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Technical Note

# Large-scale utilization of water hyacinth for nutrient removal in Lake Dianchi in China: The effects on the water quality, macrozoobenthos and zooplankton

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## HIGHLIGHTS

- ▶ We conduct a new strategy for pollutants removal by water hyacinth in a large lake.
- ▶ We evaluate the effects of the eco-engineering in the lake.
- ▶ The water hyacinth could improve the water quality around water hyacinth area.
- ▶ The water hyacinth does not obviously affect the zoobenthos and crustacean plankton.

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## ABSTRACT

An ecological engineering project using water hyacinth for nutrient removal was performed in Baishan Bay of a large shallow eutrophic lake, Lake Dianchi in China. In the present study, a systematic survey of water quality, macrozoobenthos and zooplankton inside (IWH), around (AWH) and far away (FWH) water hyacinth mats was conducted in Baishan Bay from August to October 2010. The results showed that the water quality significantly improved at AWH area. Concentrations of nitrogen and phosphorus were lower and transparency was higher at AWH area than those in IWH and FWH areas. Total densities, dominant species densities, and biodiversity indexes of macrozoobenthos and cladocerans as well as copepods did not differ ($P > 0.05$) among each other in all three areas. It was significantly ($P < 0.05$) different for those of rotifers at IWH area compared to those in AWH and FWH areas. The results might suggest a tremendous potential for the utilization of water hyacinth in the eutrophic lake like Lake Dianchi for nutrients removal.



## 1. Introduction

Human activities have increased the loads of nutrients (N and P) and accelerated the eutrophication of water bodies. About 54%, 53%, 28%, 48% and 41% of lakes in Asia, Europe, Africa, North America and South America are eutrophic (Chorus and Bartram, 1999). Eutrophication can result in serious problems in lakes, such as reduced water quality, induced cyanobacterial bloom and decreased biodiversity. Seriously, bloom cyanobacteria produces toxins, which have been considered responsible for human illnesses (Chorus and Bartram, 1999). Therefore, various strategies to improve water quality have been proposed, such as sediment dredging (Desprez, 2000), sediment curing (Murphy et al., 1999), and macrophyte restoration (Lauridsen et al., 2003). Sediment dredging is not only high cost, but may significantly reduce benthos (Desprez, 2000). Sediment curing is often using some chemicals or special materials, which are often associated with changes in salinity or pH. It may risk the life in the lake (Murphy et al., 1999). Also, there were few successful examples about submerged or emerging macrophyte restoration in large lakes. This may be due to: (1) growth of submerged or emerging macrophytes is affected by the depth and transparency of water; and (2) submerged or emerging macrophytes may assimilate nutrients from sediment instead of from water. Those macrophytes biomass, if not harvested, would decompose in the lake, and in consequence, the assimilated nutrients being released. To restore a lake from its algae dominated (eutrophic) to submerged macrophytes dominated (oligotrophy) state, both level of pollutants and transparency must be improved (Scheffer et al., 1993).

*Abbreviations:* IWH, inside water hyacinth; AWH, around water hyacinth; FWH, far away water hyacinth.

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Water hyacinth (*Eichhornia crassipes* (Mart.) Solms), is a tropical species belonging to the pickerelweed family (Pontederiaceae). It has a high capability to grow in heavily polluted water to assimilate nutrients, metal ions and organic pollutants (Malik, 2007; Nesterenko-Malkovskaya et al., 2012). It is often used as phytoremediation agent for pollutants removal (Malik, 2007; Chen et al., 2012).

Lake Dianchi, located in southwest China (24°23′–26°22′N, 102°10′–103°40′E), has an area of nearly 300 $km^2$ and an average depth of 4.7 m. Adjacent to Kunming City, Lake Dianchi once was the primary source of domestic water supply for 6.8 million residents. With rapid increase in local population and in consequences of discharging massive municipal and industrial sewage into the lake, pollution of the lake had been accelerating over the past 30 years (Wang et al., 2010). The lake is in a status of heavy eutrophication, accompanied with frequent occurrence of cyanobacteria bloom. During the past decade, many projects have been executed to improve the treatments of municipal and industrial sewage as to control external nutrient loads. Sediment dredging, sediment curing, submerged and emerging macrophytes restoration have all been practiced. The nutrient level stays at an unacceptable level, although external pollutant load has been gradually reduced to a bit lower level. In this case, in 2010, an experimental plan of an ecological engineering using water hyacinth to remove the pollutants (mainly N and P) from the lake was executed in Bayshan Bay of the lake.

