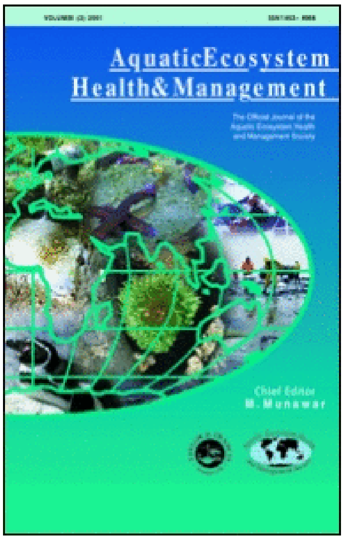

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Effects of a small planktivore (*Pseudorasbora parva*: Cyprinidae) on eutrophication of a shallow eutrophic lake in central China

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Effects of a small planktivore (*Pseudorasbora parva*: Cyprinidae) on eutrophication of a shallow eutrophic lake in central China

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An enclosure experiment was performed in Lake Yuehu, central China, to assess the effects of a gradient of Pseudorasbora parva *biomass on eutrophication state parameters, from May 15 to June 14, 2004. Experimental enclosures were placed into the lake and four treatments were conducted: Control (no fish), low fish (16.5 g m^{-3}), medium fish (55 g m^{-3}), and high fish (110 g m^{-3}). The experimental fish were an average total length of 78 ± 7 mm (mean ± standard deviation) and an average weight of 5.5 ± 1.5 g (mean ± standard deviation). In general, fish increased Secchi disk transparency (SD) and reduced chlorophyll* a *and total phytoplankton cells, especially in the medium and high fish treatments. No significant effect of fish on total nitrogen (TN) and total phosphorus (TP) was observed. Relatively higher SD, and lower TN and TP were observed in the medium fish treatment as compared to other fish treatments. Effects of fish biomass on chlorophyll* a *and total phytoplankton cells were not significantly different between the medium and the high fish treatments. Based on the observed eutrophication parameters and fish mortality, the current experiments suggest that maintaining a 55 g m^{-3} biomass of* P. parva *may be helpful for controlling eutrophic state in the studied lake. Further studies are needed to extrapolate the current results to the whole-lake management decisions.*

Keywords: lake eutrophication, biomanipulation, top-down effects, nutrients

Introduction

Lake eutrophication with deterioration of water quality and nuisance algal blooms, is a serious problem faced by lake managers and limnologists. In China, eutrophication in lakes is becoming more serious, especially in the urban lakes which receive large amounts of pollutants; some of them are the sources for drinking water supply and recreation. Biomanipulation was one useful strategy used to control the lake eutrophication (Shapiro and Wright, 1984). At the top trophic level, fish affect the structure and function of freshwater ecosystems through the "top-down" effects (Northcote, 1988). *Pseudorasbora parva* is a small planktivore and feeds mainly on aquatic insects, algae, and zooplankton (Zhang et al., 2000; Xie et al., 2000; Yang et al., 2004). This fish species is extremely abundant and plays an important role in fish communities in shallow lakes along the middle reach of the Yangtze

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River (Zhang et al., 2000, Xie et al., 2001; Xie et al., 2005; Ye et al., 2006). However, we found no study documenting the effects of *P. parva* on eutrophication in shallow lakes. Algal biomass or phytoplankton species, Secchi disk transparency (SD), chlorophyll, total phosphorus (TP), total nitrogen (TN) and N/P ratio are common indicators for trophic state of freshwater ecosystems (Danilov and Ekelund, 1999; Dodds, 2006). In this present research, we study how different levels of *P. parva* biomass affect these parameters in a shallow eutrophic lake.

Methods and Materials

Study site

Lake Yuehu (30°33' N, 114°15' E), with an area of 0.66 km^2 and an average water depth of 1.0 m, is located in Wuhan city, the biggest city in central China. It is a typical eutrophic lake due to pollution from sewage of the city (Yang et al., 2006). From results of a fishery survey in 2004, the submersed macrophytes were rare in this lake, which was different from most reported shallow suburban lakes in this region (Zhang et al., 2000; Xie et al., 2000; Ye et al., 2006).

