Impact of Water hyacinth on aquatic environment in phytoremediation of eutrophic Lakes

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CHAPTER 9

Impact of Water Hyacinth on Aquatic Environment in Phytoremediation of Eutrophic Lakes

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9.1 Introduction

Water hyacinth has a strong capacity to absorb nutrients, heavy metals and organic pollutants and is an excellent candidate for the water pollution control and eutrophic water restoration. In large lakes, there were few successful examples of submerged or emerging macrophyte restoration. This might be due to: (1) growth of submerged or emerging macrophytes is affected by the depth and transparency of the water; (2) submerged or emerging macrophytes might assimilate nutrients from sediment instead of from water; and (3) macrophyte biomass, if not harvested, decomposes in lakes, and as a result, the assimilated nutrients are returned back to the aquatic ecosystem.

It is mostly nitrogen and phosphorus that are responsible for eutrophication in the aquatic environments (Xu et al. 2010, Smith 2003). Both of these elements are considered to be the control targets for the restoration of aquatic ecosystems (Elser et al. 2007) especially using water hyacinth due to low-cost and easy management (Babourina and Rengel 2011). However, these conclusions were obtained mostly under the experimental conditions or from small scale studies.

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Before using water hyacinth for large scale application on sewage treatment and eutrophic water management, there are some challenges: (1) how to confine water hyacinth in a targeted area in eutrophic lakes or in an open system in sewage treatments, (2) dynamics of water hyacinth growth and propagation; (3) when and how much to harvest and how to dehydrate the fresh biomass; (4) disposal and/or utilization of water hyacinth juice and bagasse; (5) the ecological risk to species diversity and abundance in lakes and other large water bodies on the application of this invasive species; (6) the effects on ecosystem health regarding biogeochemical changes in the environment and water chemistry; and (7) the effects on targeted water quality.

This chapter presents the results on water quality and ecological risk assessment in two ecological engineering projects on phytoremediation of eutrophic lakes: Lake Dianchi (24º40'–25º01' N, 102º35'–102º46' E) and Lake Taihu (30º55'–31º32' N, 119º52'–120º26' E) in China. The challenges, effects and problems in applying water hyacinth for large-scale phytoremediation in these two case studies are discussed.

9.1.1 Background: ecological engineering using water hyacinth for phytoremediation

After two years of preliminary survey in Lake Taihu, an ecological engineering project was established at Zhushan Bay in Lake Taihu in 2010 to investigate the above-mentioned challenges. Lake Taihu is in the early stage heavy eutrophication development due to large number of people in the catchment and rapid development of agriculture and industries (Zheng et al. 2008). According to the China National Water Quality Standard (MEP-PRC 2002), eutrophication is characterized by total nitrogen exceeding 2.8 mg L^{-1} and phosphorus exceeding 0.058 mg L^{-1} (Kang et al. 2012) and blue-green algal blooms occurring frequently (Han et al. 2009).

The survey of eutrophication status of Lake Dianchi started in 1983 and many remediation projects were executed since then (Huang et al. 2010); however, the eutrophication status has not significantly changed (Institute of Environmental Science 1992, MEP-PRC 2002) because a rapid increase in local population and massive amounts of treated or untreated sewage being discharged (Wang et al. 2009, Zhang et al. 2014). A demonstration ecological engineering project using water hyacinth for phytoremediation was implemented in 2010 including areas of Cao Hai and Wai Hain. The project was designed to confine growth of water hyacinth and to completely harvest and dehydrate water hyacinth fresh biomass. This ecological engineering application of the floating macrophyte has been confirmed to improve the water quality in the lake (Wang et al. 2012, Wang et al. 2013).

9.2 Impact of water hyacinth on water quality in Lake Dianchi

9.2.1 Impact of water hyacinth on water quality at Baishan Bay

Lake Dianchi consists of two sections: Cao Hai and Wai Hai. Wai Hai has an area of 286.5 km^2. There is an embankment to separate the waters between the two sections and with a sluice to control water flow. Baishan Bay is located in Wai Hai (Fig. 9.2.1-1) and has a water depth of 2.5 meters.

About a 70-hectare area of water hyacinth was planted in enclosures at Baishan Bay in 2010. The bay had a relatively large population of cyanobacteria due to nutrient loading, local climate characteristics and hydraulic forces.

The project monitored water quality, macrozoobenthos and zooplankton at sites indicated in Fig. 9.2.1-1; the sites were divided in three groups: area covered with water hyacinth (sites 5, 7, 9, 10, 12, 13), near that area (sites 4, 6, 8, 11) and far from it (sites 1–3), with the latter two groups representing controls. Water hyacinth was planted in June 2010 in enclosures and harvested after 20 October 2010. Samples of water, macrozoobenthos and zooplankton were collected at 2-week intervals during the water hyacinth growth season. Water properties were presented in Table 9.2.1-1.

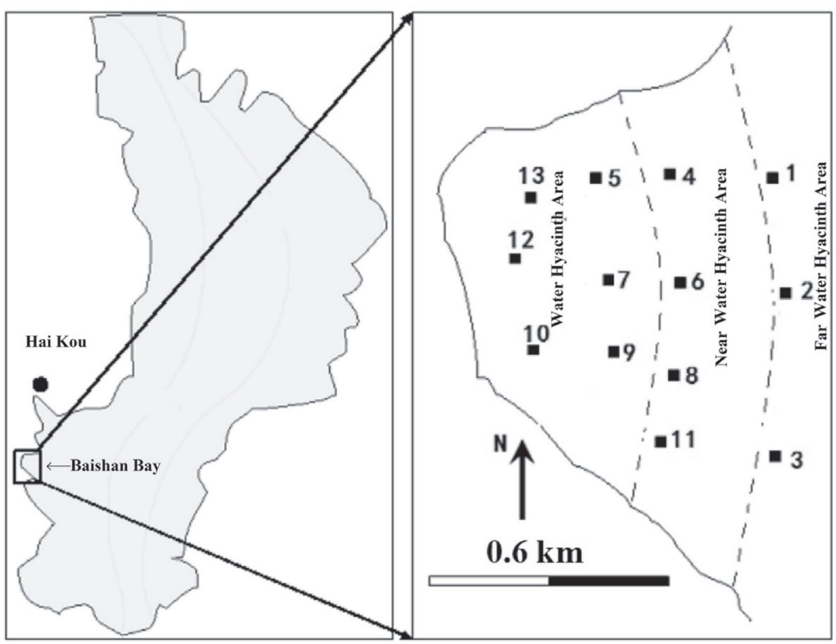

Fig. 9.2.1-1. Sampling sites in the testing area of Baishan Bay (24º45' N, 102º36' E), Lake Dianchi (redrawn with permission).

Table 9.2.1-1. Water quality summary before and after planting water hyacinth.

Sampling	TN mg L^{-1}	NH_4^+ mg L^{-1}	TP mg L^{-1}	COD_{Mn} mg L^{-1}	DO mg L^{-1}	Secchi[a] M	Chl-*a* mg L^{-1}	Ref.
Before Planting 4 May 2010	2.60	0.44	0.26	10.60	8.57	0.34	0.10	Monitoring Data From KCEP[b]
After Planting 20 October 2010	2.40	0.50	0.13	17.50	6.00	0.42	0.07	(Wang, Zhang, Han et al. 2012)

[a] Transparency measured by Secchi Disk; [b] KCEP refers to Environmental Protection Department of Kunming City.

Water temperature

The water temperature in the area before and after planting water hyacinth showed no significant difference among the three sampling areas.

Dissolved oxygen content, pH and transparency

The basic water chemistry of the Baishan Bay shows slight alkalinity (pH 8–10) due to calcium–magnesium–sodium carbonates (Wang et al. 2010). The results were presented in Fig. 9.2.1-2.

Dissolved Oxygen (DO) in water near and far the water hyacinth area declined in August and then gradually increased. Among the three areas, DO was significantly lower in the water hyacinth area than both near and far away areas ($p < 0.05$), with no significant difference between two areas away

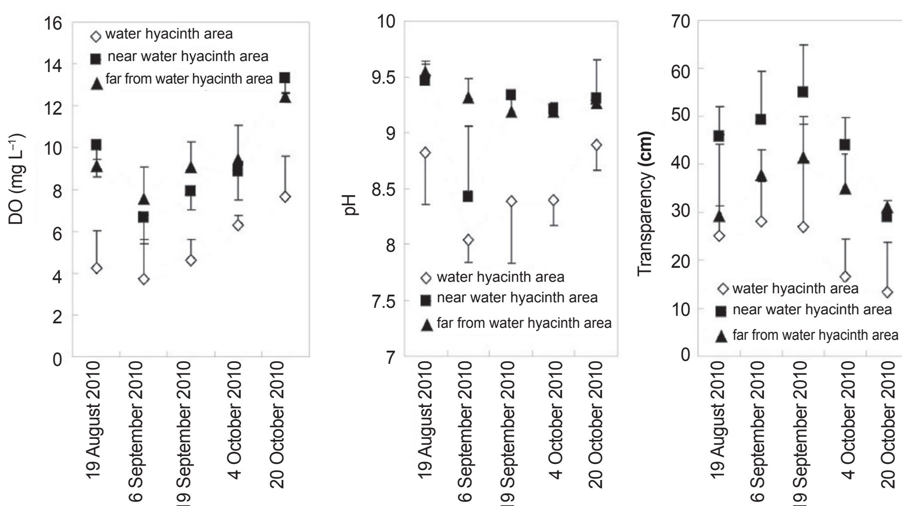

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Fig. 9.2.1-2. Changes of dissolved oxygen, pH and transparency in water column of the testing area, vertical bars representing standard error (redrawn with permission).

from water hyacinth. Due to (i) water hyacinth mat being relatively small compared with the open area in the bay and (ii) water exchange caused by frequent winds, the dissolved oxygen content stayed above 4 mg L^{-1} during the water hyacinth growing season (Fig. 9.2.1-2).

In the water hyacinth area and the nearby area, water pH showed a decrease between the August and September sampling followed by an upward trend and stayed stable around 9.3 in the far water hyacinth area. Statistical analysis showed that the pH of the water body was significantly lower in the water hyacinth area than in the areas near and far from water hyacinth ($p < 0.05$). Lowered pH in the water hyacinth mat area was expected and consistent with literature (Dai and Che 1987, Giraldo and Garzón 2002).

Water transparency showed a slow increase in August and September, and then a gradual decline in October; generally, transparency was significantly lower in the water hyacinth area than in the areas near and far ($p < 0.05$). Literature often showed that water hyacinth can increase water transparency because its roots can intercept detritus and blue-green algae (Kim and Kim 2000). The results from Baishan Bay presented a slightly different pattern that might have been caused by the interactions among the size of water hyacinth mat, wind speed (6 m s^{-1}) and quantities of blue-green algae. The hypothesis was that wind brought large amounts of blue-green algae and, while water hyacinth roots intercepted the algae, they were not decomposed quickly enough and thus water transparency decreased. However, this hypothesis needs to be further tested.

Total phosphorus and orthophosphate

The concentrations of Total Phosphorus (TP) and orthophosphate (PO_4^{3-}) showed the same pattern among the three sampling areas: declined in August then increased afterwards, especially in the water hyacinth area (Fig. 9.2.1-3). This phenomenon indicated that water hyacinth assimilation capacity exceeded a contribution of detritus and algae to increasing water phosphorus, but the trend changed due to a rapid rise in the amount of detritus and blue-green algae brought in by wind. Among the three areas, TP was lowest in the area near water hyacinth ($p < 0.05$), showing that water hyacinth has a potential to improve water quality around its mat.

Total nitrogen, ammonium and nitrate

Total nitrogen showed a decline in August and early September, then increased in late September in the water hyacinth area. It was stable during August and September in the areas near and far from water hyacinth, but with the same trends as in the water hyacinth area (Fig. 9.2.1-4).

Among the three areas, the concentration of total nitrogen was highest in the water hyacinth area, suggesting a rapid accumulation of detritus and blue-green algae during the testing period. In aquatic environments, total nitrogen,

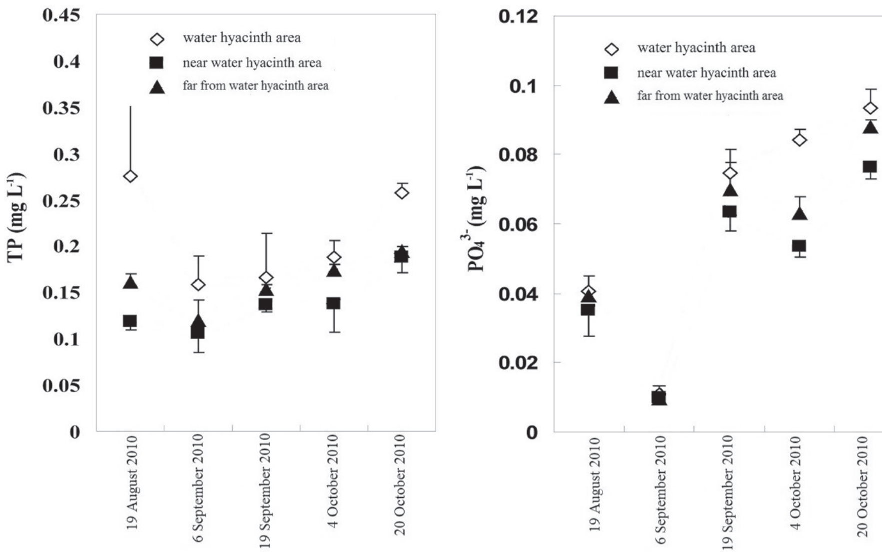

Fig. 9.2.1-3. Changes of total phosphorus and orthophosphate in water column of the testing area (redrawn with permission).