The ecological engineering consisted of three steps: firstly, in spring, the seedlings of water hyacinth were planted in the man-made enclosures, which were made of plastic foam and mesh; secondly, the macrophytes were harvested using a specially designed ship in autumn; and thirdly, the harvested macrophytes were processed to produce biogas and organic fertilizer. This program not only could remove the pollutants from the lake, but also could get some economical benefits by biogas and organic fertilizer. There was little precedent for such large-scale utilization of water hyacinth in a large eutrophication lake, so that the effects of this ecological engineering should be carried out. Previous studies about water quality effects or pollutants removal of water hyacinth usually carried out in the laboratory or in the small water body (Rommens et al., 2003; Jayaweera and Kasturiarachchi, 2004). In fact, due to the different hydrologic and contamination conditions between small water body and large lakes, the results may be different for specific bodies of water. But to date, there were few researches focus on the responds of water quality to water hyacinth in the large water body.

Distribution and biodiversity of aquatic organisms could be influenced by floating plants such as water hyacinth (Brendonck et al., 2003; Villamagna and Murphy, 2010). On the one hand, positive effects of water hyacinth on aquatic organisms may be expected due to water hyacinth could reduce the pollutants concentrations in the water and provide more favorable microhabitats by the complex roots structure (Villamagna and Murphy, 2010). On the other hand, negative effects may be occurred because water hyacinth has been found to reduce DO concentrations and block light in the water beneath water hyacinth mats (Fontanarrosa et al., 2010). The large-scale application of water hyacinth in the lake was controversial because of the uncertain ecological effects of this floating plant on the aquatic ecosystems (Malik, 2007). People are usually concerned about the ecological effects of the engineering using water hyacinth. However, the ecological effect of water hyacinth in Lake Dianchi is still scarce.

In the present study, to assess the effects of the project, a systematic survey of water quality, zoobenthos and zooplankton community and biodiversity inside water hyacinth mats (IWH), around water hyacinth mats (AWH) and far away water hyacinth mats (FWH) was conducted. The results would provide the objective understanding and evaluation of the lake remediation using water hyacinth in eutrophication lakes.

## 2. Materials and methods

### 2.1. Study areas and sampling sites

The ecological engineering project of using water hyacinth was executed in Baishan Bay (24°45′N, 102°36′E; Fig. 1), located in southwestern part of the Lake Dianchi. Baishan Bay is a typical eutrophic bay with heavy cyanobacterial bloom. The average water depth is about 2.5 m (ranges from 2.2 to 3.0 m). In June to July of 2010, ~70 ha of water hyacinths were planted in large-scale enclosures in the bay. Due to the wind, the macrophytes were floating together in the west shore of the bay (IWH area, Fig. 1). 13 sampling sites were selected. six sites (sites 8–13) were located inside the macrophyte mats (IWH area), four sites (sites 4–7) were located around 20 m to the edge of the water hyacinth mats (AWH area), and three sites (sites 1–3) were located at an average distance of 250 m to the edge of the macrophyte mats (FWH area) (Fig. 1).

### 2.2. Sampling and analytical methods

Mixed water samples were collected from three depths (0–0.5, 1–1.5, and 0.5 m above the bottom) of the water column at each sampling site using a cylinder sampler. During the vigorous growth to harvest period of water hyacinths (August–October 2010), water samples were collected at half-monthly intervals. Water temperature, pH, and DO were measured in situ by portable meter (YSI Pro Plus, USA) at the sample sites. Transparency, TN, $NH_4^+$, $NO_3^-$, TP, $PO_4^{3-}$, $COD_{Mn}$ and Chl-*a* were determined according to the Standard Methods (APHA, 1998).

Macrozoobenthos were collected monthly at each sampling site with a Peterson sampler (0.0625 $m^2$) from August to October 2010. All bottom samples were sieved with a 420-μm sieve. Specimens were manually sorted out from sediment on a white porcelain plate and preserved in 10% formaldehyde solution (Wang et al., 2007). And then, the macrozoobenthos were identified to the lowest feasible taxonomic level and counted with microscopes in the laboratory (Morse et al., 1994; Epler, 2001).

Zooplanktons were sampled three times from August to October 2010. For cladocerans and copepods, a total of 30-L water from

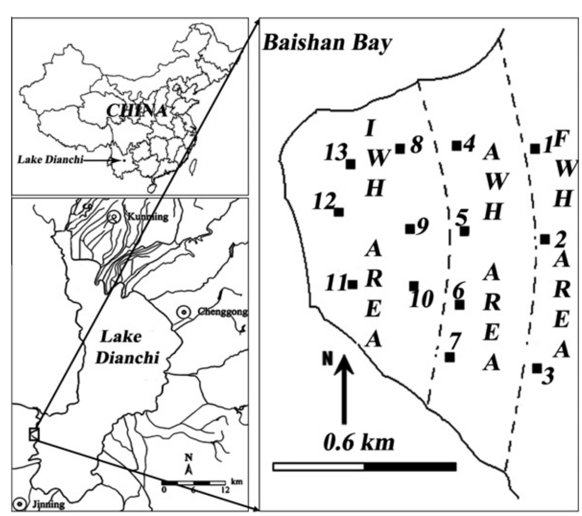


**Fig. 1.** Sampling sites inside (IWH), around (AWH) and far away (FWH) of Water hyacinth mats in Baishan Bay of Lake Dianchi.

