Ecological Engineering 36 (2010) 1611–1619

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Changes in physicochemical and biological factors during regime shifts in a restoration demonstration of macrophytes in a small hypereutrophic Chinese lake

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ARTICLE INFO

Article history:
Received 25 November 2009
Received in revised form 16 March 2010
Accepted 31 May 2010

Keywords:
Eutrophic
Turbid
Submerged macrophyte
Zooplankton
Regime shift

ABSTRACT

Shallow, eutrophic lakes are usually characterized by a turbid state devoid of submerged vegetation subject to human-induced eutrophication. In most cases, it is rather hard to restore a vegetated clear state due to reduced resilience caused by a blend of complicated factors. In this study, we successfully reestablished a plant community in a small hypereutrophic lake over a certain period. In winter and spring with transparency of >55 cm and temperature of <20 °C, a submerged stands bed formed gradually under strong human interventions. The reestablished plant bed displayed obvious seasonal succession and prolonged the clear-water stage until July 2005, when it collapsed. The regime shift to a turbid state was mainly attributed to the decreasing biomass of stands bed and mechanical damage brought about by the elimination of *Spirodela polyrhiza*, increasing water temperature, P concentration as well as periphyton biomass, etc. The reestablishment also changed the aquatic ecosystem greatly. A 'clear-water' stage was characterized by higher NO_3^-–N, NH_4^+–N, electrical conductivity, transparency and TN/TP level and more cladocerans (mainly *Daphnia pulex*), while the turbid state was characterized by higher temperature, chlorophyll a and TP level and more abundant rotifers. It is thus viable to restore submerged macrophytes in such lakes in winter and spring, when transparency is relatively high while temperature and water level are low. Nevertheless, to obtain a long-term, vegetated clear state, control of internal nutrient loading by means of obstruction, purification, dredging or solidification, is extremely necessary since nutrients play an important role in regime shifts as evidenced by the present case, too.

1. Introduction

The adverse impacts of eutrophication, accelerated by anthropogenic activities, of various ecosystems across the land-ocean continuum, have been widely recognized. In lakes, the key disaster of eutrophication is caused by the occurrence of cyanobacterial blooms. Such blooms are undesirable because cyanobacteria can be toxic to both aquatic organisms and human beings (Yin et al., 2005; Chen et al., 2009), and may cause hypoxia, and consequently disrupt food webs (Huisman et al., 2005). In China, events of algal blooms have frequently occurred in freshwater lakes, reservoirs, estuaries and coastal marine ecosystems during warm seasons. The most serious and influential events possibly are the cyanobacterial bloom in Lake Taihu in 2007 (Xie, 2008) and the macroalgal bloom at the Olympic Sailing venue in 2008 (Conley et al., 2009).

Urban lakes are very much a part of city water bodies and play an important role in promoting social development. In the past few decades, increased urban development and agricultural intensification, however, have resulted in increased nutrient loading and notorious deterioration of water quality in lakes around the world. Excessive nutrient loading has caused many shallow lakes to shift to a turbid state. For some time, it has generally been accepted that the ultimate solution to this problem is to cut off external nutrient loading (Jeppesen et al., 2005).

Restoration of severely eutrophic, shallow lakes often involves a systematic treatment, starting with the control of external nutrient inputs and internal nutrient release, followed by biomanipulation and finally the stabilization of a macrophyte-dominated lake

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0925-8574/$ – see front matter © 2010 Published by Elsevier B.V.
doi:10.1016/j.ecoleng.2010.05.006

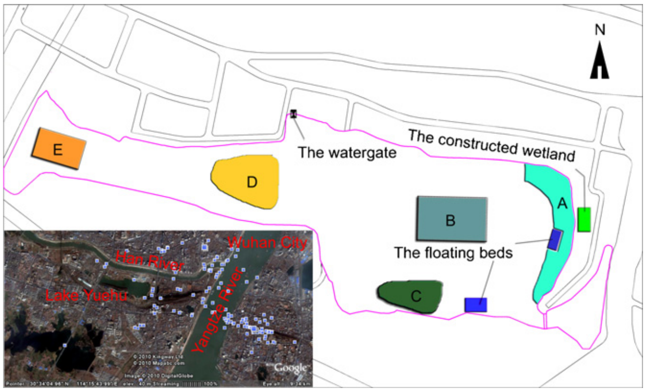

Fig. 1. The location of Lake Yuehu; A–E are study sites based on the different sediment characteristic and water depth.

Table 1
Nutrient concentration (mean ± SD) in inlet and outlet water and their removal by the constructed wetland.

Index	Inlet (mg/L)	Outlet (mg/L)	Removal rate (%)	Annual removal (tonne/year)
TN	11.69 ± 4.73	4.93 ± 2.33	55.5 ± 19.0	5.92
TP	1.66 ± 0.79	0.88 ± 0.67	46.4 ± 30.8	0.70

Note: Data were obtained by monthly monitoring from April 2005 to March 2006.

