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A restoration-promoting integrated floating bed and its experimental performance in eutrophication remediation

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ABSTRACT

Numerous studies on eutrophication remediation have mainly focused on purifying water first, then restoring submerged macrophytes. A restoration-promoting integrated floating bed (RPIFB) was designed to combine the processes of water purification and macrophyte restoration simultaneously. Two outdoor experiments were conducted to evaluate the ecological functions of the RPIFB. Trial 1 was conducted to compare the eutrophication purification among floating bed, gradual-submerging bed (GSB) and RPIFB technologies. The results illustrated that RPIFB has the best purification capacity. Removal efficiencies of RPIFB for TN, TP, NH_4^+-N, NO_3^--N, COD_{Cr}, Chlorophyll-*a* and turbidity were 74.45%, 98.31%, 74.71%, 88.81%, 71.42%, 90.17% and 85%, respectively. In trial 2, influences of depth of GSB and photic area in RPIFB on biota were investigated. When the depth of GSB decreased and the photic area of RPIFB grew, the height of *Potamogeton crispus* Linn. increased, but the biomass of *Canna indica* Linn. was reduced. The mortalities of *Misgurnus anguillicaudatus* and *Bellamya aeruginosa* in each group were all less than 7%. All results indicated that when the RPIFB was embedded into the eutrophic water, the regime shift from phytoplankton-dominated to macrophyte-dominated state could be promoted. Thus, the RPIFB is a promising remediation technology for eutrophication and submerged macrophyte restoration.

Introduction

The increasing concentrations of nitrogen and phosphorus provoke serious environmental problems in surface waters, which not only lead to eutrophication but also disturb the biodiversity of organisms (Mitsch and Jørgensen, 2003; Gurkana et al., 2006). Widespread occurrence of water eutrophication results in loss of ecological integrity, decrease of aquatic biodiversity, vanishing of submerged vegetation, potential production of toxins, etc. (Geurts et al., 2009; Estrada et al., 2011). Many conventional and novel methods with physical, chemical and biological processes have been applied to treat the negative effects of eutrophication over the past decades (Benndorf, 1995; Deppe at al., 1999; Wang et al., 2012). Among those methods, eco-technologies such as artificial floating bed (AFB) have been applied world-wide due to their advantages such as low cost and simple maintenance (Chen et al., 2013). In particular, the selected aquatic or terrestrial plants can not only remove pollutants from water, but also bring economic benefits (Keskinkan et al., 2004; Lesley et al., 2008; Bal et al., 2011). Therefore, the eco-technologies have received increasing public attention in recent years (Shan et al., 2009). In order to enhance the pollutant carrying capacity and self-purification capacity of an aquatic eco-system, it is necessary to optimize its ecological structure. Submerged macrophyte restoration is

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crucial to ecological structure (Scheffer et al., 1993). There are many important eco-functions of submerged macrophytes in aquatic eco-systems. Firstly, they can compete for light and nutrients with phytoplankton; secondly, they provide the structure for periphyton, shelter for organisms and invertebrates, and spatial refuge for zooplankton and small fish; thirdly, they reduce the mixing of the water column and resuspension; additionally, they provide food for aquatic animals; finally, they can inhibit the growth of phytoplankton by releasing allelochemicals (Van Donk and Van de Bund, 2002; Li et al., 2008; Taguchi and Nakata, 2009). However, there are many environmental conditions that can affect the restoration of submerged macrophytes. These environmental conditions include hydrodynamic factors such as waves, water depth, sediment properties, fish communities, nutrient loading and periphyton (Qin, 2009; Lloret and Marín, 2009).

Although many researchers have investigated the application of AFB and the purification capacity of submerged plants, few papers have focused on how to restore the submerged plants and maintain a stable ecosystem based on AFB technology (Lloret and Marín, 2009; Wu et al., 2010). Previous studies have generally divided the eutrophication remediation into two steps. The first one is to purify eutrophic water and the second one is to restore the submerged macrophytes (Qin, 2009). In this study, a restoration-promoting integrated floating bed (RPIFB) was designed to combine the processes of water purification and macrophyte restoration simultaneously. The RPIFB can help submerged macrophytes to overcome various constraints in the eutrophic water. It can not only reduce nutrients in the eutrophic water efficiently, but can also help submerged macrophytes to reach the photosynthetic light compensation point by adjusting the depth of the gradual-submerging bed (GSB). Then the ecological function of submerged plants can be effectively performed, and the habitat for aquatic animals can be ameliorated. The regime shift from phytoplankton-dominated to macrophyte-dominated state can be promoted.