three depths (0–0.5, 1–1.5, and 0.5 m above the bottom) was collected. The samples were filtered through a 64 μm mesh plankton net, and then preserved in 4% formaldehyde solution. Rotifer samples were collected by taking 1-L water out of the sample mixture from three depths as above. The samples were preserved with 15 mL Lugol's iodine and formaldehyde and allowed to set down in 1-L jars for 2-d. Each of the supernatants water was, then, carefully removed and the residual was collected and made to a volume of 30-mL. Zooplankton were identified to the lowest feasible taxonomic level according to reference (Chiang and Du, 1979) and counted under a Nikon microscope at a magnification of 100× using 5-mL condensed sample.

### 2.3. Data analysis

Shannon–Wiener's diversity index ($H'$), Simpson's diversity index ($D$), Margalef's diversity index ($d$) and Pielou's index ($J$) were used to assess the biodiversity (Pielou, 1975) of the three sampling areas.

Data were presented as mean ± standard deviation. Inter-group differences were assessed by MAVONA—repeated measure with paired $t$-test. When the data did not follow a normal distribution (Kolmogornov–Smirnov test) and homogeneity (Levene's test), the Mann–Whitney $U$ test was then analyzed for differences of the three areas. All statistical analyses were performed using statistics package SPSS 16.0 (SPSS, Chicago, IL, USA). The significance level was $P < 0.05$.

## 3. Results

### 3.1. Water quality in IWH, AWH and FWH areas

In the sampling period, the water temperature was slowly decreasing from 24.0 in August to 20.2 °C in October. After planting water hyacinth, the levels of DO, pH, TP, $PO_4^{3-}$, TN, $NO_3^-$, and $COD_{Mn}$ showed the same trends: decreased first, and then increased from mid-September to the end of survey in the three areas (Fig. 2a, b, d–f, h, and j). The water transparency increased from August to September, and then decreased (Fig. 2c). The concentrations of $NH_4^+$ were maintained at a lower level from August to September, and then, significantly increased after mid-September (Fig. 2g). At IWH area, Chl-$a$ concentrations were gradually increased in the sampling period, but in AWH and FWA Areas, the concentrations significantly increased and reached a plateau from September 6 (Fig. 2i).

Throughout the sampling period, the average DO concentration and pH were significantly lower at the IWH area than in the AWH and FWA areas ($P < 0.05$). The lowest DO and pH were 3.7 mg $L^{-1}$ and 8.0, respectively, which occurred in September 6 at IWH area (Fig. 2a and b). The average water transparency was found to be highest (45 cm) at the AWH area, lowest (22 cm) at the IWH area, and moderate (37 cm) at the FWH area ($P < 0.05$) (Fig. 2c). The average concentrations of TP (0.13 mg $L^{-1}$) and TN (2.1 mg $L^{-1}$) were significantly lower ($P < 0.05$) at AWH area than that in FWH (TP 0.16, TN 2.4 mg $L^{-1}$) and IWH (TP 0.21, TN 2.9 mg $L^{-1}$) areas (Fig. 2d and f). The $PO_4^{3}-$ concentrations showed no difference in the three areas before the mid-September. But after that, the $PO_4^{3-}$ concentration was the highest at IWH area, moderate at FWH area and the lowest at AWH areas (Fig. 2e). During the sampling period, the concentrations of $NH_4^+$ were significantly lower ($P < 0.05$) in IWH and AWH areas than that at FWH area, especially from mid-August to mid-September (Fig. 2g). The average of $NO_3^-$ concentrations was no significant difference among the three areas ($P > 0.05$) (Fig. 2h). The concentrations of Chl-$a$ were significantly higher in IWH and FWH areas than that at AWH area ($P < 0.05$). The lowest concentrations of $COD_{Mn}$ occurred at the FWH area (Fig. 2i and j).

### 3.2. Macrozoobenthos in IWH, AWH and FWH areas

During the sampling period, 18 species of macrozoobenthos were identified in the whole sampling areas (Table 1). 14 species were identified at IWH area, 10 species at AWH area, and six species at FWH area. The total densities of macrozoobenthos (unit: ind $m^{-2}$) in IWH, AWH and FWH areas were 297, 158 and 261, respectively. Amongst of all species, oligochaete *Limnodrilus hoffmeisteri* was the dominant species, accounted densities of 200 at IWH area, 91 at AWH area, and 222 at IWH area. Statistics analysis showed that there were no significant differences of the total species and the densities of the dominant species among the three sampling areas ($P > 0.05$).