Experimental design

The experiment was conducted in enclosures from May 15 to June 14 in 2004. The enclosures were polyethylene rectangles (length: 4 m, width: 3 m) which were supported by wood frames and surrounded by protecting bamboos. Before the experiment, four enclosures were placed into the lake with the bottom fixed into the lake sediment and the top 0.5 m above the water surface. All fishes were first removed from enclosures and preliminary water sampling and analyses were conducted to make sure all enclosures have the same pre-treatment conditions. Experimental fish, *P. parva*, with an average total length of 78 ± 7 mm (mean ± standard deviation) and an average weight of 5.5 ± 1.5 g (mean ± standard deviation), were caught from the lake directly and released to three of the pre-set enclosures with different biomass in the early morning of May 15 (day 0). According to former population studies of *P. parva* in shallow lakes (e.g. 3–5 individuals m^{-2}; Zhang et al., 2000; Xie et al., 2001), four treatments were established: Control (no fish), low fish (16.5 g m^{-3}), medium fish (55 g m^{-3}), and high fish (110 g m^{-3}). Each treatment consisted of one enclosure.

Sampling and analysis of samples

In situ measurements were conducted around 11:00 am for water depth and SD every 5 days from day 0 (May 15) to day 30 (June 14). In addition, triplicate water samples were collected at the same time for analysis of TN and TP, chlorophyll *a*, and phytoplankton cell counting (conducted every 10 days), respectively. Algae were fixed by Lugol's solution and concentrated by settling in a graduated cylinder for one week before counting. Standard methods were followed for chemical analyses (APHA, 1998) and algae identification (Huang, 1999). During the experiment, fish death was monitored and fish mortality on day 30 was calculated. In addition, diet examination was conducted for fish from the main lake and dead fish from the experimental enclosures. We followed the fore-gut analysis methods for diet examination (Xie et al., 2000).

Statistical analyses

Before analysis, all data were tested for normality using Shapiro-Wilk test and transformed if the distribution was not normal. One-way repeated measure analyses of variances (ANOVAs) were used to detect the differences between treatments using "fish" as treatment and "time" as block (Helsel and Hirsch, 1992; Zar, 1999). To meet assumptions of no interaction between time and treatment, Tukey's test for nonadditivity was conducted (Tukey, 1949; Zar, 1999). If significant level ($\alpha = 0.05$) was detected among treatments, Tukey's multiple comparisons were conducted to find the specific difference among these treatments. All analyses were conducted in SAS software environments (SAS Institute, 2003).

Results

Physicochemical parameters

During the experiment, air temperature changed from 21 °C to 32 °C and enclosure water temperature ranged from 22 °C to 27 °C. Water depth, with an average of 83 ± 3 cm, remained almost the same in all treatments. ANOVA detected significant differences ($P < 0.01$) of SD among different treatments. Tukey's test found that SD of the control was significantly lower ($P < 0.05$) than that of the Low and Medium fish treatments, and SD of

Table 1. Results of one-way repeated measures ANOVAs for testing the effects of different fish biomass treatments on Secchi disk transparency (SD), total nitrogen (TN), total phosphorus (TP), chlorophyll *a* and total number of phytoplankton cells.

