Comparative study of the treatment of eutrophic water of different submerged plants with different planting densities

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Abstract A comparison of the purification ability of eutrophic water by two submerged macrophytes with different planting densities, is outlined in this manuscript. Removal of total nitrogen (TN) and total phosphorus (TP) from eutrophic water by *Hydrilla verticillata* and *Potamogeton crispus* planted at different densities were shown to differ. Both *H. verticillata* and *P. crispus* had high removal rates of TN, TP and chlorophyll *a* from eutrophic water, and their removal ability increased with increasing plant density. At the same density, *P. crispus* had higher removal ability for TN than *H. verticillata*; conversely, *H. verticillata* had higher removal ability for TP than *P. crispus*. The results suggested that density should be taken into account in restoration programmes of submerged macrophyte and the optimal submerged macrophyte should be chosen by the highest removal rate for different eutrophic composition (TN, TP).

Key words submerged macrophytes; eutrophic water; treatment; planting density

INTRODUCTION

Eutrophication of lakes is a serious global environmental problem and one that is significantly influenced by human activities. Recovery of water quality and the repair of ecosystems damaged by increased nutrient runoff is a research area of importance (Song *et al.*, 2006). The increased loading of nutrients (e.g. TN, TP, etc.) leads to water quality deterioration and significant loss of biodiversity (Beklioglu *et al.*, 2003). The practice of controlling lake eutrophication is achieved by controlling nutrients (He, 1996), direct killing of algae (Gumbricht, 1993) biomanipulation (Carpenter & Cole, 1995; Hosper, 1998) and ecological restoration (Li, 1996). Despite the large amounts of funding that have been put into controlling eutrophication in lakes in many countries, little effect has yet been produced.

Of all the biological treatments for controlling lake eutrophication, aquatic vegetation, especially submerged macrophytes, has been recognized as being the most effective. The establishment of macrophyte stands in shallow systems can increase nutrient retention and recycling (Jones *et al.*, 1993). During the growing season, macrophytes act as a sink by accumulating nutrients in developing tissues (Engel, 1998). Weisner *et al.* (1994) demonstrated that removal of nitrate from the water column was significantly higher in vegetated than non-vegetated mesocosms due to uptake and denitrification. Macrophytes stimulate denitrification by lowering the redox potential in microzones at the sediment surface and releasing dissolved organic carbon. Nowadays in China, aquatic vegetation, especially submerged macrophytes, has declined and even disappeared from many lakes as a result of artificial eutrophication and irrational fishery management (Qiu *et al.*, 2001). Restoration of submerged macrophytes has been proposed as an ecological measure for the rehabilitation of degraded lake ecosystem and improvement of water quality in shallow eutrophic lakes.

One of the most serious problems caused by eutrophication of shallow lakes is the disappearance of submerged macrophytes and a switch to the turbid, phytoplankton-dominated state (Scheffer *et al.*, 1993; Hilt *et al.*, 2006). Submerged macrophytes represent the major component in aquatic ecosystems and help shape the physical and chemical environment, as well as the biota (Jeppesen & Søndergaard, 1999). Submerged macrophytes affect nutrient dynamics, light attenuation, temperature regimes, hydrodynamic cycles, and substrate characteristics as well as other primary producers including epiphytic and epipelic algae (Rooney *et al.*, 2003). Moreover, as one of the most important primary producers in lake ecosystems, submerged macrophytes play a key role in the health and stability of lake ecosystems. Therefore, the first and the most important step for controlling lake eutrophication is to restore and rehabilitate submerged macrophytes. However, the effect of submerged macrophytes to environmental variations (such as planting density) is complex and is not well understood. In this study the purification ability of two submerged vegetation species with different planting densities in eutrophic water is investigated.