Biodiversity indexes were presented in Table 2. The $H'$, $D$ and $d$ were significantly higher at IWH area than that in AWH and FWH areas ($P < 0.05$). The $J$ showed no significant difference among IWH, AWH and FWH areas ($P > 0.05$).

### 3.3. Zooplankton in IWH, AWH and FWH areas

Data for cladocerans, copepods and rotifers were presented in Table 3. 35 species were identified, within which 25 species at IWH area, 28 species at AWH area, and 24 species at FWH area. The total densities (density unit of zooplankton: ind $L^{-1}$) of cladocerans were 26 at IWH area, 28 at AWH area and 54 at FWH area, which showed no significant difference among the three areas ($P > 0.05$). The total densities of copepods were 33 at IWH area, 32 at AWH area and 25 at FWH area. Statistics analysis also showed no significant difference among the three areas ($P > 0.05$). The total densities of rotifers (7) were significantly lower at IWH area than that in AWH (38) and FWH areas (34) ($P < 0.05$).

*Bosmina longirostris* and *Microcyclops varicans* were the dominant species of cladoceran and copepod in the three areas. The densities of *B. longirostris* and *M. varicans*, were 10 and 25 at IWH area, 13 and 23 at AWH area, and 32 and 21 at FWH area. Statistics analysis showed that there were no significant differences of the dominant densities of cladocera and copedora among three areas ($P > 0.05$). The dominant species of rotifers was different among three areas, that of *Keratella quadrata* at IWH area, *Keratella valga* at AWH area, and *Monostyla closterocerca* at FWH area.

Biodiversity indexes of cladocerans, copepods and rotifers in three areas were presented in Table 4. The $H'$ of cladocerans and copepods showed no significant difference among three areas ($P > 0.05$), as well as $D$, $d$ and $J$. The biodiversity indexes ($H'$, $D$, $d$ and $J$) of rotifers were significantly lower at IWH area than that in AWH and FWH areas ($P < 0.05$).

## 4. Discussion

In the present study, we found DO concentration decreased in the water of IWH area, which was coherent with other studies (Rommens et al., 2003; Mangas-Ramirez and Elias-Gutierrez, 2004). DO in the water depends on the balances of oxygen via photosynthetic release by primary producers, aeration (diffusion) and oxygen consumption via respiration or aerobic micro-biodegradation. Water hyacinth could block the sun light and in consequence to reduce the oxygen release via photosynthesis by primary producers. It could also prevent the diffusion of oxygen from the air to the water (Villamagna and Murphy, 2010). This might suggest that, on a large scale bio-remediation of eutrophic waters, the enclosures to confine macrophytes may need to be designed with

