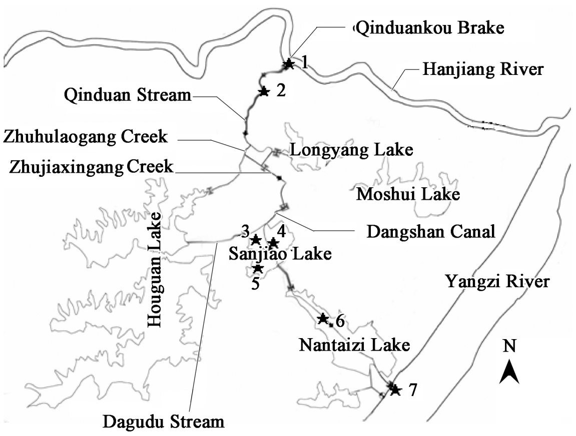

Fig. 1 Locations of sampling sites.

The physico-chemical parameters were measured by GB 7466-7494–87 analysis methods.

2 Results

2.1 Environmental parameters

By comparing the control data before drawing water (27-09-2005) with the data immediately after drawing water was finished (29-09-2005), the turbidity and suspended solid (SS) were found to have increased and other parameters had decreased (Table 1). When the water system was correspondingly stable (02-11-2005), the turbidity and SS were lower than that before drawing water. Ammonia (NH_4^+-N) and total nitrogen (TN) were higher on 2 Nov. than on 29 Sept., but they were lower than on 27 Sept. But at site 5, the changes in environmental parameters were inconspicuous on 27 Sept. and 2 Nov., except that the changes in turbidity and SS were contrary to other sites. Total phosphorus (TP) concentrations were decreased at sites 2 and 3, but they were firstly increased and then decreased at sites 4 and 5.

2.2 Zooplankton community structure

The richness of zooplankton species was lowest at sites 1 and 7 before drawing water (27-09-2005) (Fig.2) and had increased obviously when the procedure of drawing water had just finished (29-09-2005); when the ecosystem had become comparatively stable (02-11-2005) they were the

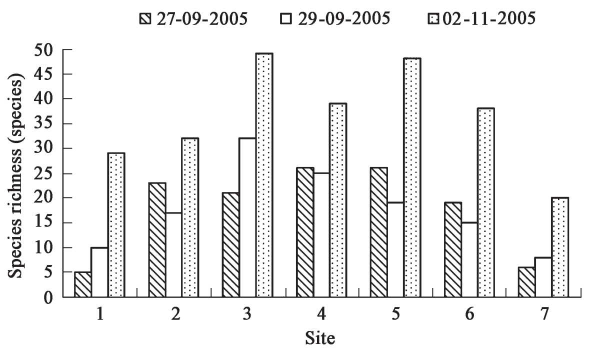

Fig. 2 Effect of drawing water on species richness of zooplankton.

Table 1 Effect of drawing water on water quality

Site	Date (d-m-y)	Turbidity (NTU)	SS (mg/L)	NH_4^+-N (mg/L)	TP (mg/L)	TN (mg/L)
Site 2	27-09-2005	28.1	9.8	1.31	0.24	5.33
	29-09-2005	114.5	32.2	0.09	0.18	1.51
	02-11-2005	20.4	6.0	2.75	0.18	5.42
Site 3	27-09-2005	24.4	20.0	0.19	0.16	1.19
	29-09-2005	35.4	20.5	0.11	0.08	0.97
	02-11-2005	18.9	26.0	0.15	0.02	0.65
Site 4	27-09-2005	45.8	31.8	0.29	0.15	1.50
	29-09-2005	37.5	15.8	0.11	0.13	1.40
	02-11-2005	18.2	10.0	0.14	0.34	0.70
Site 5	27-09-2005	40.3	20.0	0.20	0.19	1.24
	29-09-2005	30.1	9.8	0.15	0.09	1.24
	02-11-2005	43.1	20.0	0.12	0.34	0.70

highest. Species richness was much higher at site 2 than sites 1 and 7 on 27 Sept. 2005. It had decreased on 29 Sept. 2005 and then rose and exceeded the original level. Except at site 3 the trends of species richness at other sites were analogous to the one at site 2. Generally, species richness changed from low to high at the inlet and the outlet on 29 Sept. 2005, because of the effect of river water and lake water together. The change was adverse at other sites, mainly owing to the dilution of river water. After drawing water, the richness of zooplankton species increased and some species were new arrivals. For example, most of species in Sanjiao Lake on 27 Sept. 2005 such as *Brachionus* sp., *Polyarthra* sp., *Keratella* sp. and *Thermocyctops* sp. were tolerant of contamination. but oligotrophic species such as *Tintinnopsis* sp., *Acanthocystis* sp., *Lecane ludwigii*, *Gastropus stylifer* and *Calanoida* emerged on 2 Nov. 2005.