MATERIALS AND METHODS

Study site

Lake Xuanwu, with a surface area of 3.7 km^2, mean depth of 1.14 m, and maximum depth of 2.31 m, is situated to the northeast of Nanjing city (31°14–32°37′N, 118°22–119°14′E), Jiangsu Province, China. It is a lake of multiple uses: fishing, aquatic sports and sightseeing. Since the end of the 1980s, the water quality of Lake Xuanwu has deteriorated, becoming eutrophic. Nuisance algal blooms occurred in the large area of the lake and macrophytes declined considerably in summer 2005. Meanwhile a huge amount of money has been spent on controlling eutrophication using various methods (e.g. dredging, algal collection). The water quality did not improve until in June 2006; submerged macrophytes (*Potamogeton crispus* and *Hydrilla verticillata)* appeared, covering almost the whole lake. Previous research on Lake Xuanwu has demonstrated that *P. crispus* populations play a key role in improving the lake environment and water quality (Wang & Wang, 2007; Yang & Wang, 2007). The lake is segmented into several parts by causeways across the lake which still allows the passage of water between adjacent parts through a watercourse. These sub-lakes considerably differ in the distribution and pattern of submerged macrophytes (Fig. 1).

Fig. 1 The distribution of submerged macrophytes in Lake Xuanwu.

Plant material

The plants, *H. verticillata* and *P. crispus,* the water, and the sediments for the experiments were collected in April 2008 from the southeastern sub-lake of Lake Xuanwu. The plants were detached underwater to minimize damage to the roots and stems, and were transported in a chamber full of water to the laboratory. Here, plants with similar size (mean length of 19±1.1 cm) were selected for cultivation and for use in the experiment.

Experimental set-up

The outdoor controlled experiment was carried out from 15 April to 1 June 2008 at the State Key Laboratory of Hydrology, Water Resources and Hydraulic Engineering, Hohai University. Plants were pre-cultured in plastic containers for 3 days and then planted in round plastic containers (height 27 cm, diameter of base 25 cm) with 5 cm depth of substratum and 20 cm depth of water. The substratum was a homogeneous mixture of equal parts by volume of quartz sand and sediment collected from Lake Xuanwu. The experiment was a one factorial design with three planting densities (PD): low plant density (LPD, 4 individuals per container), median plant density (MPD, 8 individuals per container) and high plant density (HPD, 12 individuals per container). The plants were uniformly spaced in each container. In addition, the same substratum and water without plants was used as control (CK). In total, the experiment had four treatments with three replicates of each treatment.

Sampling and analyses

Water samples were taken every 5 days at a depth of 10 cm below the water surface, stored at 4°C and analysed for TN, TP and chlorophyll *a* (chl *a*) only within 24 h because of the limited amount of suspended sediment in the lentic environment. Water sample analysis followed the procedures described in State Environmental Protection Administration (2002). All analyses were conducted in triplicate. Chlorophyll *a* was determined colorimetrically.

Statistical analysis

The data were subjected to 2-way analysis of variance to compare the results from different densities of submerged macrophytes. Differences between individual means were tested using Least Significance Difference (LSD) tests at the 0.05 significance level. Removal was calculated for TN and TP in each treatment through the following equation:

$$R(\%) = \frac{C_0 - C_i}{C_0} \quad (1)$$

where, $C_{0.}$ is initial concentration and C_i is the concentration at sampling time *i*.

RESULTS

Effects on the concentration of TN and TP in eutrophic water

Results show that both *H. verticillata* and *P. crispus* had an ability to remove TN and TP from eutrophic water and that removal increased with increasing plant density. *Potamogeton crispus* had higher removal ability for TN than *H. verticillata*. After 20 days, *H. verticillata* at HPD had strong removal ability for TP (Fig. 2). *Potamogeton crispus* at MPD and HPD had higher removals of TN than at LPD. The probable reason why the concentration of TN increased on the last sampling date is because some leaves withered into the water. *Potamogeton crispus* removed TP from eutrophic water from the beginning of the experiment until day 15; however, from then until the end of the experiment, the concentration of TP remained almost constant. *Hydrilla verticillata* is better able to remove TP in eutrophic water body with the increasing plant density than to remove TN, but in the treatment of LPD, MPD and HPD it showed dominant removal ability to TN after the 25th day.