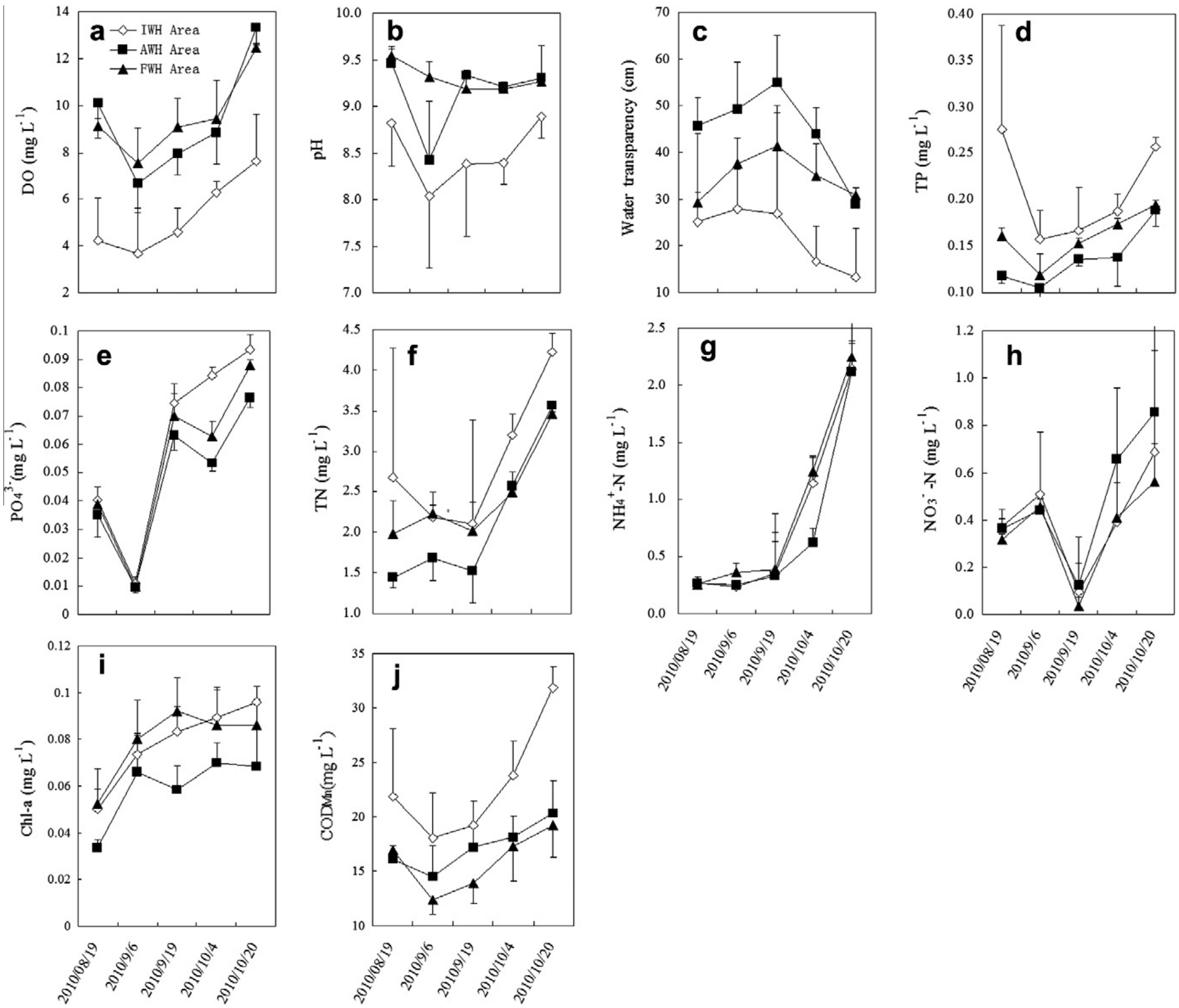


**Fig. 2.** Changes of water quality ((a) DO; (b) pH; (c) water transparence; (d) TP; (e) $PO_4^{3-}$; (f) TN; (g) $NH_4^+$; (h) $NO_3^-$; (i) chl-a; and (j) $COD_{Mn}$) in the water column of IWH, AWH and FWH areas.

patch style to leave enough uncovered space for oxygen shelters for aquatic life, especially for those of high oxygen demand species.

Giraldo and Garzon (2002) showed that water hyacinth could stabilize pH levels in water. Our results also indicated that water hyacinth could reduce pH in the water of IWH area (Fig. 2b). Due to the hydro geochemical type of strong carbonate associated calcium–magnesium–sodium character, the water in Lake Dianchi is always alkaline (pH 8–10 (Wang et al., 2010)). The macrophytes could bring the water pH to a neutral level. Decreased pH at the IWH area may be due to: (1) carbon dioxide in the water could not be fully assimilated via enough photosynthesis and (2) the macrophyte roots could decompose to add carbon dioxide to water.

The concentrations of TP, $PO_4^{3-}$, TN and $COD_{Mn}$ were higher at the IWH area than that in AWH and FWH areas (Fig. 2d–j). These phenomena may be resulted from: (1) N, P and organic matter released into the water due to decomposition of the macrophyte roots; (2) much suspended solids and algae were trapped in the root zone of the water hyacinths (Kim and Kim, 2000) that resulted in the high levels of N, P and COD; (3) reduced DO concentrations at IWH area could increase the release of nutrients from sediments (Jiang et al., 2006). The water transparence, as well as the concentrations of TP, $PO_4^{3-}$, Chl-a and TN were significantly lower at AWH area than that in IWH and FWH areas (Fig. 2c, f, and i). These phenomena may suggest that the absorption of N and P, capture of suspended particles and algae from the surrounding water by the complex water hyacinth root systems (Kim and Kim, 2000), and a rhizosphere microbial action may result in a lower N, P and suspended particle content. In the present study, an interesting phenomenon was that $NH_4^+$ concentrations were much lower in IWH and AWH areas than that at FWH area, but $NO_3^-$ concentrations were inversed in those areas (Fig. 2g and h). These may be because that water hyacinth has evolved a selective absorption of nutrients. Rommens et al. (2003) found that water hyacinth assimilated $NH_4^+$ in favor to $NO_3^-$.