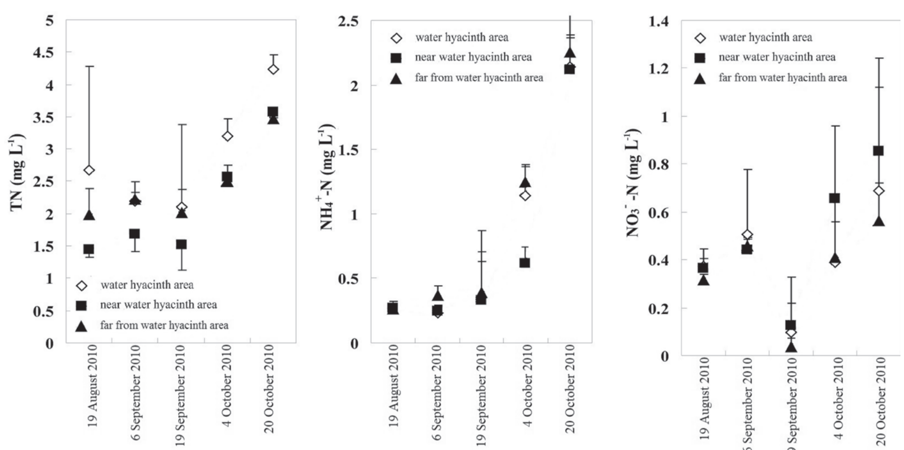

Fig. 9.2.1-4. Changes of total nitrogen, ammonium nitrogen and nitrate nitrogen in water column of the testing area (redrawn with permission).

ammonium and nitrate nitrogen are closely related because mineralization of organic matter (including decomposition of blue-green algae) increases ammonium concentration, which is easily converted to nitrate in aerobic conditions such as during the testing period discussed here. The testing results may suggest that the growth of water hyacinth trapped detritus and blue-green algae to enhance decomposition and removal from endogenous nitrogen pool. Concentration of ammonium nitrogen showed the same pattern in all three areas: stable during August and early September, and increased rapidly afterwards. Nitrate nitrogen increased on 6 September 2010, then declined and increased afterward. The results may suggest a time lag in the total nitrogen -> ammonium -> nitrate transformation, implying that in using phytoremediation to control nitrogen pollution, consideration needs to be taken of the water volume, nitrogen loading, local climate (such as wind strength and direction, and water current) and growth rate of macrophyte in order to achieve desired targets.

Chlorophyll-a and COD_{Mn} index

The results of the changes of chlorophyll-α and COD_{Mn} index were presented in Fig. 9.2.1-5.

In the areas near and far from water hyacinth, chlorophyll-*a* significantly increased in the period from 19 August to 6 September, and then stabilized; in contrast, in the water hyacinth area, it showed a continuous rising trend. This phenomenon further confirmed the above discussion on total nitrogen, ammonium and nitrate nitrogen changes during the testing period. Analysis of variance showed that chlorophyll-*a* concentration in the area near water hyacinth was significantly lower than that in the areas of water hyacinth and far away ($p < 0.05$) (Fig. 9.2.1-5).

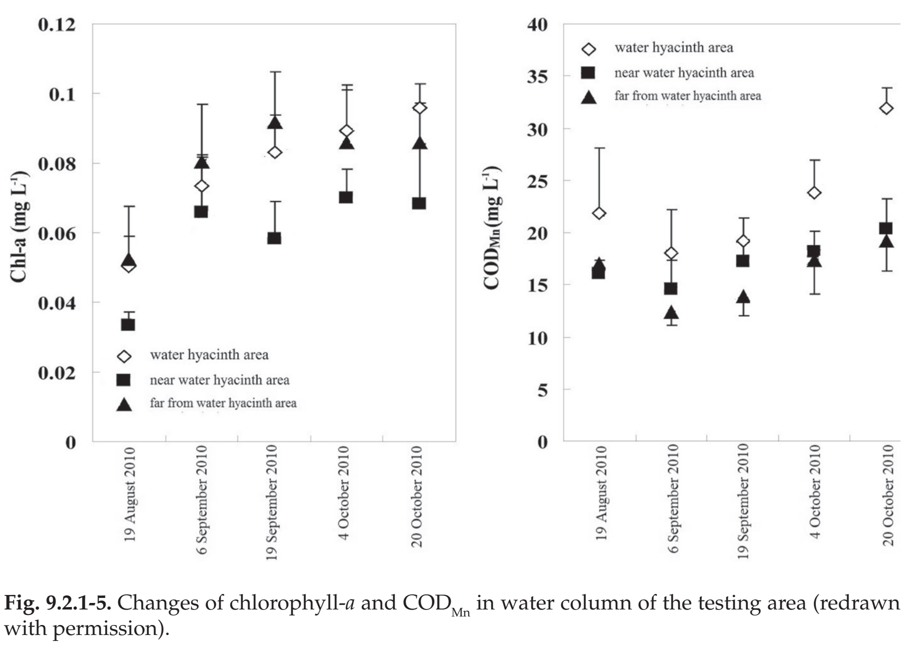

Fig. 9.2.1-5. Changes of chlorophyll-*a* and COD_{Mn} in water column of the testing area (redrawn with permission).

COD_{Mn} had a downward trend in the initial stage and rose later, especially in the water hyacinth area. Among the three regions, the concentration of COD_{Mn} was highest in the water hyacinth area, medium in the near area and lowest in the area far from water hyacinth ($p < 0.05$). Chlorophyll-*a* mainly came from algae, and COD_{Mn} was mainly contributed by small organic molecules and reducing agents. When algae and detritus were decomposed, large amounts of small organic molecules and reducing agents were produced, and nitrogen and other nutrients were released.

9.2.2 Impact of water hyacinth on water quality at Wai Hai

Water quality at Wai Hai

The experiment at Baishan Bay in 2010 had an area of water hyacinth cover of about 70 hectares representing only 0.24% of the total area in Wai Hai, meaning it was difficult to expect significant effects on the physical and chemical properties of the lake. In 2012, the use of water hyacinth for phytoremediation of eutrophic water was extended at the northern part of Wai Hai and the whole of Cao Hai in Lake Dianchi (Fig. 9.2.2-1).

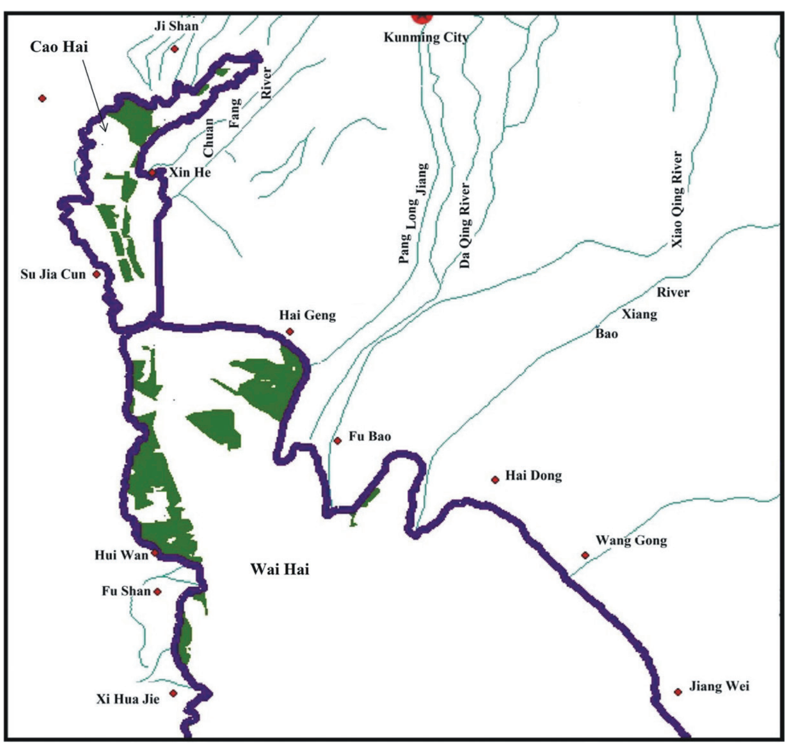

Fig. 9.2.2-1. Water hyacinth distribution at Cao Hai and Wai Hai in Lake Dianchi on 17 August 2012 (redrawn with permission).

The sites were in ultra-eutrophic state with heavily accumulation of blue-green algae. The project planted 621 hectares, or 1.5% of the total area, of water hyacinth in Wai Hai in 2012. The concentrations of nitrogen, phosphorus and ammonium were monitored at eight sites (Fig. 9.2.2-2) by sampling once a month in 2011 (before planting water hyacinth) and 2012 (after planting water hyacinth).

In 2012, the total amount of fresh water hyacinth harvested was 0.32 million tonnes, removing about 567 tonnes of nitrogen. Total nitrogen concentration was reduced from average of 2.8 mg L^{-1} in 2011 down to 2.09 mg L^{-1} in 2012 (about 25% reduction, Table 9.2.2-1).

An increase in ammonium concentration in 2012 was likely due to trapping and decomposition of blue-green algae. The data showed a significant reduction in total nitrogen, non-significant reduction in total phosphorus, and a non-significant increase in ammonium concentration (Table 9.2.2-1).

Fig. 9.2.2-2. Sampling sites in Wai Hai, Lake Dianchi in 2012.

Table 9.2.2-1. Changes in nutrient concentration (mg L^{-1}) from 2006 to 2012; the data were pooled over 12 monthly measurements each year.

Nutrients	Average from 2006 to 2010[a]	Average in 2011[b]	Average in 2012[b]
Total nitrogen	2.62	2.80	2.09
Total phosphorus	0.21	0.16	0.17
Ammonium	0.26	0.25	0.33

[a] Data from Kunming Environmental Monitoring Station; [b] Data from project monitoring.

9.2.3 Impact of water hyacinth on water quality at Cao Hai

The Cao Hai section of Lake Dianchi has an area of 10.5 km^2 with an average depth of 2.5 meters and a water holding capacity of 25 million cubic meters with hydraulic retention time of 3.8–4.2 months. Around Cao Hai, there are six rivers (R1–R6), and two large municipal waste treatment plants (marked R1 and R5), discharging effluent (about 30 tonnes d^{-1}) into the lake (Fig. 9.2.3-1).

The green patches in Fig. 9.2.3-1 represent the enclosures for water hyacinth growth, with about 500 meters in length and 150 meters in width separated by 50-meter open gaps. Xi Yuan channel (C1) is the only water outflow site of Cao Hai (discharged 94,098,100 m^3 water in 2011). Due to municipal effluent and other industrial wastewater discharge, Cao Hai is the most polluted area in Lake Dianchi. Before the ecological engineering project using water hyacinth, concentrations of total nitrogen and total phosphorus were 12–20 mg N L^{-1} and 1.2–1.6 mg P L^{-1} from 2007 to 2011; nutrient loading in 2011 was about 2,000 tonnes of nitrogen and 200 tonnes of phosphorus.

The ecological engineering project was implemented during 2011 to 2013 to investigate possibility of phytoremediation in Cao Hai. The project was designed to confine the growth of water hyacinth to 5.3 km^2 from May to October and to harvest water hyacinth starting from November (planned to finish by the end of December each year). A special heavy duty machine was designed for harvesting and dehydration. Water hyacinth juice was processed for methane fermentation, and bagasse was used for production of organic fertilizer.

Water sampling sites were set at each river near the Cao Hai (labels R1 to R6) and along the water flowing from northern Cao Hai to discharge outflow at Xi Yuan channel (C5 to C1). Water samples were collected in the period from May to November 2011 (from the initial water hyacinth planting to harvest) at a frequency of one to three times a month for 11 sites (R1–R6 and C5–C1). Three mixed water samples were collected at each site at three layers (from the water surface 0–0.5 m and 1.0–1.5 m as well as 0.5 m above the sediment surface). One liter of water was collected for each sample and immediately transported to the laboratory for chemical analysis on total nitrogen, total phosphorus, ammonium, nitrate and orthophosphate. Meanwhile, water hyacinth plants were sampled each month for the determination of nitrogen,

Fig. 9.2.3-1. Experiment layout and sampling sites at Cao Hai in Lake Dianchi.

phosphorus and water contents. Total water hyacinth biomass was measured by the combination of a GPS and on-site weighing using quadrants.