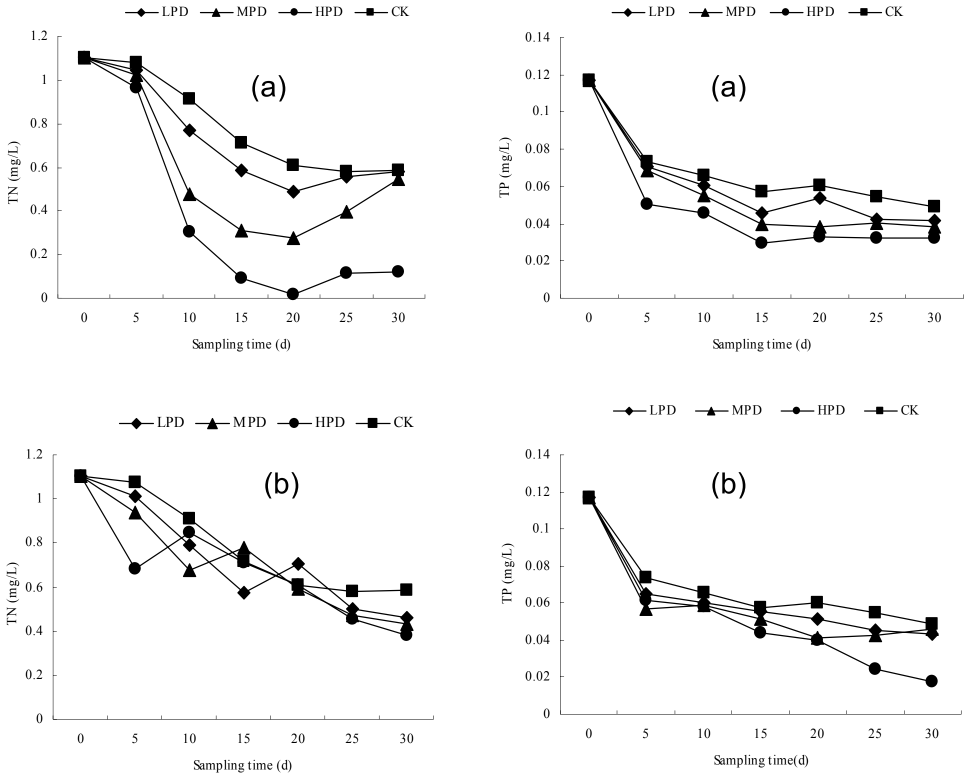

Fig. 2 Changes in mean TN and TP concentration in eutrophic water with treatment time for: (a) *Potamogeton crispus*, and (b) *Hydrilla verticillata.*