In the present ecological engineering using water hyacinth in Baishan Bay, Lake Dianchi, about 12 000 ton of fresh biomass were harvested, that could take away about 19.5 ton of N and 1.7 ton of P from the lake. High-efficiency of nutrients and other pollutants removal by this float macrophyte has been documented (Rommens et al., 2003; Malik, 2007; Skinner et al., 2007; Agunbiade et al., 2009), but large-scale utilization water hyacinth to restore a eutro-

**Table 1**
Compositions and densities (Mean ± SD, ind $m^{-2}$) of macrozoobenthos in IWH, AWH and FWH areas.

| Macrozoobenthos | Species | IWH area | AWH area | FWH area |
|---|---|---|---|---|
| Nematoda | Nematoda spp. | 4 ± 6 | 3 ± 5 | / |
| Oligochaeta | *Dero digitata* | 2 ± 3 | 5 ± 9 | / |
| | *Stephensoniana trivandrana* | 2 ± 3 | / | / |
| | ***Limnodrilus hoffmeisteri*** [a] | 200 ± 122 | 91 ± 66 | 222 ± 228 |
| | *Limnodrilus grandisetosus* | 35 ± 32 | 25 ± 18 | 19 ± 7 |
| | *Limnodrilus* sp. | 2 ± 3 | / | / |
| | *Tubifex tubifex* | 19 ± 5 | 23 ± 33 | 5 ± 9 |
| | *Branchiura sowerbyi* | 5 ± 7 | 5 ± 9 | / |
| | Tubificidae sp. | / | 1 ± 2 | 4 ± 6 |
| Gastropoda | *Radix swinhoe* | 1 ± 1 | / | / |
| Insecta | *Chironomus Plumosus* | 10 ± 9 | / | 9 ± 15 |
| | *Dicrotendipes* sp. | / | 1 ± 2 | / |
| | *Orthocladius* sp. | 1 ± 1 | 3 ± 5 | / |
| | *Baetis* sp. | / | / | 2 ± 3 |
| | Amphipterygidae sp. | / | 1 ± 2 | / |
| Crustacea | Decapoda | 1 ± 1 | / | / |
| | *Caridina* sp. | 4 ± 3 | / | / |
| | Gammaridae spp. | 11 ± 3 | / | / |
| Sum | 18 | 297 ± 146 | 158 ± 108 | 261 ± 232 |

/ Means not identified.
[a] The bold represent the dominant species.

**Table 2**
Biodiversity indexes ($H'$: Shannon–Wiener's diversity index; $D$: Simpson's diversity index; $d$: Margalef's diversity index; and $J$: Pielou's index) of macrozoobenthos in IWH, AWH and FWH areas.

| Area | $H'$ | $D$ | $d$ | $J$ |
|---|---|---|---|---|
| IWH area | 0.8 ± 0.4a | 0.4 ± 0.2a | 0.4 ± 0.2a | 0.6 ± 0.3a |
| AWH area | 0.6 ± 0.5b | 0.3 ± 0.3b | 0.3 ± 0.2b | 0.6 ± 0.4a |
| FWH area | 0.5 ± 0.5b | 0.3 ± 0.3b | 0.3 ± 0.2b | 0.5 ± 0.4a |

Different small letters indicate statistically significant differences ($P < 0.05$).

phic lake was rare. The main reason may be that, as an alien invasive species, water hyacinth may risk the structure and function of the ecosystem when the floating macrophytes at large. In the present study, we confined the floating macrophytes in enclosures and evaluated the biodiversity of marcozoobenthos and zooplanktons in IWH, AWH and FWH areas.

The results showed that the biodiversity index of marcozoobenthos ($H'$, $D$ and $d$) were higher at IWH area than that in AWH and FWH areas. In some extent, water hyacinth in the eutrophic bay has not shown some reductions on the marcozoobenthos. This may be that water hyacinth could absorb some harmful pollutants that may be beneficial to marcozoobenthos (Skinner et al., 2007; Agunbiade et al., 2009). On the other hand, complex roots of the macrophyte could provide habitats and breeding places (Villamagna and Murphy, 2010). In the present study, we found that gastropoda (*Radix*) and crustacean (decapoda) only occurred at IWH area (Table 1). The positive effects of water hyacinth on macroinvertebrates have been reported (O'Hara, 1967). In Lake Okeechobee, Florida, O'Hara (1967) found that the macroinvertebrates in the roots of water hyacinth were typical benthic species, and macroinvertebrate abundance was greater within the roots of water hyacinth than in benthic samples or within other plant-root systems. Villamagna (2009) also found richer and more-abundant macroinvertebrate communities within the roots of water hyacinth than that in open water or within emergent vegetation stands in the Lake Chapala (Mexico). These phenomena seem to be paradoxical with lower DO levels in IWH area (Fig. 2a). But in fact, in the cyanobacterial bloom lake or reservoir, photosynthesis of cyanobacteria usually creates a supersaturated DO state of the water (Scott et al., 2005; Kowalski and Mazierski, 2008; Wang et al., 2010). So that, if we could control the water hyacinth in a certain coverage area in water surface, the DO concentrations in the water could be maintained at an acceptable level. For example, in the present engineering zone in Baishan Bay, the average DO concentration at IWH area was 5.3 mg $L^{-1}$ (Fig. 2a). Moreover, the zoobenthos in the entrophic lakes were usually tolerance types, which with large ability to tolerate low DO levels in the water (Gong and Xie, 2001).