For the period before May 2011, the physical and chemical properties of the water on each site were provided by the Kunming Environmental Monitoring Station and the data on water discharge through Xi Yuan outflow site C1 were provided by Xi Yuan Channel Discharge Administration, Kunming City.

Dissolved oxygen before and during the experiment

Dissolved oxygen (DO) at R1 to R6 increased gradually from 1.8 to 4.5 mg L^{-1} from 2007 to 2011 due to management strategies for pollution control at the source. After growth of water hyacinth, DO stabilized at 4.1–5.2 mg L^{-1} at sites C5 and C4 and was 5.5–7.9 mg L^{-1} at C3 to C1 sites. Compared with the DO concentration in 2010, DO increase by 33% from May to November in 2011 (Fig. 9.2.3-2A).

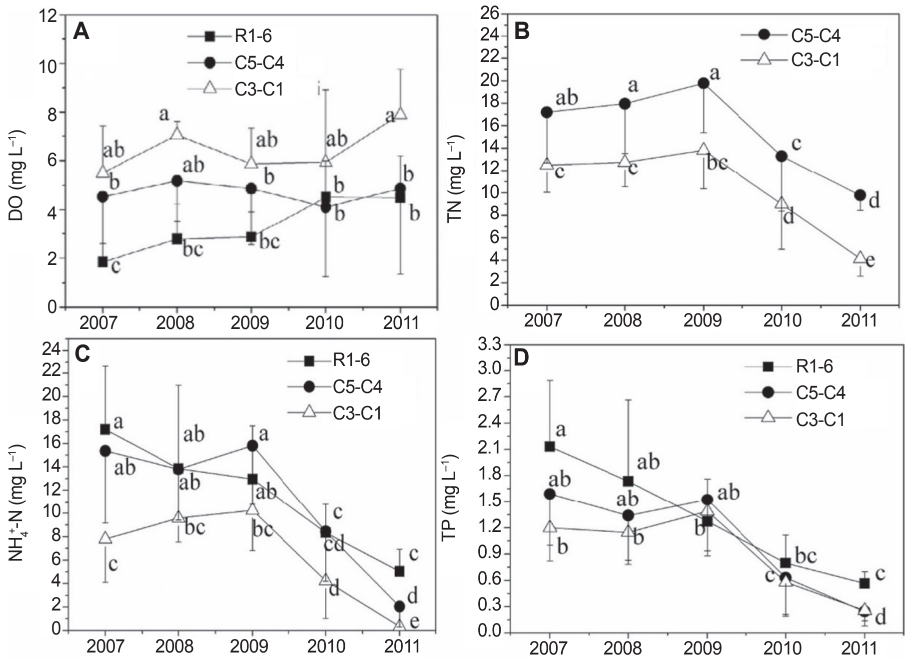

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Fig. 9.2.3-2. Changes of dissolved oxygen, nitrogen and phosphorus before and during the growth of water hyacinth at Cao Hai, Lake Dianchi (redrawn with permission).

During the experiment in 2011, water hyacinth coverage was maximized by the end of October (50% total Cao Hai surface). However, it did not cause a significant adverse impact on DO in Cao Hai. It is true that a large number of reports have shown that water hyacinth can reduce DO significantly (Rommens et al. 2003, Villamagna and Murphy 2010). In the present study, DO concentration slightly increased at sampling sites C5 to C1 after growth of water hyacinth. This phenomenon was unexpected and the reasons might have been as follows: (1) in Cao Hai, there were serious organic pollutants from 2007 to 2009 that could lower the background DO to 4–6 mg L^{-1}. After planting water hyacinth, organic pollutants were filtered by water hyacinth roots or removed by enhanced bacterial activities, reducing the consumption of oxygen in water; and (2) water hyacinth improved transparency especially in the open areas, which can enhance photosynthesis of algae and submerged plants to increase the release of oxygen.

Total nitrogen before and during the experiment

Due to a lack of data on total nitrogen at the river mouth (R1 to R6) from 2006–2010, only the total nitrogen concentration before and during the experiment in Cao Hai (C5 to C1) can be discussed. In 2010, there were only

200 hectares of natural growth of water hyacinth in Cao Hai, with the total nitrogen concentrations of 13.3 mg N L^{-1} at C5 and C4 but 9.0 mg N L^{-1} at C3–C1; the average total nitrogen concentrations from 2007 to 2009 were 18.3 mg N L^{-1} at C5–C4 and 13.0 mg N L^{-1} at C3–C1, significantly decreasing by 27 and 31% at the two sites ($p < 0.05$) (Fig. 9.2.3-2B). In 2011, the implementation of the project increased water hyacinth coverage to 420 hectares; and the total nitrogen concentrations further dropped to 9.8 at C5–C4 and 4.1 mg N L^{-1} at C3–C1 ($p < 0.05$) (decreasing by 26 and 54% compared to those in 2010).

Ammonium nitrogen before and during the experiment

During 2006 to 2011, the concentrations of ammonium correlated with those of total nitrogen (Fig. 9.2.3-2C). The concentrations of ammonium decreased gradually from 2007 to 2010 due to the same reason as mentioned in the paragraph above on dissolved oxygen. In 2011, the ammonium concentrations further dropped along the water pass from river mouth to Xi Yuan outflow, being 40% lower at R1–R6, 67% lower at C5–C4 and 89% lower at C3–C1 than the values in 2010.

Total phosphorus before and during the experiment

From 2007 to 2008, due to the management and technology improvements at the municipal wastewater treatment plants, Total Phosphorus (TP) in rivers (site R1 to R6) showed a slight downward trend. Starting from 2009, TP concentration in the rivers further decreased due to water hyacinth growth (Fig. 9.2.3-2D). In Cao Hai, TP concentration was stable during 2007 to 2009 and significantly decreased after 2010 due to the growth of water hyacinth. Compared to 2009, TP concentration decreased 59% at sites C5 and C4 and 58% at sites C3–C1 in 2010, and further decreased 60% at sites C5 and C4 and 55% at sites C3–C1 in 2011 compared to 2010.

Spatial variation in nitrogen and phosphorus concentrations

Total Nitrogen (TN) concentration decreased along the way from the entering sites (R1–R6) to Cao Hai, then exiting at Xi Yuan (C1) channel during the water hyacinth growing period (June to November). The average TN concentration of 13.8 mg N L^{-1} gradually decreased to 3.3 mg N L^{-1} at Xi Yuan (C1) (down by 76%) (Fig. 9.2.3-3A).

Statistical analysis showed that total nitrogen concentrations at R1–R6 (river into the lake), at C5 and C4 (in Cao Hai) and at C3, C2 and C1 (Xi Yuan Exit) were significantly different (Fig. 9.2.3-3A). The decreases were due to (i) denitrification enhanced by the presence of water hyacinth and (ii) nitrogen removed by water hyacinth. The natural denitrification effect can be estimated using the data from the period 2007 to 2009, during which the average TN

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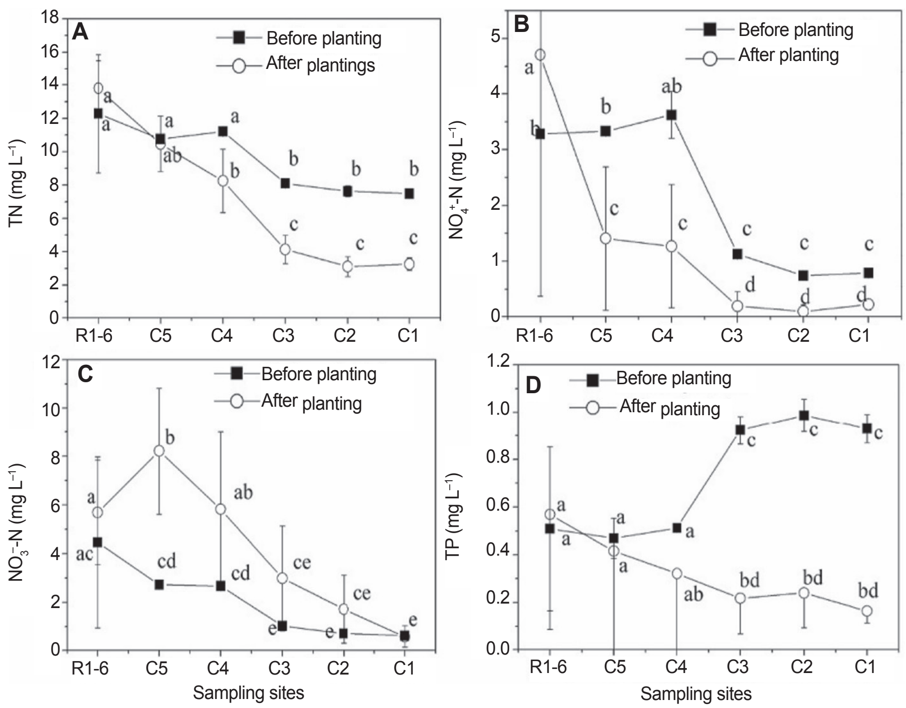

Fig. 9.2.3-3. Spatial changes of nitrogen and phosphorus before and after growth of water hyacinth (redrawn with permission).

concentration was 12.3 mg N L^{-1} at R1–R6 and 7.5 mg N L^{-1} at C1 (down by 39%). The presence of water hyacinth was estimated to contribute a net decrease of 5.1 mg N L^{-1} (37% decrease).

Ammonium (NH_4^+) and nitrate concentrations (Figs. 9.2.3-3B and 9.2.3-3C) showed a similar relationship as total nitrogen: (1) before the growth of water hyacinth, decreases of 79% in ammonium (3.3 to 0.8 mg N L^{-1}) and 89% in nitrate concentration (4.5 to 0.5 mg N L^{-1}) from sites R1–R6; (2) after planting water hyacinth, decreases of 96% in ammonium (4.7 to 0.2 mg N L^{-1}) and 94% in nitrate concentration from R1–R6 (5.5 to 0.5 mg N L^{-1}). Statistical analysis showed that and assimilation by water hyacinth were all significantly different from R1–R6 to C5–C1. Similar to total nitrogen concentration changes, the water hyacinth contribution was estimated to be a net decrease in ammonium of 0.8 mg N L^{-1} (17% decrease). One interesting phenomena was an increase in nitrate concentration at site C5 (Fig. 9.2.3-3C) due to the growth of water hyacinth.

Total phosphorus (TP) concentration indicated a more interesting impact of water hyacinth on the nutrient concentration in eutrophic water. Before growth of water hyacinth, the TP concentration increased significantly from site C4 to site C3 (Fig. 9.2.3-3D). However, after growth of water hyacinth, the TP concentration decreased from 0.55 mg P L^{-1} at sites R1–R6 to 0.15 mg P L^{-1}

at C1 site. If compared to the concentration before planting water hyacinth (0.9 mg P L^{-1}), a decrease of 83% occurred from sites of river outflows to lake water exit site.

Nitrogen concentration changes during the growth of water hyacinth in Cao Hai

From May to November 2011, total nitrogen concentrations were 11.7–16.3 mg N L^{-1} at river outflow sites, with no significant difference among the months. During the water hyacinth growing season, after the effluent passed through 147 hectares of water hyacinth area, the total nitrogen concentration dropped to 7.7 mg N L^{-1} at the middle of water ways in May to 3.5 mg N L^{-1} near lake water exit site in June (to 2.6 mg N L^{-1} in August), and then fluctuated during September to November (Fig. 9.2.3-4A).

Ammonium (NH_4^+) and nitrate concentrations fluctuated from May to November (3.3–6.7 mg N L^{-1}), which reflected the effluent discharging characteristics. The growth of water hyacinth assimilated ammonium nitrogen and kept the ammonium concentration below 1 mg N L^{-1} and

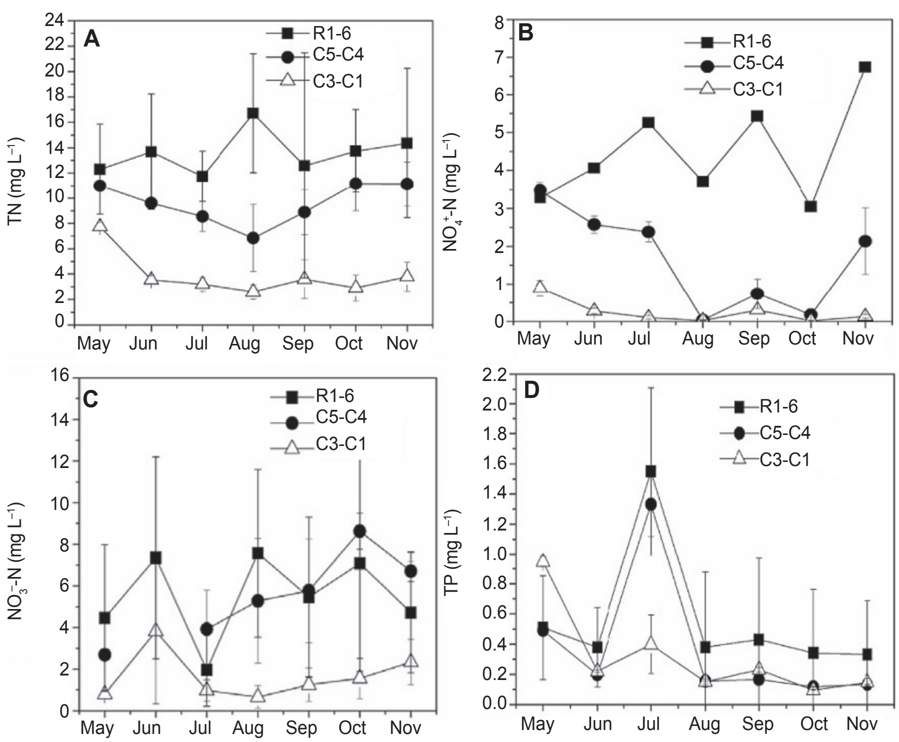

Fig. 9.2.3-4. Seasonal changes in nitrogen and phosphorus at the sampling areas after planting water hyacinth in Cao Hai (redrawn with permission).