		SD			TN			TP		
Source	d.f.	MS	F	*P*	MS	F	*P*	MS	F	*P*
Fish	3	358.29	8.45	<**0.01**	0.05	1.45	0.26	0.001	2.34	0.11
Block	6	313.95	7.41	<0.001	1.11	30.42	<0.0001	0.008	24.02	<0.0001
Error	18	42.40	—	—	0.04	—	—	0.000	—	—

	Chlorophyll *a*				Total phytoplankton cells			
Source	d.f.	MS	F	*P*	d.f.	MS	F	*P*
Fish	3	4476.22	11.94	<**0.001**	3	7.93	5.98	<**0.05**
Block	6	1874.24	5.00	<0.005	3	2.19	1.65	0.25
Error	18	375.00	—	—	9	1.33	—	—

Note: *P* values with significant treatment effects were highlighted.

the Medium fish treatment was considerably higher ($P < 0.05$) than that of the High fish treatment (Table 1, Figure 1a). TN was variable but seemed to follow a general decreasing trend from day 0 to day 30. The High fish treatment had a higher TN than others after day 15 (Figure1b). TP increased from day 15 to day 30 in all treatments and was generally the lowest in the Control treatment and the highest in the High fish treatment (Figure 1c). No significant ($P > 0.10$) effect of fish biomass on overall TN and TP was found (Table 1).

Phytoplankton biomass and relative abundance

Chlorophyll *a* was significantly different ($P < 0.001$) among treatments and Tukey's test found chlorophyll *a* in the Control and Low fish biomass treatments were significantly higher ($P < 0.05$) than that of the Medium and High treatments (Table 1, Figure 2a). Chlorophyll *a* was especially low in the Medium and High treatments in the first 10 days and the last 10 days. ANOVA detected significant differences ($P < 0.05$) of total number of phytoplankton cells among treatments, and Tukey's test identified that it was significantly higher ($P < 0.05$) in the Control than in the Medium and High treatments (Table 1, Figure 2b). Total number of phytoplankton cells decreased sharply in the first 10 days in all fish treatments except in the Control in which an increasing trend was observed. During the monitoring period, Chlorophyta, Cyanophyta and Cryptophyta together comprised over 97% of the total phytoplankton cells in all enclosures during the experiment (Figure 3). Populations of individual species indicated that the decreases in total number of phytoplankton were attributable to the suppression of Chlorophyta and Cyanophyta by fish treatments, especially the decrease of *Chlamydomonas*, *Chlorella*, and *Dactylococcopsis* and *Chroococcus* (Table 2, Figure 3).

Fish mortality and fore-gut diet composition

The beginning of fish death was observed on day 10 for the Low fish treatment and day 5 for the Medium and High fish treatments. The fish mortalities on day 30 increased with fish biomass, with the values of 22%, 26% and 47%, respectively (Table 3). The fore-guts of most main lake fish (70%) and part of the enclosure fish (40%) were empty during the experimental period. For fish with food in

Table 2. Identified dominant phytoplankton genus or species during the monitoring period.

Cyanophyta	Chlorophyta	Cryptophyta
Dactylococcopsis	***Chlamydomonas***	*Chroomonas*
D. acicularis		*C. acuta*
Chroococcus	***Chlorella***	*Cryptomonas*
C. minor	***C. vulgaris***	*C. ovata*
Merismopedia	*Scenedesmus*	
Microcystis	*S. dimorphus*	

Note: Genus or species suppressed (i.e. the species with lower densities in fish treatments than that in the control) by *Pseudorasbora parva* were highlighted.

