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Short communication

Effects of engineered use of water hyacinths (*Eicchornia crassipes*) on the zooplankton community in Lake Taihu, China

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ABSTRACT

To evaluate the ecological consequences of engineered use of water hyacinths in Lake Taihu, China, we conducted a systematic survey of the dynamics of the zooplankton community (mainly copepods, cladocerans, and rotifers) inside (INE), around (ARE), and far-outside (FAE) a large-scale enclosure of water hyacinths in Zhushan Bay, Lake Taihu from August to November 2009 and calculated five response variables for the zooplankton community for each area. INE, ARE, and FAE differed little in their zooplankton composition at the genus level: the 16 of 21 identified genera were common and the same 6 zooplankton genera were dominant in all three areas, and only 5 sparse zooplankton genera were not collected from all three areas. The average abundance of each zooplankton faunal group and their annual trends displayed similar patterns in INE, ARE, and FAE. The only significant difference ($p < 0.05$) detected was between INE and FAE in the average abundance of cladoceran fauna (INE > FAE) and rotifer fauna (INE < FAE). The four diversity indices calculated for each zooplankton faunal group did not differ among INE, ARE, and FAE. These results suggest that the zooplankton community in Lake Taihu is not significantly affected by the engineered use of water hyacinths. Thus, use of *Eicchornia crassipes* appears to be an ecologically safe biomanipulation measure for purifying polluted water in temperate lakes such as Lake Taihu.

1. Introduction

Lake Taihu, located in the Yangtze Delta plain, is the third largest freshwater lake in China. It has an area of 2250 km^2 and an average depth of 2 m. As a large shallow lake situated in a highly developed and densely populated area, it plays an important role in providing water for drinking and irrigation. However, water pollution in Lake Taihu has been worsening for quite a few years (Li et al., 1994). In May 2007, a sudden blue-green algae bloom polluted the intake area for drinking water, which resulted in a week-long suspension of the fresh water supply to half of Wuxi city's 2.3 million residents. Thus, eutrophication of the lake has become an important environmental issue that has attracted attention worldwide, and many efforts to improve water quality have been made since 2007. Such efforts include control of external nutrient loading, sediment dredging, prevention of the release of phosphorus from sediments through chemical treatments, and biomanipulation projects (Ye et al., 2011).

Ongoing biomanipulation projects include stocking the lake with silver carp (*Hypophthalmichthys molitrix*) and bighead fish (*Hypophthalmichthys nobilis*) to control algal blooms (Xie, 2003), submerged macrophyte restoration (Li, 1996; Qiu et al., 1997, 2001; Pu et al., 2001; Sun and Sheng, 2001; Cheng et al., 2006), and use of large-scale enclosures in which water hyacinths (*Eicchornia crassipes*) are planted. In Lake Taihu, the engineered use of water hyacinths has proved to be one of the most efficient approaches to reducing the nutrient load and restricting algal blooms (Cheng et al., 2006).

The engineered use of *E. crassipes* includes three main steps: (1) the planned construction and setting of man-made enclosures, which consist of plastic foam and plastic mesh; (2) large-scale planting of water hyacinths strictly within the enclosures; and (3) planned harvesting of mature water hyacinths using a specially designed salvage boat. Water hyacinths have a high nutrient uptake rate compared to other macrophytes (Zhu and Zhu, 1998; Rodríguez-Gallego et al., 2004; O'Sullivan et al., 2010), and they can change water quality by altering water clarity and decreasing phytoplankton production and concentrations of dissolved oxygen, nitrogen, phosphorous, heavy metals, and other contaminants (Villamagna and Murphy, 2010). For example, 1 kg of *E. crassipes* (wet weight) can absorb 2.36 mg of ammonium, 1.13 mg

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of nitrate, and 0.39 mg of phosphate each hour (Rommens et al., 2003). Negative aspects of this species stem from its rapid mat-like proliferation and free-floating behavior but not the plant itself (Kusemiju, 1988). Overall, the engineered use of water hyacinths involves harnessing their efficiency at drawing nutrients from polluted water while overcoming problems such as hindrance to water transport, clogging of irrigation intakes and hydropower and water supply systems, and hindrance to fishing (Cheng et al., 2006).