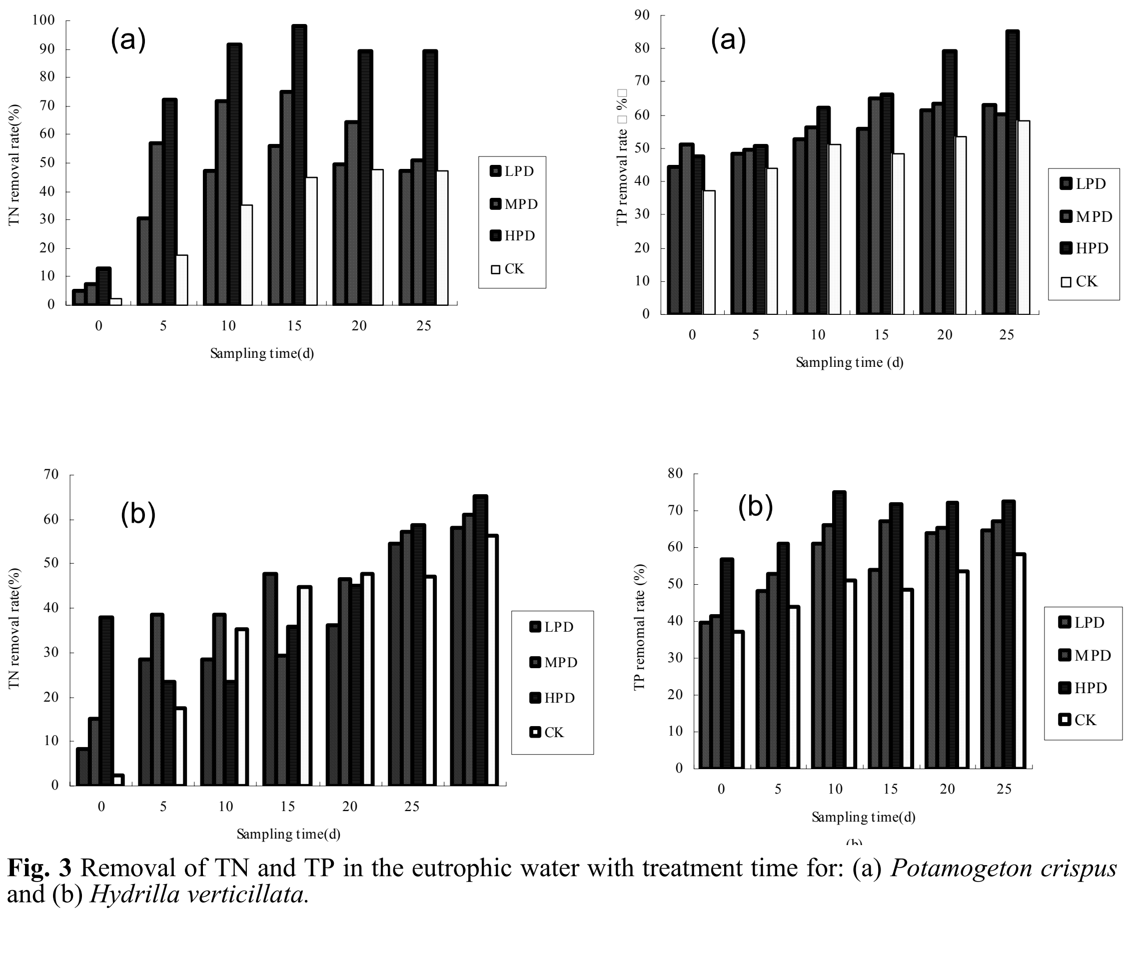

Fig. 3 Removal of TN and TP in the eutrophic water with treatment time for: (a) *Potamogeton crispus* and (b) *Hydrilla verticillata.*