At site 1 the density and biomass of zooplankton firstly decreased but afterwards increased rapidly augmented to 36,452 ind./L on 2 Nov. 2005 (Fig.3). The potential reasons were that the water from Qinduan Stream infiltered into Hanjiang River and the waterbody was almost immobile at site 1. The density always increased at site 7, but the change in biomass was reversed and always at low levels (below 0.1 mg/L). It resulted from influent lake water with a mass of zooplankton (mainly microzooplankton). The density and biomass variational tendency of zooplankton at site 2 were similar to those at site 1 and they were much lower after drawing water than before. At other sites (except that at site 3) the density and biomass were higher before drawing water than afterwards. At site 3 they were much higher after drawing water than beforehand. Although density and biomass were lower on 2 Nov. than on 29 Sept., 2005 at site 3, they were higher than at sites 4 and 5. The reason was that site 3 was the transitional area from river water to lake water. The velocity of water flow here became slow because the water flew from narrow river-way to wide lake country. So a quantity of zooplankton stayed at this site.

The densities of protozoa and rotifers decreased and those of crustaceans increased in Sanjiao Lake. The density of zooplankton was reduced in Nantaizi Lake (at site 6) because pollution was more serious than in Sanjiao Lake and the changed water environment may have made the density low.

2.3 Biodiversity index

Except that at site 2, the Shannon-Weiner diversity indices were, on the whole, higher when the water bodies were relative stable than before drawing water (Table 2). Significant differences between the species on 27 Sept. and 2 Nov., 2005 were found (P=0.002) (Table 3). The same phenomena occurred between on 29 Sept. 2005 and 2 Nov. 2005 (P=0.002). Significant differences were found between the density of phytoplankton on 27 Sept. and 29 Sept., 2005 (P=0.043), as well as the result between that on 27 Sept. and 2 Nov., 2005 (P=0.03). Significant differences in biomass were only discovered between 27 Sept. 2005 and 2 Nov. 2005 (P=0.045). They showed that drawing water could be important for species immigration and community succession and for enhancing the diversity of zooplankton.

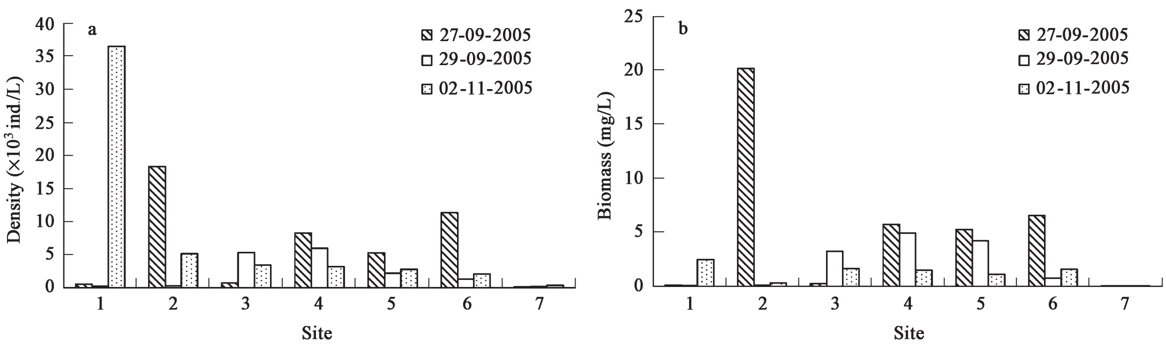

Fig. 3 Change on zooplankton density (a) and biomass (b) before and after drawing water.

Table 2 Change on Shannon-Weiner diversity index

Date (d-m-y)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
27-09-2005	1.93	3.83	2.57	3.90	3.55	3.78	2.04
29-09-2005	2.51	2.87	5.39	3.87	2.61	3.35	1.97
02-11-2005	2.74	1.85	4.19	4.20	3.72	3.90	2.68

Table 3 Comparison of difference in zooplankton before and after drawing water by analysis of variance (multiple comparison, method of LSD)

Date (d-m-y)	*P* value (between the species)			*P* value (between the density)			*P* value (between the biomass)		
	27-09	29-09	02-11	27-09	29-09	02-11	27-09	29-09	02-11
27-09-2005		1.000	0.002		0.043	0.03		0.107	0.045
29-09-2005	1.000		0.002	0.043		0.923	0.107		0.627
02-11-2005	0.002	0.002		0.03	0.923		0.045	0.627	

3 Discussion

By connecting the rivers and lakes, river water low in nutrients flowed into lakes higher in nutrients, so diluting the lake water and improving its water quality; the excess nutrients were transported away. And sampling-time was often an important factor according to the variations of physical-chemic parameters. Ocampo *et al*. (2006a) found hydrological connectivity had important ramifications for Cl^- and NO_3^- transport and export from an upland to a riparian zone. The previously collected data from Susannah Brook, an agricultural catchment in Washington D.C., USA, showed that a marked shift in catchment NO_3^- responses as the season progressed (Ocampo *et al*., 2006b). The degree of connectivity to the main river branches is most likely to be of major importance: the river carries high amounts of suspended silt and nutrients. These suspended silt and nutrients can be transported via a chain of lakes connected by canals (Ocampo *et al*., 2006b). The first lakes in the chain are often characterised by high suspended sediment concentrations and a high sedimentation (Coops *et al*., 1999). Water dilution has an effect on the physico-chemical parameters. Difference occurred at site 2 may due to its landscape geometry with a narrow and immobile stream channel.