E. crassipes is one of the world's most prevalent invasive aquatic plants, and it is exotic to Lake Taihu. To date, the ecological effects of its engineered use on the lake's aquatic ecosystem remain unclear. Thus, an evaluation of the ecological consequence of use of this species in Lake Taihu is urgently needed. To address this issue, we conducted a systematic survey of the dynamics of the zooplankton community (mainly copepods, cladocerans, and rotifers) inside (INE), around (ARE), and far-outside (FAE) a large-scale water hyacinth enclosure in Zhushan Bay, Lake Taihu and calculated and compared five important response variables (genera composition, average abundance, average abundance trends, genera richness and diversity indices) of the zooplankton community in the three areas. Because the zooplankton community is the most important (and a highly sensitive) component of a lake's aquatic ecosystem (Masifwa et al., 2001; Meerhoff et al., 2006), we hypothesized that the ecological effect of the engineered use of water hyacinths on the lake's aquatic ecosystem could be evaluated through the responses of the lake's zooplankton community.

2. Materials and methods

2.1. Research area

Our experiment was conducted in Zhushan Bay, which is one of the most hypereutrophic bays in Lake Taihu. It lies in the northwest part of the lake and is situated by Changzhou City. The water area of the bay is 66 km^2, with a water depth of 1.2–2 m (Zhang, 2004).

The water hyacinth enclosure that was the focus of this study was located along the eastern shore of the bay, where the Secchi depth ranged from 0.15 to 0.30 m. Of the 33 sampling sites, 9 (S25–S33) were located inside the water hyacinth enclosure (INE area), 13 (S12–S24) were situated around the water hyacinth enclosure (average distance of 10 m to the enclosure; ARE area), and 11 (S1–S11) were located far from the enclosure (average distance of 500 m to the enclosure; FAE area) (Fig. 1).

2.2. Sampling period

The large-scale enclosure was constructed in May 2009. Water hyacinths were planted in early July 2009. Periodic sampling was conducted fortnightly from late August to early November when water hyacinths were being harvested and the samplings totaled up to 6 times.

2.3. Zooplankton sampling and analysis

Zooplankton samples were collected from the surface layer at 0.5 m depth using a 1 L Patalas sampler. Each sample was filtered through a 35 μm mesh plankton net, and retained zooplankton were preserved in a 5% formaldehyde solution. Zooplankton were identified according to Jiang et al. (1979) and sorted to the genus level. To enumerate the zooplankton, individuals in a 5 mL condensed sample were counted directly in a 5 mL counting chamber using a Nikon microscope at a magnification of 100×.

2.4. Statistical analysis

The following five response variables were calculated for the zooplankton communities of INE, ARE, and FAE: genera