(Madgwick, 1999). There is a growing awareness that the condition of eutrophication can rarely be reverted by nutrient reduction alone, as internal loading and biological components of the lake will delay its response to external control. Additional remedies, such as suction dredging and biomanipulation, should be implemented (Moss et al., 1996).

Most shallow lakes tend to be either in a turbid state dominated by phytoplankton or in a clear-water state dominated by submerged macrovegetation (Weisner et al., 1997). Submerged macrophytes are crucial for the stabilization of clear-water state in shallow, mesotrophic to eutrophic lakes. The ability of submerged macrophytes to moderate the structure of food webs with respect to lake eutrophication management has been intensively studied in recent years (Marklund and Sandsten, 2002; Muylaert et al., 2003; Genkai-Kato, 2007). Many lake managers have adopted the option of increasing macrophyte abundance to restore eutrophic waters, with a view to improve water quality, increase water transparency and reduce phytoplankton biomass (Qiu et al., 2001; Wang et al., 2009).

For this paper, a full investigation on physicochemical and biological parameters of a small hypereutrophic Chinese lake was accomplished over a period of 20 successive months with the restoration of submerged macrophytes to this lake through a demonstration project. The investigated period (August 2004–March 2006) encompasses the process of switching from turbid-water state to clear-water one and back to turbid state again. Through the analysis of interactions between physicochemical and biological parameters and their indicating properties, a profound understanding on regime shifts in trophic states can possibly be reached, which is instrumental in making decisions for restoring such eutrophic lakes.

2. Materials and methods

2.1. Study site

Lake Yuehu (30°33′N, 114°15′E) is a shallow (mean depth 1.2 m), hypereutrophic lake with area of 61 ha, located in the centre of Wuhan, China (Fig. 1). Its bank was built by laying stones stuck in cement. Deep sediment (1.5–2.0 m) covered more than 50% of the whole area, and mainly distributed around the central parts (B and E area, Fig. 1) with water depth between 1.3 and 1.5 m, while the other parts (littoral and D area) had shallower water depth (0.7–1.2 m) and less nutrient-rich sediment. In this study, the area of A–E that reflected the general environmental characteristic of the lake was chosen as the study sites.

The lake, without tributaries, is adjacent to the joining of the Han River to the Yangtze River. Precipitation was the major source of water, but the lake also received large inputs of nutrients from the drainage area. Usually, the lake water flowed out automatically into the Han River via a controlled watergate, but in the rainy season, excessive water was pumped out to maintain a stable water level. Fish stocking had persisted for decades before the year 2004. In recent years, cyanobacterial blooms occurred repeatedly in warm seasons. An investigation made in autumn 2002 showed no submerged macrophytes left in the lake. Function of the aquatic ecosystem degraded severely.

2.2. Investigation of macrophyte reestablishment

In order to restore the lake, a tentative attempt to reestablish a plant community dominated by submerged macrophytes was made. Prior to or during the reestablishing, a range of engineering measures was successively adopted to pave the way for the goal. This included cleaning up fish in March 2004, clogging three major runoff ditches along the lakeside, and constructing a wetland on the lakeshore and two floating beds in the lake for water purification. The area for the wetland and floating beds was 4200 and 2000 m^2, respectively. The floating beds were set up in July 2004 with polystyrene foam board as carrier. Originally, *Canna indica* was planted. After a growing season, the plant was removed in November 2004. Then, *Lolium multiflorum* was planted, which was removed in May 2005 due to withering. Finally, *C. indica* was planted again. The wetland was designed for recirculating lake water, and put into operation in December 2004, with a treatment capacity of 2500 m^3/day of lake water near a sewage outlet. The treatment efficiency of the wetland is shown in Table 1.

In April 2004, seeds of *Vallisneria spiralis* and propagules of *Potamogeton crispus* were planted in most parts of the lake (*ca.* 70% overall area) except the centre. Later, during the first 10 days of the next month, 30 tonnes of fresh *Elodea nuttallii* was transplanted from another demonstration site (Lake Lianhua, in the same city) to the eastern and southern littoral zones of Lake Yuehu. Unfortunately, plant grew poorly later. Only a small population of *V. spiralis* germinated near the littoral and the D area (Fig. 1). The D area also had a small population of lotus (germinated from the propagule bank in the sediment). Afterwards, cyanobacterial bloom occurred and *Eichhornia crassipes* reproduced rapidly, which inhibited the growth of *V. spiralis* to almost disappearing. *E. crassipes* was cleaned out in January 2005.

In winter 2004 and the following spring, macrophyte reestablishment was performed again. During January–February 2005, a total of 20 tonnes of fresh *E. nuttallii* coupled with a small quantity of *Ceratophyllum demersum* was evenly planted in the area of A–E. Later in April 2005, in order to increase species richness and stabilize the plant community, 160 kg of winter buds of *Hydrilla verticillata* was additionally seeded over the whole lake.

2.3. Sampling and treatment

During the process of reestablishing, tracking survey on aquatic plants was conducted intermittently. The biomass of aquatic