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nitrate concentration below 3.5 mg N L^{-1} at sites C5–C1 in May and almost 0 mg N L^{-1} for ammonium and 0.5 mg N L^{-1} for nitrate in August. At sites R1–R6, there were fluctuations in concentrations during September to November, decreasing significantly to 0.02 mg N L^{-1} for ammonium and 2.1 mg N L^{-1} for nitrate at C3–C1 in November (Figs. 9.2.3-4B and 4C).

The TP concentration was 1.55 mg P L^{-1} at R1–R6, reduced to 1.35 mg P L^{-1} and then to 0.4 mg P L^{-1} along the water flowing direction in July; in other months, it was stable at 0.15 mg P L^{-1} passing through the testing sites. Based on decreases in TP concentration, there was removal efficiency of 74% in July and 57% in October and November (Fig. 9.2.3-4D).

Fate of nitrogen and phosphorus in Cao Hai in 2011

Cao Hai is an open ecosystem with ~100 million cubic meters of water flowing from six rivers and leaving at Xi Yuan channel each year. The water in rivers comes mainly from the catchment and the discharge of municipal wastewater, industrial wastewater and non-point agricultural leachate and drainage. The removal of the nutrient can be estimated by the formula:

$$R_i = (IN_i - OU_i) + (E5_i - E11_i) \quad [9.2.3\text{-}1]$$

Where R_i is nutrient removed; i = nitrogen or phosphorus; IN_i is the amount of nutrient flow into Cao Hai; OU is the amount of nutrient outflow from Cao Hai; E5 is the amount of nutrient remained in water in May; E11 is the amount of nutrient remained in water in November.

IN_i is calculated as the volume of water flowing into Cao Hai multiplied by average concentration of the nutrient in water. OU is calculated as the volume of water drained from Cao Hai multiplied by average concentration of the nutrient in water. Nitrogen and phosphorus assimilated by water hyacinth are calculated by multiplying harvested biomass (211 kt) by average nitrogen and phosphorus concentration in dry matter (41 g N kg^{-1} and 2.8 g P kg^{-1}) (Table 9.2.3-1).

Water hyacinth can significantly enhance the activity of microorganisms to promote nitrification and denitrification processes and increase nitrogen removal via nitrous oxide and molecular nitrogen (Gao et al. 2012). In natural aquatic ecosystem, excessive nitrogen is removed mainly through mineralization, nitrification and denitrification to nitrous oxide (N_2O) and molecular nitrogen (N_2) back to atmosphere. The processes are driven by microorganisms in water or sediment (Risgaard-Petersen and Jensen 1997, Zhao et al. 1999). In phytoremediation, nitrogen is removed by both plant uptake and the microorganism-driven processes. The experiment showed that 761 tonnes of total N were removed, among which 63.8% (or 486 tonnes) was removed via uptake by water hyacinth (Table 9.2.3-1). Literature suggested that water hyacinth may contribute 42–83% of total removed nitrogen (Zhang et al. 2010). The higher the nitrogen concentration in effluent, the lower the removal proportion water hyacinth contributed.

Table 9.2.3-1. Nitrogen uptake by water hyacinth and nitrogen removed from Cao Hai in Lake Dianchi from May to November 2011.

Month	Water outflow million t	Outflow TN conc. mg N L^{-1}	Outflow TN tonne	Inflow water million t	TN conc. inflow mg N L^{-1}	Inflow TN t	TN removed t	Uptake by water hyacinth t	Removed by water hyacinth %
5	12	3.48	42.1	12	12.3	153			
6	14	5.2	72.9	14	13.7	196			
7	11	3.3	36.7	11	11.7	134			
8	6	2.94	17.6	6	16.7	105			
9	14	1.99	28.2	14	12.6	182			
10	6	2.22	13.5	6	13.7	88			
11	5	2.6	13.5	6	14.3	79			
Total	68		224.5			937	761[a]	486	63.8

[a] Including the nitrogen removed from the pool originally in lake water.

Excessive phosphorus in eutrophic waters is mainly removed by sedimentation and biological assimilation. The experiment at Cao Hai showed that water hyacinth removed 139% of phosphorus from the water (Table 9.2.3-2). This result implied the release of P from the sediment. The activity of phosphorus on the interface of sediment-water is dominated by the concentrations in sediment and water (Surridge et al. 2007). When the concentration of phosphorus is lower in surface water than sediment, the phosphorus can be released from sediment to surface water, and vice versa. In the Cao Hai case, when water hyacinth removed most of phosphorus from surface water, sediment may release phosphorus to the surface water. This result is consistent with the literature (Fan and Aizaki 1997).

9.3 Impact of water hyacinth on biodiversity and structure of biological communities in Lake Dianchi

9.3.1 Macrozoobenthos at Baishan Bay in Lake Dianchi

Sample collection and analysis

The samples were collected from Baishan Bay experiment area (Fig. 9.2.1-1) from August to October 2010. Macrozoobenthos was collected monthly at 13 sampling sites of 0.0625 m^2 each with a Peterson sampler. All bottom samples were sieved through a 420-µm sieve. Specimens were manually sorted out from sediment on a white porcelain plate and preserved in 10% v/v formaldehyde solution. The macrozoobenthos was identified to be at the lowest feasible taxonomic level and counted under a microscope in the laboratory and weighed.

Table 9.2.3-2. Phosphorus uptake by water hyacinth and phosphorus removed from Cao Hai in Lake Dianchi from May to November 2011.

Moth	Water outflow million t	Outflow TP concn mg P L^{-1}	Outflow TP t	Inflow water million t	TP concn inflow mg P L^{-1}	Inflow TP t	TP removed t	Uptake by water hyacinth t	Removed by water hyacinth %
5	12	0.335	4.05	12	0.58	7.19			
6	14	0.718	10.07	14	0.48	6.95			
7	11	0.362	4.03	11	0.51	5.85			
8	6	0.214	1.28	6	0.53	3.34			
9	14	0.122	1.73	14	0.58	8.46			
10	6	0.128	0.78	6	0.53	3.37			
11	5	0.082	0.43	6	0.89	4.91			
Total	68		22.36			40.05	23.8	33.1	139

Au is this correct?

To estimate the biodiversity, Shannon-Wiener, Margalef, Gini-Simpson and Pielou indices were calculated using the formulae as defined below.

Shannon-Wiener index:

$$H' = -\sum_{i=1}^{s} P_i \ln P_i = -\sum_{i=1}^{s} (N_i/N) \ln(N_i/N) \qquad [9.3.1\text{-}1]$$

Margalef index:

$$d = (S-1)/\ln(N) \qquad [9.3.1\text{-}2]$$

Gini-Simpson index:

$$D = 1-\sum_{i=1}^{s} P_i^2 \qquad [9.3.1\text{-}3]$$

Pielou index:

$$J = H'/\ln(S) \qquad [9.3.1\text{-}4]$$

Where P_i is the proportion of the *i*th species in a specific group and is calculated as the number of individuals (N_i) belonging to the *i*th species in the total number (N) of individuals; S is the total number of species in the samples; H' is the Shannon-Wiener index.

Statistical method of one-way ANOVA was employed to identify significant differences among three groups (water hyacinth area, near water hyacinth area and area far away from water hyacinth) on the biodiversity indices as well as environmental parameters in surface water and sediment. When the data did not follow normal distribution and homogeneity, the Mann–Whitney U test was used to identify differences among the three areas. All statistical analyses were performed using software SPSS v16.0 for Windows. The significant level was set at $p < 0.05$.

Benthos community and density

The sample data showed a total of 18 species present in all the samples of three areas, among which, eight species of Oligochaeta (44.4% of total species), five species of Insecta (27.8% of total), Crustacea three species (16.7% of total) and Gastropoda and Nematoda one species each (5.6% of total species each). In the water hyacinth area, total of 14 species were collected including Oligochaeta seven species, Gastropoda one species, Insecta two species, Crustacea three species and Nematoda one species (unidentified class). In the area near water hyacinth, total of 10 species were collected including Oligochaeta six species, Insecta three species and Nematoda one species. Far from water hyacinth area, only six species were collected including Oligochaeta four species and Insecta two species. The common species presented in all three areas were *Limnodrilus hoffmeisteri*, *Limnodrilus grandisetosus* and *Tubifex tubifex*; whereas Gastropoda (*Radix swinhoe*) and Crustacea (Decapoda, *Caridina* sp. and *Gammaridae* spp.) were only present in the water hyacinth area (Table 9.3.1-1).

Table 9.3.1-1. Species compositions of benthic macrozoobenthos at the sampling areas from August to October 2010.

Taxon	**Water hyacinth area**	**Area near water hyacinth**	**Area far from water hyacinth**
Nematoda			
1. *unidentified* sp.	+	+	
Oligochaeta			
Naididae			
2. *Dero digitata*	+	+	
3. *Stephensoniana trivandrana*	+		
Tubificidae			
4. *Limnodrilus hoffmeisteri*	+	+	+
5. *Limnodrilus grandisetosus*	+	+	+
6. *Limnodrilus* sp.	+		
7. *Tubifex tubifex*	+	+	+
8. *Branchiura sowerbyi*	+	+	
9. *unidentified* sp.		+	+
Gastropoda			
Mesogastropoda			
Lymnaeidae			
10. *Radix swinhoe*	+		
Insecta			
Diptera			
Chironomidae			
11. *Chironomus Plumosus*	+		+
12. *Dicrotendipes* sp.		+	
13. *Orthocladius* sp.	+	+	
Phemeroptera			
Baetidae			
14. *Baetis* sp.			+
Odonata			
15. *unidentified* sp.		+	
Crustacea			
Decapoda			
16. *unidentified* sp.	+		
Atyidae			
17. *Caridina* sp.	+		
Amphipoda			
Gammaridae			
18. *unidentified* sp.	+		

The densities (expressed as individuals per square meter) of macrozoobenthos were 295 in the water hyacinth area, 159 near water hyacinth and 261 far from the water hyacinth area. In all three sampled areas, the dominant species of macrozoobenthos were mainly Oligochaeta (*Limnodrilus hoffmeisteri* and *Limnodrilus grandisetosus*), which accounted for 264 individuals in the water hyacinth area, 151 individuals near water hyacinth and 250 individuals far from the water hyacinth area, representing 90, 95 and 96% of the total densities in three areas, respectively (Table 9.3.1-2).

Due to different weight of individual benthic fauna, the biomass distribution and density were different in the three experiment areas. In the water hyacinth area, the biomass of macrozoobenthos was mainly of Oligochaeta (*Limnodrilus hoffmeisteri* and *Limnodrilus grandisetosus*) and Insects (Chironomidae) representing 56 and 30% of the total, respectively. Similar numbers were recorded in the area far from water hyacinth (Oligochaeta 61% and Insects 39% of the total). However, in the area near water hyacinth, the biomass was mainly Oligochaeta, representing 99.3% of the total (Table 9.3.1-2).

Functional feeding groups analysis showed that the species composition was collector-gatherer (density: 97%, biomass: 93%), parasite (density: 1.3%, biomass: 0.6%), scraper (density: 1.3%, biomass: 1.8%) and shredders (density: 0.6% biomass: 3.0%) in the water hyacinth area; in the area near water hyacinth: collector-gatherer (density: 97%, biomass: 96%), parasites (density: 1.8%, biomass: 2.9%) and predator (density: 1.0%, biomass: 0.7%); and only collector-gatherers in the area far from water hyacinth.

Dominant species

In the all sampling areas, Oligochaeta were the dominant taxa with the average density of 259 individuals m^{-2} representing 93% of the total number, among which *Limnodrilus hoffmeisteri* was the main species with an average density of 201 individuals m^{-2} or 72% of the total. The average densities of *Limnodrilus hoffmeisteri* were 219, 104 and 281 individuals m^{-2} in the areas of water hyacinth, and near and far from water hyacinth, respectively, representing 68, 60 and 86% of the total. From August to October, density of *Limnodrilus hoffmeisteri* increased first then dropped in the water hyacinth area and far from water hyacinth, while it showed a continuous drop near the water hyacinth area (Fig. 9.3.1-1A). However, biomass in all three sampling areas showed a similar pattern (Fig. 9.3.1-1B). This is because the biomass of the second dominant family Chironomidae was larger than the biomass of Oligochaeta so that the ratio of the total biomass was similar among the three areas (Fig. 9.3.1-1B).