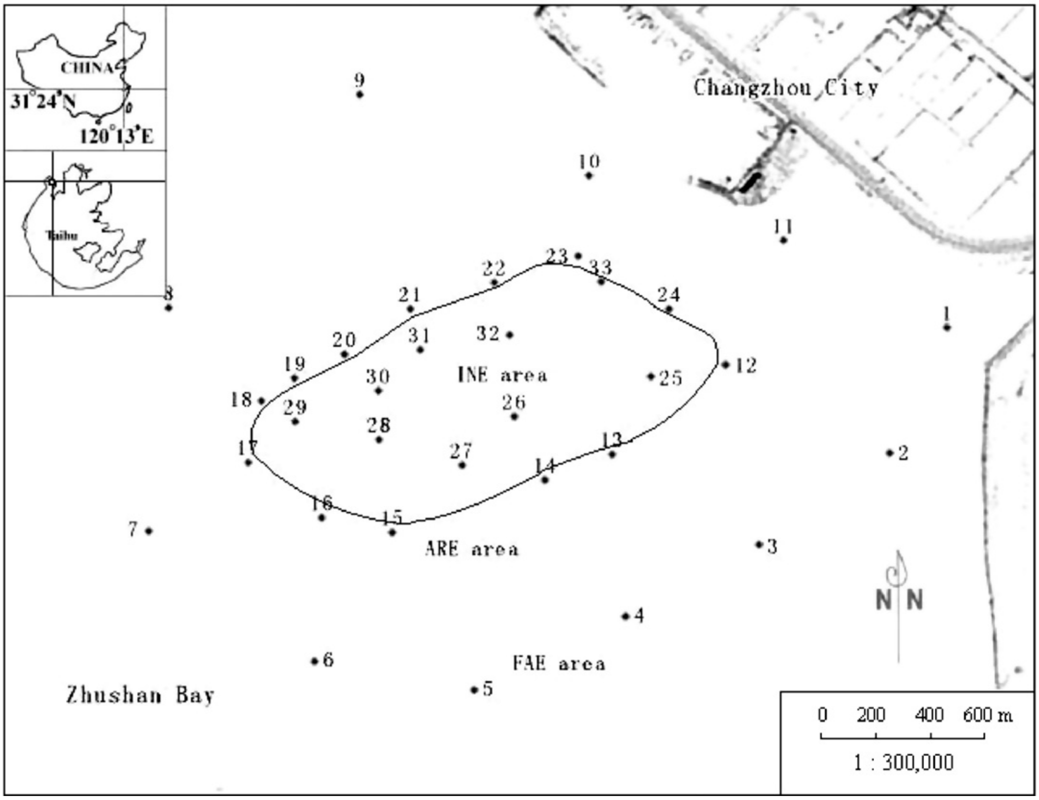

Fig. 1. Location of the water hyacinth enclosure and the sampling sites in Zhushan Bay of Lake Taihu.

composition, average abundance, average abundance trends, genera richness and diversity indices. The differences in the mean value of each zooplankton response variable among INE, ARE, and FAE, with temporal variations considered, were analyzed using a one-way balanced ANOVA; $p < 0.05$ was considered to be significant. All statistical analyses were performed using SPSS 13.0 for Windows. The genera richness is the number of zooplankton genera collected in each area. The following four diversity indices for each zooplankton faunal group in INE, ARE, and FAE at different sampling times were calculated using Biodiversity Mapping V1.0 software: Simpson index, Shannon-Weiner index, Sørensen index, and Jaccard index.

3. Results and discussion

3.1. INE, ARE, and FAE had highly similar zooplankton community size, richness value and the same dominant zooplankton genera

A total of 21 zooplankton genera (6 cladoceran, 5 copepod, and 10 rotifer) were identified from 198 samples collected from 33 sampling sites at 6 sampling times. Sixteen genera were common to INE, ARE, and FAE, and only 5 sparse ones were not collected at all sites.

The same six genera (BB, MS, MC, MO, BR, and KE) were dominant in INE, ARE, and FAE (Table 1). The zooplankton richness values at INE, ARE, and FAE were 19, 20 and 19 respectively (Table 1). These results illustrate the high similarity of zooplankton community size and the identity of dominant genera among the three study areas, and they indicate that the engineered use of water hyacinths has a very small effect on the lake's zooplankton community.

3.2. INE, ARE, and FAE exhibited similar average abundance and average abundance trends of the three zooplankton faunal groups

The average abundance (ind./L) of Cladocera, Copepoda and Rotifera in INE, ARE, and FAE was 57.6 ± 4.3, 51.2 ± 2.8 and 29.5 ± 6.3; 4.5 ± 1.2, 3.7 ± 0.8 and 3.2 ± 0.4; and 15.7 ± 1.9, 20.5 ± 1.9 and 22.8 ± 2.6 respectively. The performance of each zooplankton faunal group's average abundance among INE, ARE, and FAE was almost similar, except that of cladoceran fauna between INE and FAE (INE > FAE, $p < 0.05$) and rotifer fauna between INE and FAE (INE < FAE, $p < 0.05$). The high abundance of cladocerans in INE may be due to the protection and abundant food resources provided by the water hyacinths. Cladocerans may benefit more from water hyacinth protection than the other types of zooplankton because they are less efficient at avoiding planktivorous fish (Blancher, 1984; Kiorboe and Saiz, 1995; Negreiros et al., 2009). The lower abundance of rotifer fauna in INE was consistent with a previous report that rotifer density was greatest in open water compared to all other vegetated habitats in India (Arora and Mehra, 2003). This phenomenon may be explained in part by the exploitative competition for limiting food resources that occurs between rotifers and cladocerans within the aquatic macrophyte community. Cladocerans such as *Daphnia* have superior competitive abilities compared to other zooplankton (Gilbert, 1988; MacIsaac and Gilbert, 1989) and could suppress rotifer abundance in areas where cladocerans are abundant (i.e., INE) (Gilbert, 1988).