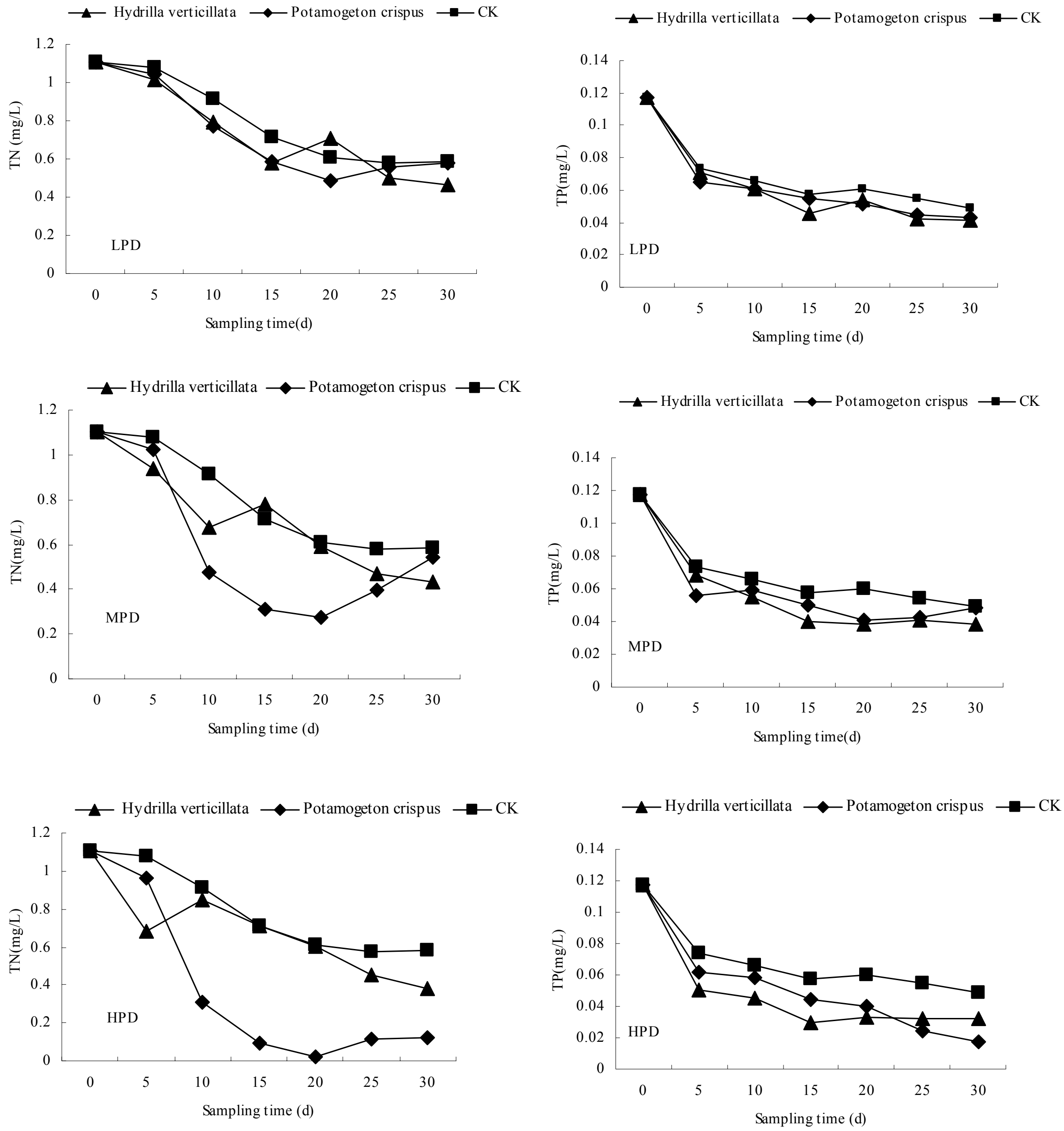

Fig. 4 Changing mean concentration of TN and TP by *Potamogeton crispus* and *Hydrilla verticillata* at different planting densities (LPD, MPD and HPD).

For *P. crispus* at the end of the experiment, the mean removals of TN were 46%, 51% and 85% for the LPD, MPD and HPD treatments, respectively, and the mean removals of TP were 57%, 61% and 81% for the LPD, MPD and HPD treatments, respectively (Fig. 3). The maximum mean removal of TN was 95% on day 15, and the maximum mean removal of TP was 81% at the end of the experiment. For *H. verticillata*, the results show (Fig. 3) that at the end of the experiment, the mean removals of TN were 58%, 61% and 65% for the LPD, MPD and HPD treatments, respectively, and the mean removals of TP were 65%, 67% and 73% for the LPD, MPD and HPD treatments, respectively. The maximum mean removal of TN was 65% on day 25, and the maximum removal rate of TP was 76% on day 10. The results showed that *P. crispus* had higher removal of TN from eutrophic water than *H. verticillata* at the beginning of the experiment, and its ability to remove TP from eutrophic water increased with the treatment time. In contrast, *P. crispus* removed more TP from eutrophic water than *H. verticillata* at the end of the experiment. Therefore, different submerged macrophytes with different planting densities should be considered in order to remove TN and TP from eutrophic water successfully.