Characteristics of community indices

Variance analysis showed that in the water hyacinth area and the nearby area, Margalef, Shannon-Wiener, Gini-Simpson and Peilou indices decreased slightly (non-significantly) from August to September, and then increased

Table 9.3.1-2. Density (individuals m^{-2}) and biomass ($g\ m^{-2}$) of macrozoobenthos at the sampling areas in August to October 2010.

Taxon	Water hyacinth area				Area near water hyacinth				Area far from water hyacinth			
	Density	**%**	**Biomass**	**%**	**Density**	**%**	**Biomass**	**%**	**Density**	**%**	**Biomass**	**%**
Oligochaeta	264	89.6	0.36	55.8	151	95.0	0.37	99.3	250	95.8	0.25	61.1
Gastropoda	1	0.3	0.03	3.9	0	0	0	0	0	0	0	0
Insecta	11	3.7	0.19	29.7	5.3	3.3	0	0.7	11	4.2	0.16	38.9
Crustacea	15	5.1	0.07	10.5	0	0	0	0	0	0	0	0
Nematoda	4	1.2	0	0.2	2.7	1.7	0	0	0	0	0	0
Total	295	100	0.65	100	159	100	0.38	100	261	100	0.40	100

significantly in October ($p < 0.05$). In the area far from water hyacinth, diversity indices of Margalef, Gini-Simpson and Shannon-Wiener gradually reduced from August to October, and were significantly lower in October than August. However, Peilou index was similar in August, September and October in that area (Table 9.3.1-3).

Comparing different areas, Margalef diversity, Gini-Simpson and Shannon-Wiener indices were significantly higher in the water hyacinth area than areas near and far from water hyacinth. However, Peilou index at the three areas was not significantly different (Table 9.3.1-3).

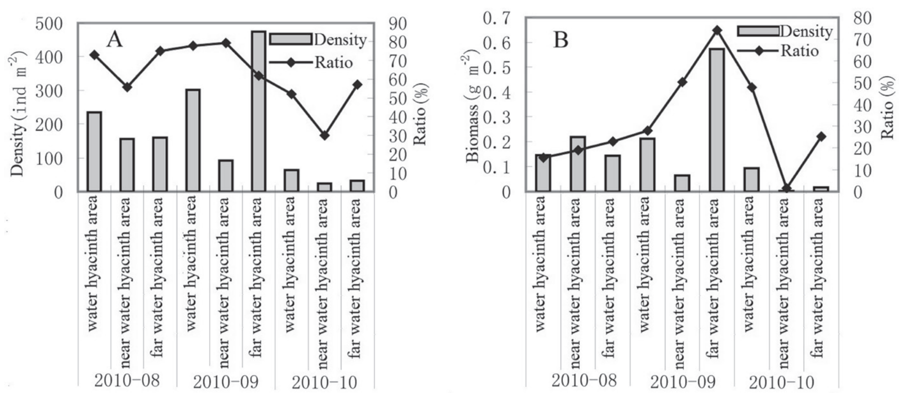

Fig. 9.3.1-1. Density (A) and biomass (B) changes of *Limnodrilus hoffmeisteri* in the sampling areas.

Table 9.3.1-3. Characteristics of community indices of macrozoobenthos in various sampling areas in August to October 2010 (mean ± SD).

Area	Month	Margalef	Gini-Simpson	Shannon-Wiener	Peilou
Water hyacinth area	8	0.38 ± 0.22a	0.40 ± 0.24a	0.71 ± 0.43a	0.60 ± 0.35ab
	9	0.42 ± 0.29a	0.36 ± 0.21a	0.68 ± 0.42a	0.54 ± 0.34a
	10	0.56 ± 0.12b	0.60 ± 0.14b	1.10 ± 0.27b	0.84 ± 0.12b
	8–10	0.43 ± 0.23A	0.42 ± 0.22 A	0.77 ± 0.41A	0.62 ± 0.31A
Area near water hyacinth	8	0.27 ± 0.20ab	0.31 ± 0.28a	0.54 ± 0.47a	0.52 ± 0.42a
	9	0.18 ± 0.25a	0.18 ± 0.21a	0.38 ± 0.44a	0.39 ± 0.48a
	10	0.46 ± 0.03b	0.62 ± 0.01b	1.03 ± 0.02b	0.93 ± 0.02b
	8–10	0.27 ± 0.21B	0.32 ± 0.26 B	0.57 ± 0.45B	0.55 ± 0.43A
Area far from water hyacinth	8	0.38 ± 0.20a	0.40 ± 0.23a	0.72 ± 0.44a	0.65 ± 0.20a
	9	0.18 ± 0.26ab	0.29 ± 0.41ab	0.49 ± 0.70ab	0.45 ± 0.63a
	10	0.11 ± 0.15b	0.22 ± 0.31b	0.32 ± 0.45b	0.46 ± 0.65a
	8–10	0.25 ± 0.21B	0.32 ± 0.26 B	0.54 ± 0.46B	0.54 ± 0.40A

Notes: Different lowercase letters represent significant ($p < 0.05$) differences in the same area but different months; different uppercase letters represent significant ($p < 0.05$) differences among different areas.

9.3.2 Zooplankton at Baishan Bay in Lake Dianchi

Sample collection and analysis

The location and sampling periods were the same as mentioned earlier, but focused on planktonic crustaceans Cladocera, Copepoda and Rotifera.

Composition of zooplankton as influenced by water hyacinth

At all three sampling areas, 36 species of zooplankton were obtained: 15 species in six genera belonged to Cladocera, nine species in four genera were Copepoda, and 11 species in seven genera belonged to Rotifera. In the water hyacinth area, 24 species of zooplankton included 11 species of Cladocera, nine species of Copepoda and four species of Rotifera. In the area near water hyacinth, 28 species comprised 11 species of Cladocera, eight species of Copepoda and nine species of Rotifera. In the area far from water hyacinth, 24 species included 12 species of Cladocera, seven species of Copepoda and five species of Rotifera (Table 9.3.2-1). Species co-occurring in all three areas were *Bosmina longirostris*, *Bosmina coregoni*, *Bosmina fatali*, *Ceriodaphnia cornuta*, *Alona rectangular*, *Daphnia hyalina*, *Daphnia cucullata*, *Mesocyclops leuckarti*, *Mesocyclops pehpeiesis*, *Cyclops strenuus*, *Cyclops vicinus*, *Microcyclops varicans*, *Microcyclops robustus*, *Microcyclops intermedius*, *and Keratella quadrata*. *Limnoithona sinensis* and *Lepadella ovalis* were only found in the water hyacinth area. *Brachionus forficula*, *Filinia maior* and *Lecane luna* were only found in the area near water hyacinth, whereas *Ceriodaphnia cornigera*, *Ceriodaphnia quadrangular* and *Trichocera gracilis* were only found in the area far from water hyacinth (Table 9.3.2-1).

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Spatial and temporal distribution of zooplankton as influenced by water hyacinth

During the sampling period (August to October 2010), the number of Cladocera gradually declined in the water hyacinth area, gradually increased in the nearby area, and increased in September but decreased in October in the area far from water hyacinth (Fig. 9.3.2-1). Analysis of variance showed that the density of Copepoda was not significantly different in the water hyacinth area and the area far from water hyacinth during the sampling period, but was significantly different between the water hyacinth and nearby areas in the period August to October ($p < 0.05$, Fig. 9.3.2-1). The density of Rotifera was also not significantly different in the water hyacinth and nearby areas from August to October. The Copepoda density did not differ in the water hyacinth and far away areas in the August-October period. In October, Rotifera were not present in the area far from water hyacinth.

Table 9.3.2-1. Species composition of zooplankton in the sampling areas from August to October 2010.

Taxon	**WHA**	**ANWH**	**AFWH**
Cladocera			
Bosmina			
1. *Bosmina longirostris*	+	+	+
2. *Bosmina coregoni*	+	+	+
3. *Bosmina fatali*	+	+	+
Ceriodaphnia			
4. *Ceriodaphnia cornuta*	+	+	+
5. *Ceriodaphnia pulchella*	+		+
6. *Ceriodaphnia cornigera*			+
7. *Ceriodaphnia megalops*			+
8. *Ceriodaphnia quadrangula*			+
Moina			
9. *Moina macrocopa*		+	+
Alona			
10. *Alona rectangular*	+	+	+
Daphnia			
11. *Daphnia hyalina*	+	+	+
12. *Daphnia cucullata*	+	+	+
13. *Daphnia longispina*	+	+	
14. *Daphnia pulex*	+	+	
Diaphanosoma			
15. *Diaphanosoma brachyurum*	+	+	
Copepoda			
Mesocyclops			
16. *Mesocyclops leuckarti*	+	+	+
17. *Mesocyclops pehpeiesis*	+	+	+
Cyclops			
18. *Cyclops strenuus*	+	+	+
19. *Cyclops vicinus*	+	+	+
Microcyclops			
20. *Microcyclops varicans*	+	+	+
21. *Microcyclops robustus*	+	+	+
22. *Microcyclops intermedius*	+	+	+
23. *Microcyclops longiramus*	+	+	
Limnoithona			
24. *Limnoithona sinensis*	+		

Table 9.3.2-1. contd....

Au.: Pl check spelling.

Table 9.3.2-1. contd.

Taxon	WHA	ANWH	AFWH
Rotifera			
Brachionus			
25. *Brachionus angularis*	+	+	
26. *Brachionus calyciflorus*		+	+
27. *Brachionus forficula*		+	
28. *Brachionus falcatus*		+	+
Keratella			
29. *Keratella quadrata*	+	+	+
30. *Keratella valga*	+	+	
Monostyla			
31. *Monostyla closterocerca*		+	+
Filinia			
32. *Filinia maior*		+	
Lepadella			
33. *Lepadella ovalis*	+		
Lecane			
34. *Lecane luna*		+	
Trichocera			
35. *Trichocera gracilis*			+

Notes: WHA = water hyacinth area; ANWH = area near water hyacinth; AFWH = area far from water hyacinth; + refers to species represent at site.

The total densities of Cladocera were 26, 28 and 54 individuals L^{-1} in the areas of water hyacinth, nearby and far away, respectively, and were not significantly different among the areas. The total densities of Copepoda were 33, 32 and 25 individuals L^{-1} in the areas of water hyacinth, nearby and far away, respectively, with no significant difference among the areas. The densities of Rotifera were 7, 38 and 34 individuals L^{-1} in the areas of water hyacinth, nearby and far away, respectively, with significant differences between the water hyacinth area and the nearby area ($p < 0.05$).

Dominant species

The dominant species in Cladocera was *Bosmina longirostris* with density of 10 individuals L^{-1} (37% of the total Cladocera density) in the water hyacinth area, 13 individuals L^{-1} (47% of the total Cladocera density) in the area near water hyacinth and 32 individuals L^{-1} (60% of the total Cladocera density) in the area far from water hyacinth. Due to large variations in standard deviation, the densities of the dominant species in Cladocera were not significantly different among the three areas.

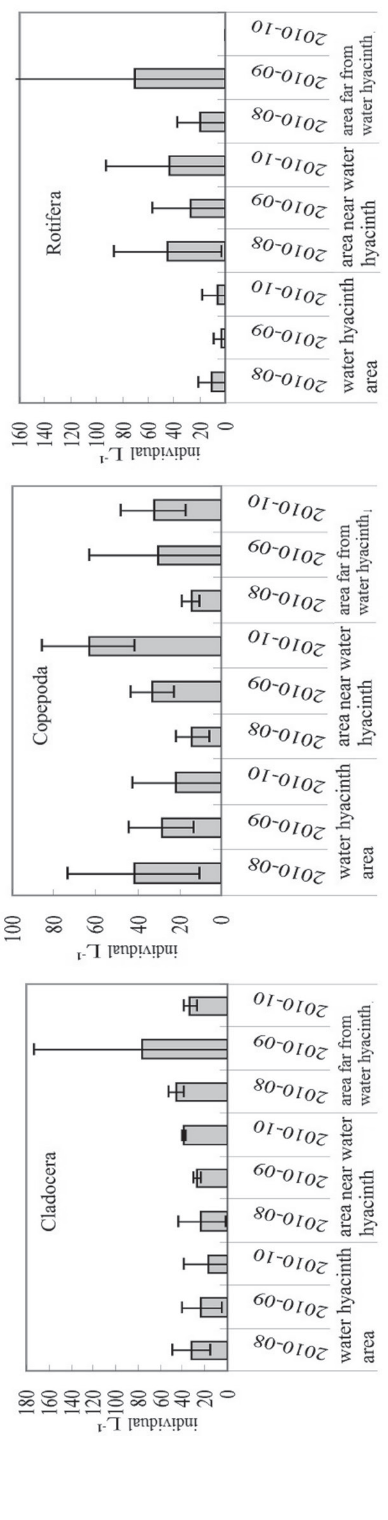

Fig. 9.3.2-1. Variations of zooplankton in the sampling areas.