The annual trend of average abundance of each zooplankton faunal group in INE, ARE, and FAE showed similar patterns (Fig. 2). No significant difference was detected among the three areas ($p > 0.05$).

All of these results indicated that the effect of the engineered use of water hyacinths on the average zooplankton abundance and dynamics was very limited in Lake Taihu.

3.3. Diversity indices for each zooplankton faunal group were similar among INE, ARE, and FAE

The SNK test (the Student-Newman-Keuls test) result revealed no significant difference in the α diversity indices for each zooplankton faunal group among INE, ARE, and FAE area ($p > 0.05$). The β diversity indices for any combination of INE, ARE, and FAE were >0.7, indicating the high similarity of zooplankton species between them (Table 2). These results implied that both the diversity and

Table 1

List of taxa and dominant genus in INE, ARE and FAE in Zhushan Bay, Lake Taihu. A total of 21 zooplankton genera (6 cladoceran, 5 copepod, and 10 rotifer) were identified from 198 samples collected from 33 sampling sites in six sampling times. 6 dominant zooplankton genera (D.G., marked by *) in INE, ARE and FAE were the same and their percents (Mean % of D.G.) also provided. Only DC, DF, SB, LI, and TR were not collected in all three areas. The genera richness values in INE, ARE and FAE were 19, 20 and 19 respectively.

Zooplankton	Family	Genus	Code	Distribution			Mean % of D.G.		
				FAE	ARE	INE	FAE	ARE	INE
Cladocera	Bosminidae	Bosmina Baird	BB	*	*	*	75.4	85.4	74.4
	Daphniidae	Ceriodaphnia Dana	CD	+	+	+			
		Daphnia (*D.s. str.*)	DS	+	+	+			
		Daphnia (*D. carinata*)	DC	+	N	N			
	Moinidae	Moina Baird	MB	+	+	+			
	Chydoridae	Alona Baird	AB	+	+	+			
	Sididae	Diaphanosoma Fischer	DF	N	+	+			
Copepoda	Oithonidae	Limnoithona Burckhardt	LB	+	+	+			
	Centropagidae	Sinocalanus Burckhardt	SB	N	+	+			
	Cyclopidae	Mesocyclops Sars	MS	*	*	*	58.5	50.8	61
		Cyclops Müller	CM	+	+	+			
		Microcyclops Claus	MC	*	*	*	35	28.4	34.6
Rotifera	Lecanidae	Monostyla	MO	*	*	*	21.5	6.4	20
		Lecane	LE	+	+	+			
	Gastropodidae	Ascomorpha	AS	+	+	+			
	Lindiidae	Lindia	LI	+	N	N			
	Testudinellidae	Filinia	FI	+	+	+			
	Philodinidae	Rotaria	RO	+	+	+			
	Trichocercidae	Trichocerca	TR	N	+	N			
	Brachionidae	Brachionus	BR	*	*	*	45.9	57.4	48.9
		Keratella	KE	*	*	*	23.3	28.1	25.7
		Lepadella	LP	+	+	+			
Total	15 (6 + 3 + 7)	21 (6 + 5 + 10)	22	19	20	19			

Note. *: dominant genus; +: recorded; N: not recorded.

Table 2
Diversity indices of each zooplankton faunal group in INE, ARE and FAE during the period of study. The four diversity indices of each zooplankton faunal group in INE, ARE and FAE did not differ significantly ($p > 0.05$).