In the present study, the cladoceran and copepod community diversity and densities showed no significant difference in IWH, AWH and FWH areas. Also, the same dominant species of cladocerans and copepods, and similar dominant species densities in the three sampling areas were found. The results were similar with the studies by Meerhoff et al. (2003). Chen et al. (2012) also reported the similar results in the Lake Taihu (China). In our investigation, we found the structure and community diversity of rotifer were significantly affected by water hyacinth (Tables 3 and 4). The lower abundance of rotifer at IWH area was consistent with Chen et al. (2012). Arora and Mehra (2003) also found that rotifer abundance was highest in open water compared to all other vegetated habitats of Yamuna River (India). Zooplankton could be affected by light intensity, turbulence, temperature, algae, dissolved oxygen, and food availability (Villamagna and Murphy, 2010). The decreasing density and biodiversity of rotifer at IWH area may be the result of comprehensive effects in water (e.g. influence of light intensity, DO, food availability, and so on) of water hyacinth. This may need further studies.

Although we only investigated the effects of water hyacinth in a short period, we considered that a 3-month investigation could show the effects of the floating macrophyte on aquatic ecosystem, especially the implementation area being about 70 ha. The water hyacinth in Lake Dianchi was planted in June and harvested in October. In the early stage (before July), the biomass and coverage area of the floating macrophyte was small. It is reasonably to consider that the most effective stage may be coherent with the stage of vigorous growth to harvest of water hyacinth (August to October).

Our results confirmed the tremendous potential to use water hyacinth in the eutrophic lakes such as Lake Dianchi. However, in the traditional view, there were two of main reasons to restrict the utilization of water hyacinth for nutrients removal in the large

**Table 3**
Compositions and densities (Mean ± SD, ind $L^{-1}$) of zooplankton in IWH, AWH and FWH areas.

| Zooplankton | Species | IWH area | AWH area | FWH area |
|---|---|---|---|---|
| Cladocera | *Bosmina longirostris* | **10 ± 2.9**[a] | **13 ± 11**[a] | **32 ± 30**[a] |
| | *Bosmina coregoni* | 0.9 ± 0.9 | 0.6 ± 0.7 | 0.4 ± 0.4 |
| | *Bosmina fatali* | 0.5 ± 0.5 | 0.3 ± 0.1 | 0.1 ± 0.2 |
| | *Ceriodaphnia cornuta* | 2.0 ± 1.8 | 1.7 ± 2.3 | 8.9 ± 14 |
| | *Ceriodaphnia pulchella* | 0.1 ± 0.1 | / | 0.0 ± 0.1 |
| | *Ceriodaphnia cornigera* | / | / | 0.1 ± 0.2 |
| | *Ceriodaphnia megalops* | / | / | 1.0 ± 1.5 |
| | *Ceriodaphnia quadrangula* | / | / | 0.7 ± 1.1 |
| | *Moina macrocopa* | / | 0.1 ± 0.1 | 1.2 ± 1.5 |
| | *Alona rectangular* | 0.1 ± 0.1 | 0.0 ± 0.1 | 0.0 ± 0.1 |
| | *Daphnia hyalina* | 7.7 ± 5.2 | 6.1 ± 3.8 | 8.3 ± 2.9 |
| | *Daphnia cucullata* | 4.2 ± 3.1 | 2.3 ± 1.4 | 1.2 ± 2.8 |
| | *Daphnia longispina* | 0.3 ± 0.1 | 0.3 ± 0.4 | / |
| | *Daphnia pulex* | 0.7 ± 0.6 | 3.5 ± 5.7 | / |
| | *Diaphanosoma brachyurum* | 0.1 ± 0.1 | 0.0 ± 0.1 | / |
| Copepoda | *Mesocyclops leuckarti* | 3.1 ± 3.5 | 6.2 ± 6.0 | 2.9 ± 1.3 |
| | *Mesocyclops pehpeiesis* | 1.2 ± 1.6 | 1.1 ± 1.8 | 0.4 ± 0.9 |
| | *Cyclops strenuus* | 0.3 ± 0.3 | 0.1 ± 0.2 | 0.0 ± 0.1 |
| | *Cyclops vicinus* | 0.5 ± 0.6 | 0.0 ± 0.0 | 0.0 ± 0.1 |
| | *Microcyclops varicans* | **25 ± 8**[a] | **23 ± 19**[a] | **21 ± 10**[a] |
| | *Microcyclops robustus* | 0.6 ± 0.5 | 0.3 ± 0.2 | 0.0 ± 0.1 |
| | *Microcyclops intermedius* | 1.3 ± 1.6 | 0.5 ± 0.4 | 0.1 ± 0.1 |
| | *Microcyclops longiramus* | 0.5 ± 0.4 | 0.0 ± 0.1 | / |
| | *Limnoithona sinensis* | 0.6 ± 0.8 | / | / |
| Rotifera | *Brachionus angularis* | 1.4 ± 1.9 | 1.7 ± 5.0 | / |
| | *Brachionus calyciflorus* | / | 5.7 ± 3.7 | 4.9 ± 5.2 |
| | *Brachionus forficula* | / | 0.8 ± 2 | / |
| | *Brachionus falcatus* | 0.5 ± 0.7 | 3.9 ± 1.3 | 3.7 ± 2.6 |
| | *Keratella quadrata* | **4.4 ± 1.0**[a] | 9.0 ± 1.7 | 14 ± 17 |
| | *Keratella valga* | 0.2 ± 0.8 | **11 ± 9**[a] | / |
| | *Monostyla closterocerca* | / | 4.1 ± 4.6 | **15 ± 20**[a] |
| | *Filinia maior* | / | 1.2 ± 1.8 | / |
| | *Lepadella ovalis* | 0.4 ± 0.5 | / | / |
| | *Lecane luna* | / | 1.0 ± 1.4 | / |
| | *Trichocera gracilis* | / | / | 0.4 ± 0.6 |