The dominant species of Copepoda was *Microcyclops varicans* with density of 25 individuals L^{-1} (75% of the total Copepoda density) in the water hyacinth area, 23 individuals L^{-1} (74% of the total Copepoda density) in the area near water hyacinth and 21 individuals L^{-1} (86% of the total Copepoda density) in the area far from water hyacinth, with no significant difference among the three areas.

The dominant species of Rotifera were different among the three areas: *Keratella quadrata* in the water hyacinth area (4.4 individuals L^{-1}, or 68% of the total Rotifera density), *Keratella valga* in the area near water hyacinth (11 individuals L^{-1}, or 28% of the total Rotifera density) and *Monostyla closterocerca* in the area far from water hyacinth (15 L^{-1}, or 39% of the total Rotifera density).

Biodiversity indices

Shannon-Wiener (H'), Gini-Simpson (D) and Margalef (d) indices in Cladocera decreased gradually during August to October in all three sampled areas, but without statistically significant difference (Table 9.3.2-2). All the indices in Copepoda showed a similar pattern as in Cladocera, although they were lower in the area far from water hyacinth compared to the other two areas. However, these indices in Rotifera were higher in the area near water hyacinth than those in the water hyacinth and far away areas ($p < 0.05$, Table 9.3.2-2).

Correlation analysis

There was no significant correlation among main physical and chemical indicators of water, the total densities of Cladocera and Rotifera species and the dominant species of Rotifera. The total density and the dominant species (*Microcyclops varicans*) of Copepoda were significantly and positively correlated only with total nitrogen and total phosphorus in water. The dominant species (*Bosmina longirostris*) of Cladocera was significantly and negatively correlated with chlorophyll-*a* concentration in water. Shannon-Wiener index in Cladocera showed a significant and positive correlation with the water temperature and negative correlation with NH_4^+ and PO_4^{3-}. Shannon-Wiener index in Copepoda showed a significant and positive correlation with the water temperature and negative correlation with NH_4^+. Shannon-Wiener index in Rotifera showed a significant and positive correlation with the dissolved oxygen and water pH (Table 9.3.2-3).

9.4 Impact of water hyacinth on biodiversity and structure of biological community in Lake Taihu

The total water hyacinth growth area at Zhushan Bay in Lake Taihu covered only 0.09% of the total water surface area of the lake. Hence, it was expected that the impact of water hyacinth on water quality would be minimal in the

Table 9.3.2-2. Shannon-Wiener (*H'*), Margalef (*d*), Gini-Simpson (*D*) and Peilou (J) indices in Cladocera, Copepoda and Rotifera in the sampled areas from August to October 2010.

Area		Cladocera				Copepoda				Rotifera			
		H'	*d*	*D*	*J*	*H'*	*d*	*D*	*J*	*H'*	*d*	*D*	*J*
Mean	WHA	1.08a	1.39a	0.56a	0.68a	0.65a	0.89a	0.34a	0.51a	0.10a	0.06a	0.06a	0.11a
	NWHA	0.93a	1.27a	0.48a	0.30a	0.59a	0.93a	0.33a	0.54a	0.79b	0.54b	0.42b	0.61b
	FWHA	0.85a	1.03a	0.46a	0.61a	0.43a	0.51a	0.27a	0.48a	0.37ab	0.20ab	0.24ab	0.41ab
Standard deviation	WHA	0.45	0.44	0.22	0.20	0.43	0.59	0.22	0.28	0.26	0.17	0.16	0.28
	NWHA	0.36	0.69	0.18	0.12	0.29	0.84	0.17	0.26	0.68	0.50	0.33	0.43
	FWHA	0.42	0.44	0.23	0.28	0.30	0.40	0.21	0.39	0.43	0.23	0.28	0.45

Notes: WHA refers to Water Hyacinth Area; ANWH refers to Area Near Water Hyacinth; AFWH refers to Area Far from Water Hyacinth; different lower case letters for a specific index represent significant differences ($p < 0.05$).

Table 9.3.2-3. Correlation analysis of physico-chemical parameters and zooplankton.

	WT	**DO**	**pH**	**Chl-*a***	**TN**	**NH_4^+**	**NO_3^-**	**TP**	**PO_4^{3-}**
Cladocera	0.08	0.04	0.22	0.26	–0.01	0.03	–0.12	0.07	–0.09
Copepoda	–0.05	–0.11	0.10	0.19	0.38*	0.13	0.18	0.53**	0.06
Rotifera	0.12	0.16	0.10	0.03	–0.21	–0.13	–0.05	–0.13	0.07
Bosmina longirostris	–0.08	0.12	0.12	–0.44*	0.07	0.30	–0.10	0.01	0.23
Microcyclops varicans	–0.17	–0.01	0.10	0.22	0.49*	0.26	0.24	0.58**	0.09
Keratella quadrata	0.19	0.02	–0.07	–0.13	–0.19	–0.17	–0.20	–0.09	0.24
H′ (Cladocera)	0.40*	–0.34	–0.17	–0.33	–0.16	–0.51**	–0.06	0.09	–0.43*
H′ (Copepoda)	0.46**	–0.24	–0.26	–0.24	–0.30	–0.39*	–0.28	–0.19	–0.09
H′ (Rotifera)	–0.04	0.36*	0.37*	0.21	–0.27	–0.17	0.29	–0.26	–0.23

Notes: WT = Water Temperature (ºC); DO = Dissolved Oxygen (mg L^{-1}); Chl-*a* = Chlorophyll-*a* (mg L^{-1}); TN = Total Nitrogen (mg L^{-1}); TP = Total Phosphorus (mg L^{-1}); * and ** refer to $p < 0.05$ and $p < 0.01$.

Lake Taihu area, and the ecological engineering project at the lake only focused on biological diversity inside and outside the water hyacinth mat. The main contribution to water purification was assessed by determining the amount of nitrogen and phosphorus removed by harvesting water hyacinth biomass.

9.4.1 Macrozoobenthos at Zhushan Bay in Lake Taihu

Sample collection and analysis

Zhushan Bay (120º04'00"–120º04'40" E, 31º27'01"–31º27'22" N) is located northwest in Lake Taihu, Jiangsu Province, China (Fig. 9.4.1-1).

The ecological engineering project selected a demonstration area of 2 km^2 to grow water hyacinth in enclosures in the center of Zhushan Bay. A total of 33 sample sites (Fig. 9.4.1-1) in and around the enclosures were selected to investigate the impacts of water hyacinth on macrozoobenthos. Sites 1–12 referred to the areas far from water hyacinth; sites 13–24 referred to the area near water hyacinth; and sites 25–33 referred to the water hyacinth area. Water hyacinth plantlets were introduced to the area in July 2009. Samples were collected early each month from August to October 2009 using a 0.025-m^2

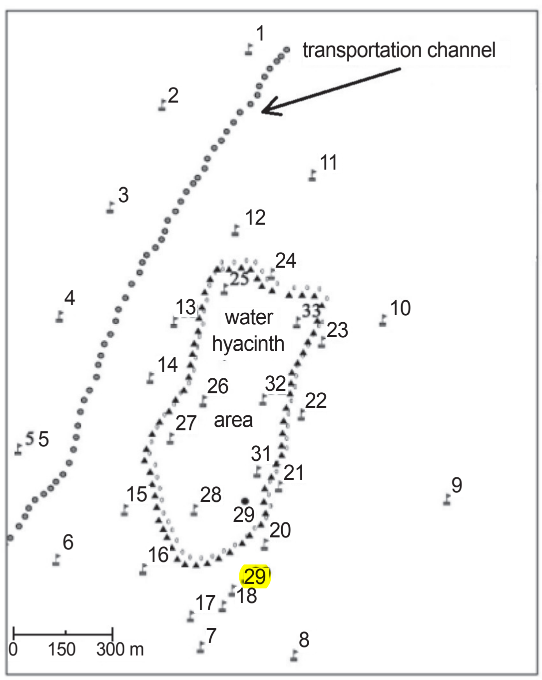

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Fig. 9.4.1-1. Sampling sites at Zhushan Bay in Lake Taihu, site 1–12 referring to far from water hyacinth areas, site 13–24 referring to near water hyacinth areas, site 25–33 referring to water hyacinth areas (redrawn with permission).

Peterson sampler. All bottom samples were sieved through a 245-μm sieve. Specimens were manually sorted out from sediment on a white porcelain plate and preserved in 10% v/v formaldehyde solution. Macrozoobenthos and zooplankton were identified to the lowest feasible taxonomic level and counted under microscopes in the laboratory, weighed and calculated per square meter.

To estimate the biodiversity, Shannon-Wiener and Gini-Simpson indices were used as defined in formulas [9.3.1-1] and [9.3.1-3]. Index of Relative Importance (IRI) was defined to assess dominant species:

$$IRI = (W + N) \times F \qquad [9.4.1\text{-}1]$$

where W is the biomass weight ratio of ith species to the total weight of the all species; N is the ratio of the ith species density (individual L^{-1}) to the total number of the species; F is the frequency of the ith species presence (Simenstad et al. 1991).

Macrozoobenthos composition

During the 3-month investigation, total of 120 samples were collected; and eight common species belonging to five families were identified (Table 9.4.1-1). These species appeared in all sampled areas.

Table 9.4.1-1. Species composition of macrozoobenthos in all sampled areas and the index of relative importance (IRI) (Liu et al. 2014).

Taxon	**IRI**	**%**	**Taxon**	**IRI**	**%**
Oligochaeta			Gastropoda		12.5%
Tubificidae		25%	*Bellamya aeruginosa*	113	
Limnodrilus hoffmeisteri	48		Bivalvia		25%
Rhyacodrilus sinicus	91		*Anodonta elliptica*	<1	
Diptera			*Unio douglaniae*[a]		
Chironomidae		25%	Clitellata		12.5%
Pelopia sp.	15		Hirudinea		
Chironomus plumosus	22		*Hirudo nipponica*	<1	

[a] Deleted from statistical analysis because it appeared less than twice.

Spatial and temporal changes in macrozoobenthos density

Gastropoda and Diptera larvae were found in all three sampled areas, whereas Oligochaeta rate of occurrence varied slightly. The average density and biomass weight of Gastropoda were highest in the water hyacinth area and were higher in the area near than far from water hyacinth. The density and biomass weight of Diptera larvae and Oligochaeta were higher in the area near than far from water hyacinth, but were lowest in the water hyacinth area (Table 9.4.1-2).

The dynamic changes in the average densities in each month showed that Oligochaeta density declined from August to October 2009 in the area far from water hyacinth, but in the area near water hyacinth it increased first and then declined (Fig. 9.4.1-2). The same occurred for the water hyacinth area.

The average density of Diptera increased from August to September, then declined in October in the area far from water hyacinth, but in the water hyacinth area it continuously declined from 1040 individuals m^{-2} in August to 449 individuals m^{-2}. The average density of Gastropoda showed a decline in the areas far from and near water hyacinth over the sampling period. Overall, macrozoobenthos declined in the area far from water hyacinth and increased in the area near water hyacinth during the monitoring period.

Table 9.4.1-2. Average density (individuals m^{-2}) and biomass (g m^{-2}) of macrozoobenthos in all sampled areas in Lake Taihu.

Taxon	Water hyacinth area			Area near water hyacinth			Area far from water hyacinth		
	%	Density	Biomass	%	Density	Biomass	%	Density	Biomass
Gastropoda	100	440	673	100	371	486	100	277	373
Oligochaeta	81	2409	2.4	100	4917	5.0	81	4630	4.8
Diptera	100	2058	4.6	100	5653	9.3	100	4043	7.3

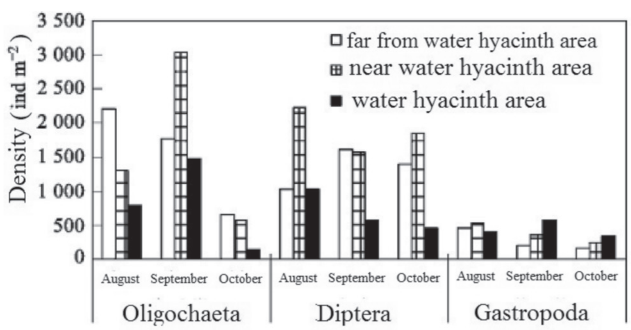

Fig. 9.4.1-2. Density changes of macrozoobenthos from August to October 2009 in the sampling areas in Lake Taihu (redrawn with permission).