Effects on chlorophyll *a* in eutrophic water

Concentrations of chl *a* decreased sharply with treatment time in all planted containers, in contrast to the controls (Fig. 5). Concentrations of chl *a* also decreased with increasing planting density. Removal of TN and TP by two submerged plant species increased with increasing plant density (Fig. 4) and the same submerged vegetation had different removals with different planting densities. Hence the planting density should be taken into account in restoration programmes of submerged vegetation for controlling eutrophication, and the optimal density should be determined at different stages of the restoration process.

Chl *a* concentrations in the *P. crispus* experiments decreased dramatically in the first 10 days of the experiment, and decreased chl *a* concentration 1.5 to 2 times more than *H. verticillata*. However, after day 15, chl *a* removal was similar for both *P. crispus* and *H. verticillata*. For both submerged macrophytes, concentration of chl *a* decreased by 10 times at the end of the experiment compared to the start, which suggests that submerged macrophytes play a key role in controlling lake eutrophication.

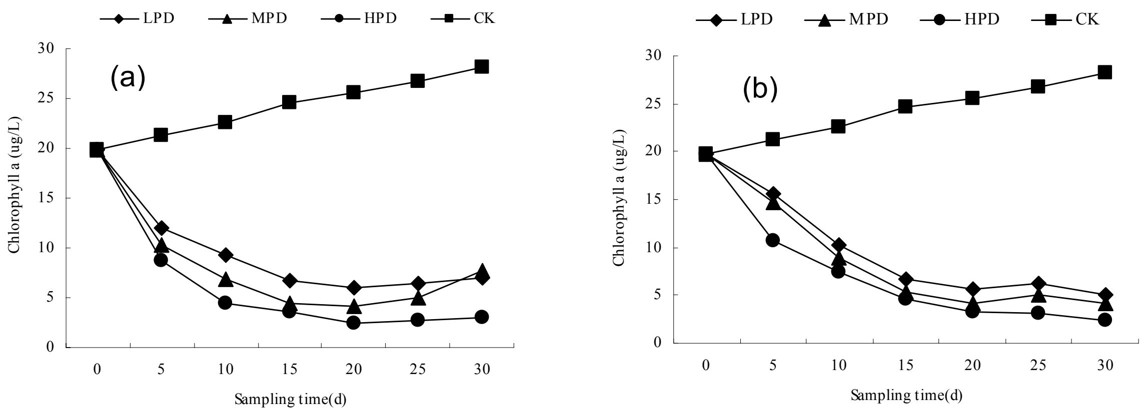

Fig. 5 Changes in mean chlorophyll *a* concentrations in eutrophic water with treatment time for: (a) *Potamogeton crispus*, and (b) *Hydrilla verticillata.*

CONCLUSIONS

The re-establishment of submerged macrophytes is essential for the long-term success in controlling lake eutrophication. However, the choice of an appropriate planting density for two major submerged macrophytes, *P. crispus* and *H. verticillata,* which grow well and are distributed throughout the lake, is essential. Through an outdoor controlled experiment with three planting densities, we draw the following conclusions regarding the artificial restoration of submerged macrophytes for controlling lake eutrophication at the earliest stage:

– *Potamogeton crispus* and *H. verticillata* all reduced TN, TP and chl *a* concentration concentrations in eutrophic lake water, and their ability to remove TN, TP and chl *a* increased with the increasing planting density.
– In general, at the same density, *P. crispus* had a better removal of TN than *H. verticillata*; conversely *H. verticillata* had a better removal of TP than *P. crispus*.
– At the same density and treatment time, different submerged macrophytes had different abilities for removal of TN, TP and chl *a*.
– Planting density should be seriously considered for restoration programmes using submerged macrophytes and the optimal submerged macrophyte should be chosen by the best removal rate for different nutrients (TN, TP).

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