Outdoor experiments were carried out to (1) evaluate the water purification efficiency of the RPIFB; (2) verify whether the biotic components can maintain health in the RPIFB; (3) analyze the restoration-promoting capabilities of the RPIFB on eutrophication.

1 Materials and methods

1.1 Materials and biota of RPIFB

All plants and animals used in the RPIFB were collected from the Xiangjiang River Basin in Changsha, China. Aquatic animals such as *Misgurnus anguillicaudatus* (body length 6.0 ± 1.2 cm), *Bellamya aeruginosa* (weight 4.0 ± 1.3 g) and plants such as *Canna indica* Linn. (plant height 35.0 ± 2.6 cm), *Potamogeton crispus* Linn. (plant length 25.0 ± 1.2 cm) were all tamed and cultured with experimental water for a month.

Natural zeolite was obtained from Jinyun, Zhejiang Province, China. Its typical unit cell composition is $Na_6[(AlO_2)_6(SiO_2)_{30}] \cdot 24H_2O$ with a density of 2.16 g/cm^3 and particle size of (4.0 ± 1.2) mm, moisture content of 7.0% to 14.0%, pore diameter of 3.4 to 4.0 Å, and specific area of 230 to 320 m^2/g.

The experimental water was pumped from a pool which is in severe-eutrophic state in the Xiangjiang River Basin. Discharge of domestic wastewater was the main nutrient source of the pool, which is rich in freshwater blue-green algae and protozoa. The initial water-quality parameters such as total phosphorus (TP, 3.36 ± 0.01 mg/L), total nitrogen (TN, 10.20 ± 0.10 mg/L), ammonia-nitrogen (NH_4^+-N, 2.65 ± 0.15 mg/L), nitrate-nitrogen (NO_3^--N, 1.10 ± 0.02 mg/L), chemical oxygen demand (COD_{Cr}, 88.26 ± 9.61 mg/L), Chlorophyll-*a* (Chl-*a*, 15.15 ± 1.65 μg/L) and water turbidity (85.00 ± 5.00 NTU) were analyzed (Jin and Tu, 1995; NEPA, 2002).

All the tubular structural skeleton elements of RPIFB were made of ethylene vinyl acetate, and the cage that coated the RPIFB was an oxidation-resistant polyvinyl chloride (PVC) net.

1.2 Design of RPIFB

The perspective drawing (**Fig. 1a**) shows that the RPIFB was comprised of a floating bed (FB) and GSB. The FB contained three isosceles trapezoid interposed baskets (ITIBs), which could hold aquatic plants above the water. The GSB with an inner orthohexagonal interposed basket (OIB) could hold submerged plants under the water. Buoyancy of the RPIFB was largely provided by three inflatable cuboid air chambers (ICACs), and partly by the tubular structural skeletons. The proportions between plant growing area and total hexagon surface area (G/T) and the dimensions of the main components in the RPIFB are shown in **Table 1**.

An ample photic zone in the ITBs was designed to

Table 1 Dimensions and flat surface area ratio of main components in restoration-promoting integrated floating bed (RPIFB)[a]

Component	Plane area	Edge length	G/T (%)
FB	S	$6 \times l$	37.5
GSB	S	$6 \times l$	100.0
ITIB	$S/8$	$l + 3 \times l/2$	12.5
OIB	$S/4$	$6 \times (l/2)$	25.0

[a] FB: floating bed; GSB: gradual-submerging bed; ITIB: isosceles trapezoid interposed basket; OIB: orthohexagonal interposed basket; G/T: the proportions between plant growing area and total hexagon surface area; S: the plane area of external orthohexagonal skeletons for FB and GSB, $S = 3182.6$ cm^2; l: the edge length of orthohexagonal skeletons in FB and GSB, $l = 35.0$ cm.