With regard to zooplankton, the community structure changed from eutrophic-indicator species (*Brachionus*, *Polyarthra*, *Keratella* and *Thermocyctops*) to species more characteristic of oligotrophic conditions (*Tintinnopsis*, *Acanthocystis*, *Lecane ludwigii*, *Gastropus stylifer*). Li *et al*. (2006) also found that the dominant species *Brachionus* spp. and *Keratella* spp. were replaced by *Tintinnopsis* spp. in Xihu Lake, Hangzhou City after drawing water.

Species richness increased in the lakes and Qinduan Stream after drawing water, but these were lower on 29 Sep. 2005 because of dilution. However, the changes in species richness were the opposite at sites 1, 3 and 7. Zooplankton density and biomass showed decreasing trends (except sites 1, 3 and 7). The reason for the differences at site 3 may result from great amount of nutrition and plankton and landscape geometry from narrow stream channel (at site 2) to wide lake body with slower velocity of water flow (at site 3). Knösche (2006) found that the sediments from impounded river sections and from mouth sections of backwaters were characterised by a high proportion of particles from 0.1 to 0.5 mm size fractions, and sediments from distal sections of backwaters and of oxbow lakes tended to exhibit high element ratios with much higher variability, so these results were interpreted as a spatially limited impact of the river on the floodplain water sediments.

In this study, crustacean density increased at sites 2 and 3, but densities of protozoa and rotifers decreased. Other research found that in all the species of these communities, the relatively large cladoceran *Ceriodaphnia reticulata* significantly responded to the treatment, it achieved high densities when the connected area was large enough. *C. reticulata* was an important role in driving the increased local community similarity and decreased regional species richness as connectivity increased (Forbes and Chase, 2002). Dilution also had some effect on the assemblage of rotifers. The greatest density of rotifers was observed in lagoons due to the relative stability of these environments in terms of current velocities relative to the rivers. This result probably occurred due to the low current velocity of the river which promoted the development of plankton and consequently influenced the high density of rotifers in connected lagoons (Aoyagui and Bonecker, 2004). These were consistent to the results at site 2.

Zooplankton density increased at sites 1 and 7 probably resulting from inflow of eutrophic water. Zooplankton diversity (Shannon-Weiner diversity index) also increased. Zooplankton communities were different among different habitats. Landscape geometry can be an important factor and connectivity also can have an important effect on zooplankton community structure. Aoyagui and Bonecker (2004) found the highest values of species richness in the rivers and the lowest ones in isolated lagoons, and the abundances was different during different hydrological periods. Highest abundances during the high water period were observed in isolated lagoons, whereas connected lagoons had highest abundances during the low water period. Forbes and Chase (2002), however, found no effects of habitat geometry on any measure of species diversity or composition and no effect of habitat connectivity on local species diversity. However, increasing connectivity led to a decrease in regional diversity, but an increase in the percent similarity of local communities within regions. These data supported the concept that the connection among local patches may decrease regional diversity when patches were previously heterogeneous, and this has been proved from empirical surveys of connected and unconnected habitats (Harrison, 1997, 1999; Quinn and Harrison, 1988), as well as theoretical modeling (Hastings and Gavrilets, 1999; Amarasekare, 2000; Mouquet and Loreau, 2002). Research has also shown no relation between the local species richness and three connectivity variables and that the connectivity only acts secondarily by increasing the general species richness within a pond through dispersal from ponds with different environmental conditions (Cottenie and De Meester, 2003). Some exception in our study may have been due to the landscape geometry and the diversity increased a little. This can be related to the rate of connectivity, the discharge of drawing water and the velocity of flow. Havel *et al*. (2000) found positive correlation between connectivity and species richness. It supported and illustrated the importance of connections for local species diversity.

In conclusion, during the present study, the quality of water in lakes improved, zooplankton species richness and diversity increased, and the density and biomass decreased (expect at lake entrances) by drawing water. Dilution played an important role in the variation. Also, landform geometry could have affected the variation. Drawing water could be important for water quality improvement and ecosystem restoration. Connectivity rate and the discharge of drawing water must be cautiously calculated for preservation of region species richness.

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