Zooplankton	α diversity index						β diversity index					
	Simpson index			Shannon-Weiner index (H': bit)			Sørensen index			Jaccard index		
	FAE	ARE	INE	FAE	ARE	INE	FAE vs ARE	FAE vs INE	ARE vs INE	FAE vs ARE	FAE vs INE	ARE vs INE
Cladoceran	0.34	0.24	0.39	0.61	0.45	0.58	0.83	0.83	1.00	0.71	0.71	1.00
Copepod	0.40	0.46	0.29	0.60	0.79	0.48	0.89	0.89	1.00	0.80	0.80	1.00
Rotifer	0.57	0.57	0.61	1.05	1.04	1.11	0.89	0.94	0.94	0.80	0.89	0.89

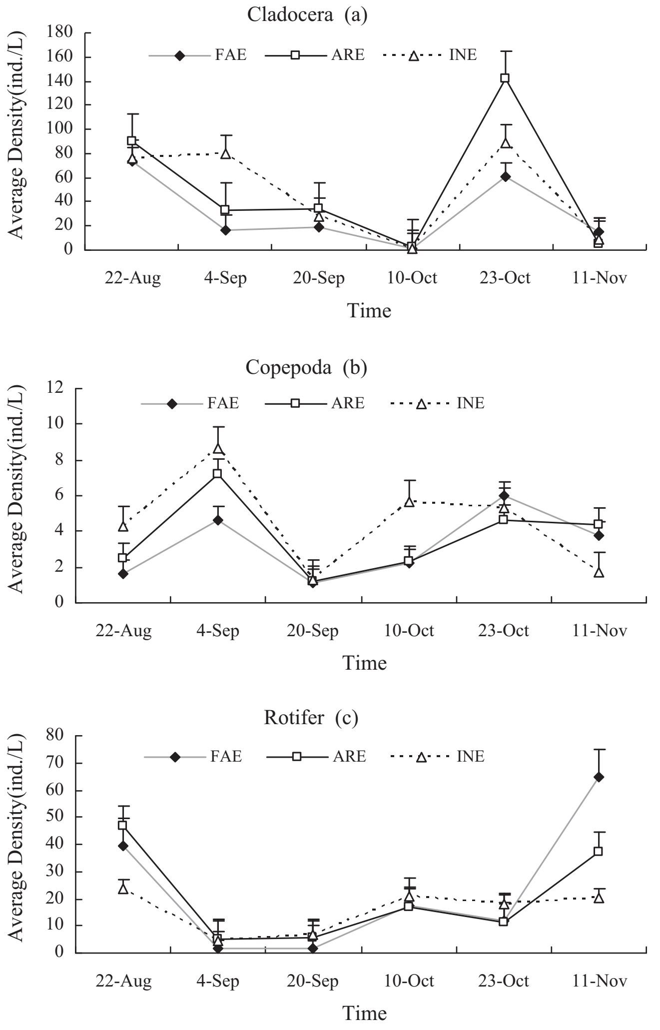

Fig. 2. Trends of average density (ind./L) of each zooplankton faunal group in INE, ARE and FAE during the period of investigation. Values were means ± S.E.

the stability of the zooplankton community were not significantly influenced by the engineered use of water hyacinths in Lake Taihu.

4. Conclusions

The main conclusions of this study are as follows:

(1) The engineered use of water hyacinths does not have a large effect on the size, structure, species richness, biodiversity, and dynamic of the lake's zooplankton community. Thus, it is ecologically safe to use *E. crassipes* in the lake's aquatic ecosystem.

(2) Because *E. crassipes* is a highly efficient and ecologically safe biomanipulation measure for purifying polluted water, the engineered use of this species to fight water pollution in temperate lakes such as Lake Taihu has tremendous potential.

This study represents the first report of the responses of the zooplankton community in Lake Taihu to the engineered use of water hyacinths. Because zooplankton are important in maintaining the balance of aquatic ecosystems and are primarily affected by the structure of the macrophyte community (Masifwa et al., 2001; Meerhoff et al., 2006), zooplankton community size can be used as an indicator of shifts in the trophic state of lakes (Ferdous and Muktadir, 2009), and zooplankton community responses could represent the main responses of the lake's aquatic ecosystem.

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