/ Means not identified.
[a] The bold represent the dominant species of cladocera, copedopa and rotifera.

**Table 4**
Biodiversity indexes ($H'$: Shannon–Wiener's diversity index; $D$: Simpson's diversity index; $d$: Margalef's diversity index; and $J$: Pielou's index) of cladocerans, copepods and rotifers in the IWH, AWH and FWH areas.

| Areas | | Cladocerans | | | | Copepods | | | | Rotifers | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $H'$ | $D$ | $d$ | $J$ | $H'$ | $D$ | $d$ | $J$ | $H'$ | $D$ | $d$ | $J$ |
| Average | IWH | 1.1a | 0.6a | 1.4a | 0.7a | 0.7a | 0.3a | 0.9a | 0.5a | 0.10a | 0.1a | 0.1a | 0.1a |
| | AWH | 0.9a | 0.5a | 1.3a | 0.3a | 0.6a | 0.3a | 0.9a | 0.5a | 0.8b | 0.4b | 0.5b | 0.6b |
| | FWH | 0.9a | 0.5a | 1.0a | 0.6a | 0.4a | 0.3a | 0.5a | 0.4a | 0.4ab | 0.2ab | 0.2ab | 0.4ab |
| Standards | IWH | 0.5 | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.6 | 0.3 | 0.3 | 0.2 | 0.2 | 0.3 |
| | AWH | 0.4 | 0.2 | 0.7 | 0.1 | 0.3 | 0.2 | 0.8 | 0.3 | 0.7 | 0.3 | 0.5 | 0.4 |
| | FWH | 0.4 | 0.2 | 0.4 | 0.3 | 0.3 | 0.2 | 0.4 | 0.4 | 0.4 | 0.3 | 0.2 | 0.5 |

Different small letters indicate statistically significant differences ($P < 0.05$).

eutrophic lake. One was that, decreased DO by water hyacinth probably significantly affected the biodiversity in the water. As discussed before, in an algae bloom shallow lake, the DO was usually supersaturated. If the water hyacinth coverage controlled in a certain area in water surface, the DO concentrations may not reach at a quite lower level which was harmful for the aquatic ecosystems. Our results have confirmed this point. In the present study, we indicated that eco-engineering used water hyacinth suitably in eutrophic lake (like Lake Dianchi) has not large effects on aquatic ecosystems, e.g. macrozoobenthos diversity. The other reason was that, water hyacinth may affect the photosynthesis of submerged vegetation. In fact, in many algae-dominant eutrophic lakes like Lake Dianchi, submerged vegetation have almost vanished (Lu et al., 2012). Lakes are known exist in two alternative stable states: oligotrophy (clear with abundant submerged macrophytes) and eutrophy (turbid with abundant algae) (Scheffer et al., 1993). The purpose of eco-restoration is to change the eutrophy lake to an oligotrophy lake. Hence, reducing the pollutants (especially nutrients) levels in the lake were the first and most important step for eco-restoration in the lake. To some extent, we considered that utilization of water hyacinth in lakes to remove nutrients could be used as the first step of lake management, and then to restore the ecosystem of the lake with other strategies, e.g. submerged vegetation reestablish.

## 5. Conclusions

This work has systematically assessed the ecological engineering on a large scale using water hyacinth to remove nutrients in

Lake Dianchi. The results showed that water quality improved around the water hyacinth mats. Moreover, there were no significant adverse effects on macrozoobenthos and zooplanktons (cladocerans and copepods) of the ecological engineering using of water hyacinth. Our results confirmed the tremendous potential to use water hyacinth for nutrients removal in the entrophic lakes such as Lake Dianchi.

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