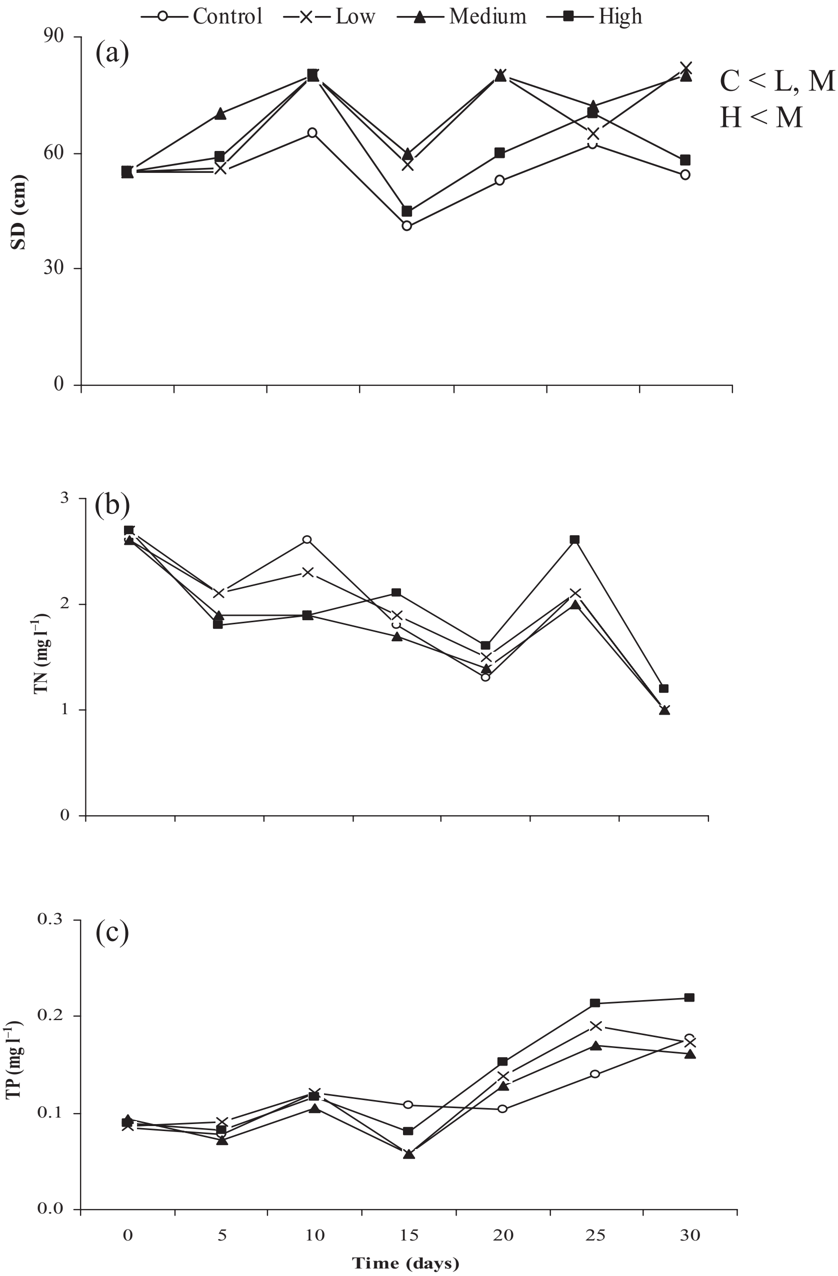

Figure 1. (a) Depth of Secchi disk transparency (SD), (b) concentrations of total nitrogen (TN) and (**c**) total phosphorus (TP) in different treatments. Note: results of Tukey's multiple comparisons were presented if significant differences were detected by ANOVA.

their fore-guts, the diet was dominated by Chlorophyta (e.g. *Chlamydomonas*), partly Cyanophyta, and Chironomid larvae. The algae and aquatic insects contributed to 85% and 10% of the diet based on occurrence, respectively.

Discussion

The current study was the first exploration of the effects of *P. parva* on eutrophic state in shallow eutrophic lakes. Before fish release, similar

Table 3. Number of fish died and mortality on day 30 in different fish treatments.

Treatment	Day 0	Day 5	Day 10	Day 15	Day 20	Day 25	Day 30	Mortality (Day30)
Low	0	0	3	3	3	3	8	22%
Medium	0	4	10	15	15	15	31	26%
High	0	11	27	27	28	29	112	47%

Note: The number of fish died was accumulated based on each sampling day.

physicochemical and phytoplankton conditions were observed in all enclosures. After fish release, *P. parva* increased the clarity of water and the Medium fish treatment resulted in the highest SD. The relatively low values of SD in the High fish treatment may have resulted from the high resuspension of detritus by fish (Heerdt and Hootsmans, 2007). Former studies found fish stocking increased TP in lakes (Havens, 1991; Lazzaro et al., 1992; Vanni et al., 1997), but no significant effect of *P. parva* on TP or TN was observed in the present study (Table 1).