Temporal and spatial changes in macrozoobenthos biomass and community structure

Given that the individual Gastropoda specimens generally have larger biomass than those in Oligochaeta and Diptera, even a small number of individual Gastropoda collected would have larger biomass than a relatively large number of Oligochaeta and Diptera specimens. In the area far from water hyacinth, the biomass of Oligochaeta and Gastropoda declined from August to October, while biomass of Diptera increased from August to September and then decreased in October (Table 9.4.1-3). In the area near water hyacinth, the biomass of Gastropoda declined from August to October, while Oligochaeta biomass increased from August to September and then decreased in October, and Diptera biomass declined from August to September and then increased in October. In the water hyacinth area, the biomass of Diptera declined from August to October, while biomass of Oligochaeta increased from August to September and then decreased in October, and Gastropoda biomass increased from August to September and then decreased slightly in October. In phytoremediation of eutrophic waters, species of Oligochaeta and Diptera may be regarded as indicators of the eutrophic status, whereas Gastropoda species are indicators of healthy aquatic environments.

Table 9.4.1-3. Average biomass (g m^{-2}) of macrozoobenthos from August to October 2009 at three sampling areas.

Sampling period	August			September			October		
Sampling group	**O**	**D**	**G**	**O**	**D**	**G**	**O**	**D**	**G**
Area far from water hyacinth	2.58	1.17	502	1.42	3.11	303	0.82	2.99	315
Area near water hyacinth	2.19	3.76	608	2.39	1.86	439	0.44	3.64	413
Water hyacinth area	0.75	1.93	507	1.49	1.77	854	0.18	0.90	657
Average for all areas	1.84	2.29	539	1.77	2.25	532	0.48	2.51	462

Notes: O = Oligochaeta; D = Diptera; G = Gastropoda.

Changes in biodiversity at the sampled areas

Shannon-Wiener and Gini-Simpson Biodiversity indices changed the same way as the density and biomass of the species in the three sampling areas, i.e., increased from August to September and then declined slightly in October. The two indices showed large variation and were higher in the water hyacinth area than the areas far from and near water hyacinth, especially in August and September (Fig. 9.4.1-3).

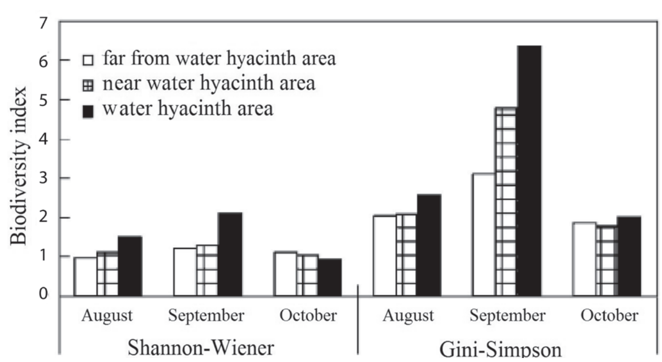

Fig. 9.4.1-3. Changes of biodiversity indexes of macrozoobenthos from August to October 2009 in the sampling areas (redrawn with permission).

9.4.2 Zooplankton at Zhushan Bay in Lake Taihu

Sample collection and analysis

The survey of zooplankton was conducted in the same areas (Fig. 9.4.1-1) and but different sampling schedule from 22 August to 11 November 2009. Zooplankton samples were collected from 0 to 0.5 m depth using a 1-L Patalas sampler. Samples were filtered through 35-µm mesh net, the zooplankton were preserved in a 5% v/v formaldehyde solution, identified and sorted to the genus level, and counted directly using a Nikon microscope at 100 x magnification.

Composition of zooplankton

Altogether 22 genera of zooplankton (protozoa not identified) were found, among which seven genera of Cladocera; five genera of Copepoda; and 10 genera of Rotifera (Table 9.4.2-1).

The species were evenly distributed in the areas of water hyacinth, near and far away with 19, 20 and 19 genera, respectively. Among the total genera, 17 were commonly distributed in all three sampled areas; only five genera showed a different distribution pattern in the three areas. The data indicated that the ecological engineering project using water hyacinth for phytoremediation of the large lake had little effects on the zooplankton community structure.

Changes in zooplankton density

The Cladocera average density in the water hyacinth area and nearby was significantly higher than in the area far from water hyacinth ($p < 0.05$). The average density of copepods showed an increasing (but non-significant) trend from the area far from water hyacinth to the area near water hyacinth and the water hyacinth area. The Rotifera density was significantly lower in the water hyacinth area than in the areas near and far from water hyacinth ($p < 0.05$). Total zooplankton density was higher in the water hyacinth and nearby areas compared with the area far from water hyacinth ($p < 0.05$, Table 9.4.2-2).

Temporal and spatial distribution of zooplankton

In the three sampled areas, the densities of Cladocera, Copepoda and Rotifera showed a similar pattern during August to November 2009, with no significant differences (Figs. 9.4.2-2a, 9.4.2-2b and 9.4.2-2c). The data suggested that the adverse effects of water hyacinth on zooplankton were very limited at Zhushan Bay in Lake Taihu if the population of the macrophyte can be controlled in properly-sized enclosures and harvested on time (Chen et al. 2012).

Table 9.4.2-1. List of taxa and dominant species in the sampled areas at Zhushan Bay in Lake Taihu from 22 August to 11 November 2009.

Taxon			Distribution			Dominant species (%)		
Zooplankton	**Family**	**Genus**	**FWHA**	**NWHA**	**WHA**	**FWHA**	**NWHA**	**WHA**
Cladocera	Bosminidae	*Bosmina Baird*	*	*	*	75	85	74
	Daphniidae	*Ceriodaphnia Dana*	+	+	+			
		Daphnia (D.s. str.)	+	+	+			
		Daphnia (D. carinata)	+	N	N			
	Moinidae	*Moina Baird*	+	+	+			
	Chydoridae	*Alona Baird*	+	+	+			
	Sididae	*Diaphanosoma Fischer*	N	+	+			
Copepoda	Oithonidae	*Limnoithona Burckhardt*	+	+	+			
	Centropagidae	*Sinocalanus Burckhardt*	N	+	+			
	Cyclopidae	*Mesocyclops Sars*	*	*	*	59	51	61
		Cyclops Müller	+	+	+			
		Microcyclops Claus	*	*	*	35	28	35
Rotifera	Lecanidae	*Monostyla*	*	*	*	22	6	20
		Lecane	+	+	+			
	Gastropodidae	*Ascomorpha*	+	+	+			
	Lindiidae	*Lindia*	+	N	N			
	Testudinellidae	*Filinia*	+	+	+			
	Philodinidae	*Rotaria*	+	+	+			
	Trichocercidae	*Trichocerca*	N	+	N			
	Brachionidae	*Brachionus*	*	*	*	46	57	49
		Keratella	*	*	*	23	28	26
		Lepadella	+	+	+			
Total	15 (6 + 3 + 7)	22 (7 + 5 + 10)	19	20	19			

Note*: dominant genus; +: present; N: not present; AFWH: area far from water hyacinth; ANWH: area near water hyacinth; WHA: water hyacinth area.

Table 9.4.2-2. Average density (individuals L^{-1}) of zooplankton in the three sampled areas from 22 August to 11 November 2009 at Zhushan Bay in Lake Taihu.

Zooplankton	**Water hyacinth area**	**Area near water hyacinth**	**Area far from water hyacinth**
Cladocera	57.6 ± 4.3a	51.2 ± 2.8[a]	29.5 ± 6.3[b]
Copepoda	4.5 ± 1.2[a]	3.7 ± 0.8[a]	3.2 ± 0.4[a]
Rotifera	15.7 ± 1.9[b]	20.5 ± 1.9[a]	22.8 ± 2.6[a]
Total	77.8 ± 5.8[a]	75.4 ± 4.0[a]	55.5 ± 7.8[b]

Note: Different low case letters indicate significant differences among the areas.

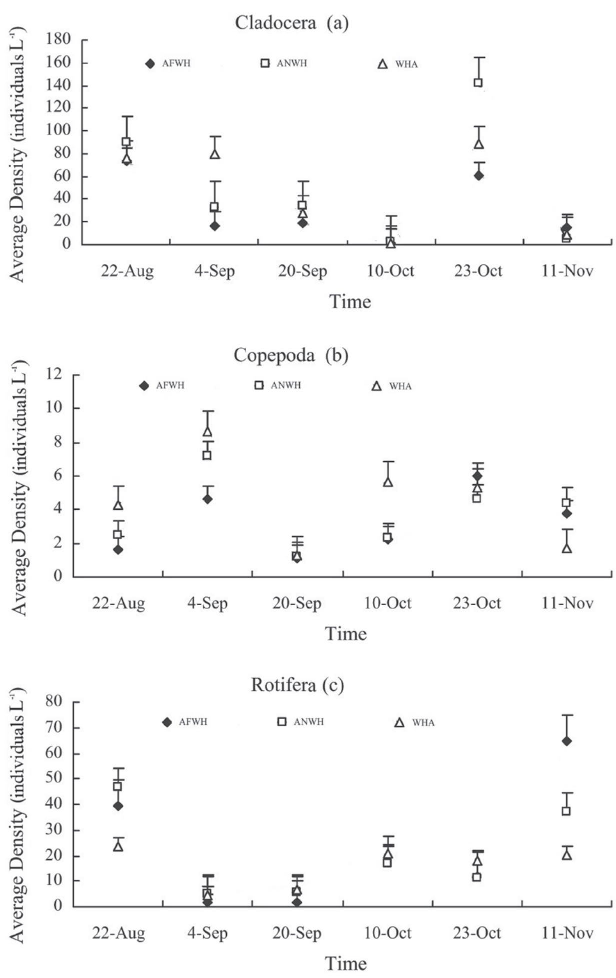

Fig. 9.4.2-1. Average density (mean + SE) of zooplankton from 22 August to 11 November 2009 in the area far from water hyacinth (AFWH), area near water hyacinth (ANWH) and water hyacinth area (WHA) (redrawn with permission).

Biodiversity indexes

Shannon-Wiener (*H'*) and Gini-Simpson (*D*) indices for each zooplankton group (Cladocera, Copepoda and Rotifera) were not statistically different in the sampling period (Table 9.4.2-3). Hence, the data suggested that both the biodiversity and the stability of the zooplankton community were not significantly influenced by the confined growth of water hyacinth in Lake Taihu.

Table 9.4.2-3. Diversity indices of zooplankton sampled from 22 August to 11 November 2009 in the area far from water hyacinth (AFWH), the area near water hyacinth (ANWH) and the water hyacinth area (WHA).

Zooplankton	Shannon-Wiener index (*H'*)			Gini-Simpson index (*D*)		
	FWHA	NWHA	WHA	FWHA	NWHA	WHA
Cladocera	0.34	0.24	0.39	0.61	0.45	0.58
Copepoda	0.40	0.46	0.29	0.60	0.79	0.48
Rotifera	0.57	0.57	0.61	1.05	1.04	1.11

9.5 Discussion and conclusions of the impact of water hyacinth on water quality and biodiversity

This case study investigated the water quality at Baisan Bay and Cao Hai in Lake Dianchi, and macrozoobenthos and zooplankton at Zhushan Bay in Lake Taihu and Baishan Bay in Lake Dianchi. Lake Taihu and Lake Dianchi are two large shallow lakes with hypereutrophic status; hence, the results from this case study may not be applicable to deep lakes and less eutrophic lakes and reservoirs, but the principles would be sound in general. During the investigation, the assessment of macrozoobenthos and zooplankton at Cao Hai and evaluation of water quality at Zhushan Bay were not done for various reasons. Further research is warranted also because of the complexity of the management of noxious weeds, water quality improvement and maintenance, and ecosystem management.

Summary of water quality at Baishan Bay

In the water hyacinth area, dissolved oxygen concentration decreased compared with the control area, but was still above the critical level for most species of fish and other aquatic animals. One important concern using water hyacinth for phytoremediation in eutrophic waters is that the water hyacinth mat may decrease dissolved oxygen concentration to cause damage to aquatic ecosystems. Dissolved oxygen in water is controlled primarily by photosynthesis of algae and submerged macrophytes plus oxygen exchanges at the air-water interface (Hunt and Christiansen 2000). Water hyacinth mat can impact all the primary contributors by blocking incident sunlight via covering the air-water interface, and reducing wind speed and waves. Also, decomposition of intercepted detritus and algae may result in consumption of a relatively large amount of oxygen, further depressing dissolved oxygen concentration (Meerhoff et al. 2003). Another situation occurring in eutrophic waters is the stratification of dissolved oxygen concentration in the water column because sunlight penetration into water is relatively low, restricting photosynthesis to the surface layer and causing oxygen depression in the lower layers of the water column (Wang et al. 2010). The results of this experiment suggest that the location and the size of water hyacinth mat versus the open space between enclosures should be carefully managed in order to optimize dissolved oxygen concentration in water with heavy algal load to avoid depression of dissolved oxygen. For example, in a 0.4-hectare test pond with water hyacinth coverage of less than 25% of the water surface, dissolved oxygen concentration was above the critical level for fish (McVea and Boyd 1975).