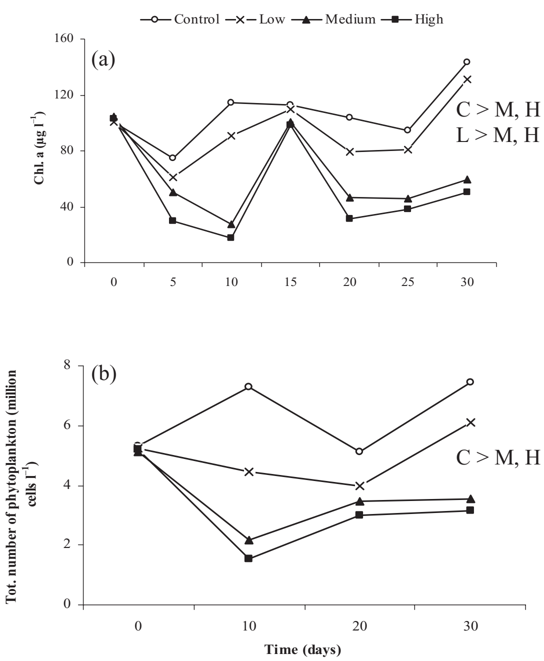

Figure 2. (a) Concentrations of chlorophyll *a* (Chl.*a*) and (b) total number of phytoplankton in different treatments. Note: results of Tukey's multiple comparisons were presented if significant differences were detected by ANOVA ($\alpha = 0.05$); Letters indicate treatments as follows: C = Control, L = Low Fish, M = Medium Fish, and H = High Fish.

Chlorophyll *a* and total phytoplankton cells decreased with fish biomass, and the decrease was faster in higher fish biomass than the low fish biomass treatment. These were in agreement with the results obtained from former studies of effects of *P. parva* on algae (Han and Li, 1995; Hu et al., 1998). In present research, however, *P. parva* affected Chlorophyta more than Cyanophyta. This was partially confirmed by the diet examination. It may be that the effects of *P. parva* on phytoplankton depended on habitat and food availability in lakes (Yang et al., 2004). Moreover, the presence of submersed macrophytes can change the abundance and feeding ecology of this fish in shallow lakes (Xie et al., 2000; Xie et al., 2001). The overall effects of *P. parva* on algae may have partially resulted from direct grazing by fish and partially from interactions between fish, aquatic insects, and zooplankton (Matveev et al., 2000; Rejas et al., 2005). Competition for food and habitat conditions could have contributed to the higher fish mortality as fish biomass increased.

Based on the observed SD, TN, TP, chlorophyll *a*, and fish mortality, it seems that maintaining a 55 g m^{-3} biomass of *P. parva* may be helpful for controlling eutrophic state in Lake Yuehu. However, before extrapolating this to the whole-lake management decisions, two processes need to be further explored. First, seasonal experiments are needed to further elucidate the effects of *P. parva* on eutrophication because of different seasonal feeding patterns of *P. parva* (Xie et al., 2000) and the seasonal periodicity of inter-relationships between phytoplankton variability, nutrient and grazing factors (Lau and Lane, 2002). Secondly, experimental designs that focus on studying the effects of nutrients along with *P. parva* and comparisons with the main lake are needed to discover the highly dynamic top-down and bottom-up effects in this eutrophic lake ecosystem.