A decrease of pH in the water hyacinth area at the Baishan Bay was influenced by the biological nature of the macrophyte and the geology of the rock base (prevalence of carbonates in the calcium–magnesium–sodium material, with a pH of 8–10) (Institute of Environmental Science 1992). A decrease in water pH by the growth of water hyacinth may have resulted from intensive respiration of water hyacinth roots releasing carbon dioxide into the water, while low incident sunlight penetration in the water column resulted in relatively low photosynthesis and poor absorption of carbon dioxide from water. Water hyacinth is a good water pH stabilizer (Giraldo and Garzón 2002) because in acidic aquatic environments, the water pH may be increased towards neutral by the growth of water hyacinth.

In the water hyacinth area in this case study, the concentrations of total phosphorus, orthophosphate and total nitrogen were higher than those in the areas near and far from water hyacinth. If taking the hydraulic and wind conditions into consideration, and the data from chlorophyll-*a* and COD_{Mn} analysis, it may be suggested that water hyacinth roots trapped a lot of suspended particles and algae that were decomposed, causing a release of nutrients into the water (Kim and Kim 2000).

Although the dissolved oxygen concentration was above the critical level during the investigation period, there was depression of dissolved oxygen under the water hyacinth mat. This situation may not only impact aquatic animals, but also biological processes in the sediment, potentially increasing the nutrient release (Zhu et al. 2009). In the application of phytoremediation, the water hyacinth mat size, gap between mats, and harvesting strategies need to be further investigated for the best remediation result.

The case study found an interesting phenomenon, i.e., NH_4^+ concentration in the water hyacinth area and nearby was lower than in the area far from water hyacinth, while NO_3^- concentration showed opposite distribution. This finding may be caused by water hyacinth biology: (1) preferential absorption of ammonium over nitrate, with ammonium absorption occurring at two-fold greater rate than nitrate (Rommens et al. 2003); and (2) microbes accumulated on the water hyacinth roots may enhance transformation of ammonium to nitrate (Gao et al. 2012).

Water hyacinth can effectively decrease nitrogen and phosphorus concentrations in the surface water of relatively shallow lakes (<2.5 meters). In good conditions, ammonium can be totally eliminated (concentration down to 0 or below the detection limit) during the active growth of water hyacinth.

Phosphorus can be removed in excess of what was initially present in the surface water (it should be borne in mind that phosphorus may be released from the sediment when its concentration is very low in the overlying water). This phenomenon occurs in shallow lakes, such as Cao Hai in Lake Dianchi, and may not be relevant in deep lakes.

Successful phytoremediation relies on confining water hyacinth to designed locations as well as complete and timely harvesting of the huge fresh biomass of water hyacinth. The experiment at Cao Hai suggested there are benefits in effectively expanding water hyacinth population during the growing season (May to November for Cao Hai) to increase the biomass of water hyacinth population followed by harvesting as early as possible to control the population at a suitable size and thus reduce the management and equipment costs.

Macrozoobenthos at Baishan Bay

During the experimental period, 18 species of macrozoobenthos were collected from Baishan Bay: 14 in the water hyacinth area, 10 in the nearby area and six in the area far from water hyacinth. Margalef, Gini-Simpson and Shannon-Wiener indices were significantly higher in the water hyacinth area than the areas near and far away. The number of species and the biodiversity indices appeared not to support the hypothesis that water hyacinth negatively impacts biodiversity of macrozoobenthos. The reason may be that water hyacinth has complex effects on macrozoobenthos, including improvement of water quality to provide better ambient environment for macrozoobenthos, and providing shelter and food resources for macrozoobenthos. For example, Gastropoda (*Radix swinhoe*) and Crustacea (Decapoda, *Caridina* sp. and *Gammaridae* spp.) were present only in the water hyacinth area. This result was consistent with the literature report from Lake Okeechobee, Florida, USA (O'Hara 1967). Other researchers reported that macroinvertebrates such as Gastropoda and Arachnida were associated mostly with the water hyacinth areas in Lake Chivero, Zimbabwe (Brendonck et al. 2003), or that higher density and biodiversity of macroinvertebrates were associated with water hyacinth mats compared with the areas of open water and submerged macrophytes in Lake Chapala, Mexico (Villamagna 2009).

Concentration of dissolved oxygen was lower in the water hyacinth area than the areas nearby and far away. The extent of depression of dissolved oxygen concentration by water hyacinth is important. During the experiment in Lake Dianchi, the special design of the ecological engineering project and appropriate management strategies resulted in dissolved oxygen concentration maintained above 3.8 mg L^{-1}. However, whether or not such design and strategies would play the same roles at other locations needs to be further researched, with the case study providing only a general theoretical principle to underpin practice.

In hypereutrophic lakes, macrozoobenthos were largely pollutant-tolerant species that can survive at low dissolved oxygen concentration (Ellis 2011). The analysis of composition of functional feeding groups at the Baishan Bay also revealed that collector-gatherers were mainly associated with water hyacinth. The phenomenon may imply that collector-gatherers were adapted to the food sources associated with water hyacinth: plant detritus, roots and trapped algae. However, in the three monitoring areas, more functional feeding groups (including shredders, scrapers and parasites) appeared in the water hyacinth area than in the areas nearby and far away. This may imply that strategic phytoremediation design and controlled growth of water hyacinth may have positive impacts on abundance and biodiversity of aquatic fauna communities.

Zooplankton at Baishan Bay in Lake Dianchi

A total of 28 species in the area near water hyacinth was higher than the total number of species in the water hyacinth area and far from water hyacinth area. This result was consistent with the conclusion about the water quality being good in the area near water hyacinth (see earlier). The good water quality in the area near water hyacinth may also have contributed to the densities of Cladocera and Copepods gradually increasing from August to October (Fig. 9.3.2-1).

The densities of Cladocera and Copepoda, and the Shannon-Wiener, Gini-Simpson, Margalef and Peilou indices were not significantly different in the three sampling areas. This result may imply that short-term ecological engineering project has a minimal impact on Cladocera and Copepoda, which is consistent with the literature reports (Meerhoff et al. 2003, Chen et al. 2012). Meerhoff et al. (2003) found that micro-crustaceans abundance and biodiversity index were not significantly different between the submerged plant area and the water hyacinth area in hypertrophic Lake Rodó (34°55' S 56°10' W), Uruguay.

The case study found that water hyacinth significantly affected rotifer community structure, especially the dominant species in different monitoring areas. In the water hyacinth area, rotifer density and the Shannon-Wiener, Margalef, Gini-Simpson and Peilou indices were significantly lower than those in the near and far away areas. Literature also reported that rotifer density was lower in the water hyacinth area than the open area in the backwaters of the Delhi Segment of the Yamuna River (Arora and Mehra 2003). Large crustacean zooplankton can prey on rotifers to reduce their population (Yang et al. 2008). In this case study, the density of large crustacean zooplankton was lower in water under the water hyacinth mat than in the open water nearby and far away, which implies that the low rotifer density in the water hyacinth area may not have been caused by the crustacean zooplankton. In natural conditions, a lot of environmental factors such as incident sunlight, turbidity, water temperature, algal population and composition, dissolved oxygen and available food sources may influence the rotifer density and community structure (Villamagna and Murphy 2010). The actual reasons for the lower rotifer population in the water hyacinth area reported here needs to be further investigated.

In this case study, the active water hyacinth growing period (August to October) was selected to investigate zooplankton population dynamics as influenced by the presence of macrophyte since the period before July was the establishment stage of water hyacinth. The results suggested that using water hyacinth for phytoremediation may not cause damage to zooplankton community if the growth area, size of the water hyacinth mat and biomass can be controlled effectively. However, the size of the mat, the period of active growth, and the open space between water hyacinth mats need to be determined taking into account local climate, hydraulic patterns and the extent of eutrophic status because they all impact the management strategy. The basic principle is to design small enclosures and leave large enough gaps (such as twice the mat size) for initial set up.

Macrozoobenthos at Zhushan Bay in Lake Taihu

During the sampling period in different areas, macrozoobenthos were mainly Tubificidae in Oligochaeta (*Limnodrilus hoffmeisteri* and *Rhyacodrilus sinicus*), Chironomidae in Diptera (*Pelopia* sp. and *Chironomus plumosus*) and Gastropoda (*Bellamya aeruginosa*). Given that *Limnodrilus hoffmeisteri* and Chironomidae larvae can survive well in heavily polluted aquatic environments, they are often the dominant species indicating the contamination status (Riley et al. 2007, Kazanci and Girgin 1998). In the study presented here, Tubificidae (*Limnodrilus hoffmeisteri*) and the Chironomidae larvae were more abundant in the areas far from and near water hyacinth compared with the water hyacinth area in August and September, but significantly declined in October 2009, and also declined continuously from August to October in the water hyacinth area. The results should be interpreted together with the local environmental conditions and the settings for the confined growth of water hyacinth. Although the experiment area was set at the center of Zhushan Bay, it was still subjected to wave (wind) action and hydraulic current to mix the water layers, minimizing the negative effects on dissolved oxygen concentration.

The Gastropoda (*Bellamya aeruginosa*) biomass and density increased from August to September, and then decreased slightly in October 2009 in the water hyacinth area compared to the areas far away and near water hyacinth in Zhushan Bay, Lake Taihu. Gastropoda are ecologically important in aquatic environments. Adults of *Bellamya aeruginosa* live mainly at the bottom and feed on benthic algae, bacteria and organic debris and have adaptability ecological niches (Cai et al. 2009). It is assumed that dense fibrous root system of water hyacinth can intercept algae and detritus, creating favorable conditions and food resources for Gastropoda. The dense mat of the macrophyte may also modulate hydraulic patterns to make the environment more suitable to Gastropoda (Zhu 2007, Yuan et al. 2008) in addition to the suitable water temperature (30ºC) at the time of sampling.

In October, the biomass and density of Gastropoda and the dominant species of Oligochaeta and Chironomidae in Diptera all declined in October in all three sampled areas. This phenomenon may be caused by the changes in aquatic environment at Zhushan Bay in Lake Taihu. The water temperature and dissolved oxygen at the region decreased in October due to seasonal changes and increased decomposition of water hyacinth detritus and intercepted algae. The measured dissolved oxygen was as low as 3.2 mg L^{-1} in October 2009. Although the exact reasons for the decreased macrozoobenthos in the region may need further investigation, it is fairly certain that the confined growth of water hyacinth did not cause damage to biodiversity of macrozoobenthos during the experimental period.

Biodiversity and zooplankton at Zhushan Bay in Lake Taihu

The zooplankton biodiversity indices showed the same pattern as Gastropoda macrozoobenthos. The Shannon-Wiener and Gini-Simpson indices for Cladocera, Copepoda and Rotifera were not significantly different during the monitoring period among different sampled areas. These results from the investigation demonstrated that using water hyacinth as a biological agent for phytoremediation in eutrophic waters did not cause a significant impact on biodiversity and community structure of zooplankton.

Conclusions

This case study shows the results of the ecological engineering project using water hyacinth in two typical hypereutrophic lakes focusing on water quality and biodiversity on macrozoobenthos and zooplankton. The results showed that water hyacinth can effectively remove nitrogen and phosphorus and other pollutants from the water. However, the impact of water hyacinth on the water quality depends on the balance of input and output of plant nutrients, the growth period, the population size of water hyacinth compared to the total water surface area or hydraulic retention time in a particular water body. For example, at the Baishan Bay and Zhushan Bay, a small quantity of water hyacinth mat did not result in any water quality change in the lakes. On the other hand, at Cao Hai in Dianchi Lake, the water quality improved significantly due to the large coverage (~50% of the total water surface) of water hyacinth. The impact of water hyacinth on macrozoobenthos was mostly positive; and on zooplankton was not significant. This is because water hyacinth can improve water quality and provide food resources and shelter for aquatic fauna. Another important reason is that in this case study, the growth of water hyacinth was confined and completely harvested and processed, so that the negative impacts on dissolved oxygen were well controlled.

A good management system in such ecological engineering project means increased investment and technology inputs. For this reason, the most appropriate methods would vary for different locations, including the size of water hyacinth mat, gaps between mats, growth period, initial population size, time and methods of harvesting and processing, equipment, etc. Different water bodies would have different sources of pollutants, hydraulic properties and local climate (incident sunlight, wind, primary production pattern, etc.). All those factors influence the outcomes of an ecological engineering project. The case study presented here may provide theoretical underpinning, particularly regarding the effects of small water hyacinth coverage on macrozoobenthos and zooplankton in relatively small bays in lakes. At large coverage of 50% at Cao Hai in Lake Dianchi, the impact of water hyacinth on benthic and planktonic fauna was unfortunately not investigated, which should not be implied to mean unimportance; rather, the investigation was interrupted for various reasons. The preliminary investigation found that the various types of pollution at Cao Hai in Dianchi Lake were quite serious; the benthic fauna either did not exist or was represented only by the pollution indicator *Limnodrilus hoffmeisteri* and Chironomidae larvae.

By evaluating the biology of water hyacinth, water quality improvement, biodiversity of macrozoobenthos and zooplankton as well as reclamation of water resources, the ecological engineering using water hyacinth for phytoremediation was potentially practicable. The present study can be viewed as pioneering pollution control and remediation in practice.

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