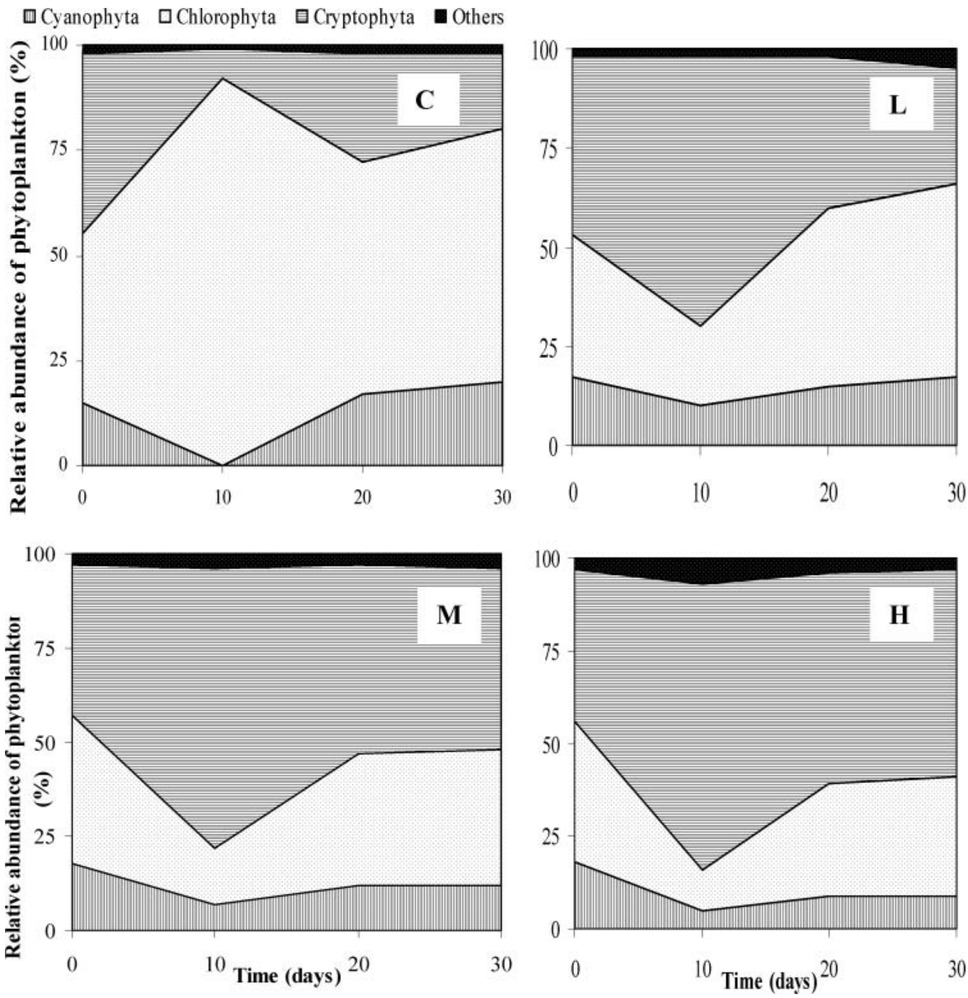

Figure 3. Relative abundance (%) of phytoplankton (Cyanophyta, area with vertical lines; Chlorophyta, area with dots in white background; Cryptophyta, area with horizontal lines; and others, area with dots in black background) in different treatments. Note: Letters indicate treatments as follows: C = Control, L = Low Fish, M = Medium Fish, and H = High Fish.

Conclusions

The current research applied experimental enclosures to study effects of the *Pseudorasbora parva*: Cyprinidae on eutrophication status of a shallow lake in Central China. From the current study, we have the following conclusions:

1. Maintaining a medium biomass of *P. parva* (i.e. 55 g m^{-3}) seems to be reasonable in controlling eutrophication status in the studied lake;
2. More complex and longer-term experimental designs that combine enclosure experiments and lake-scale biomanipulations are needed to fully understand the funcition of *P. parva* in controlling lake eutrophication; and
3. The current research results may be applied to control eutrophication in other shallow eutrophic urban lakes along the Yangtze River Basin and lakes that have similar geographical and eutrophic conditions.

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