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Full Length Research Paper

Vegetation characteristics and water purification by artificial floating island

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Wetland restoration is commonly presented as an important strategy for maintaining and enhancing water quality and ecosystem capital. Artificial floating island (AFI) with softstem bulrush (*Scirpus validus* Vahl), spiked loosestrlfe (*Lythrum salicaria* Linn.), yellow-flowered iris (*Iris wilsonii*) and dwarf cattail (*Typha minima*) were monitored on an experimental scale from June to July 2011. The objectives were to identify major types of AFI based on plants, and to evaluate chemical and vegetative characteristics of each type. The result shows that AFI with plants had a strong capacity for the removal of nitrogen and phosphorus. In particular, softstem bulrush (*S. validus* Vahl*)* and spiked loosestrlfe (*L. salicaria* Linn.) were excellent aquatic plants in Beijing wetland restoration.

Key words: Artificial island, emergent plant, removal efficiency.

INTRODUCTION

Environmental pollution poses a grave menace to the sustainable development of many countries, and this has been of concern to the public and government in the world. Artificial floating islands (AFIs) have nowadays been adopted to help purify water worldwide due to four major functions; 1) water purification, 2) providing habitats for certain animals, 3) shore line erosion protection, and 4) the enhancement of landscape features (Nakamura et al., 1999). Boutwell (2002) reported a reduction of NO_3 -N, NH_3 –N and K, and total suspended solids from water collected underneath AFIs dominated by cattails (*Typha* spp.). Chang (2006) studied the specific growth rate of 20 aquatic plant species and reported on the nutrient absorptions characteristics of three. Nakamura and Shimatani (1997) studied changes in water quality caused by AFIs using experimental test cells (4 m by 4 m in size). They reported summer algal blooms occurred in the control cells but not in the cells that contained AFIs (Nakamura et al., 2008). Shimada et al. (2007) developed two kinds of AFIs designed for emergent and submerged plants, respectively. Their finding demon-strated improvement in water clarity caused by AFIs may trigger the establishment and expansion of natural vegetation and minimize the need for expansive AFI coverage. To assess this method, some pilot-scale studies were designed and implemented in various places throughout the world.

Stewart et al. (2008) reported that microbes growing within a unit volume of BioHaven Floating Island material are capable of removing 10 600 mg of nitrate per day, 273 mg of ammonium per day, and 428 mg of phosphate per day (unit island volume is defined as having a top surface area of 1.0 ft^2 and a thickness of 0.6 ft). Another experiment indicated that floating treatment wetlands (FTWs) are capable of achieving dissolved Cu mass removal rates in the order of 3.8 to 6.4 mg m^{-2} day^{-1} and Zn mass removal rates of 25 to 88 mg m^{-2} day^{-1} (Headly and Tanner, 2007). In pilot-scale subsurface wetlands, studies revealed that chemical oxygen demand (COD), total nitrogen (TN), and total phosphorous (TP) removal loads of *Salix babylonica, Phragmites australis, Typha angustata* and *Zizania latifolia* vegetation reached 0.112 to 0.172, 5.7 to 7.1, and 0.0674 to 0.152 g m^{-2} day^{-1}, respectively, accounting for 24.5 to 37.6, 34 to 42 and

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Table 1. Schematic representation of the experimental design.

A_1	B_1	C_1	D_1	E_1
A_2	B_2	C_2	D_2	E_2
A_3	B_3	C_3	D_3	E_3
A_4	B_4	C_4	D_4	E_4
A_5	B_5	C_5	D_5	E_5

A = AFI; B = AFI with softstem bulrush (*Scirpus validus* Vahl); C = AFI with spiked loosestrlfe (*Lythrum salicaria* Linn.), D = AFI with yellow-flowered iris (*Iris wilsonii*) and E = AFI with dwarf cattail (*Typha minima*). A_1 to A_5, B_1 to B_5, C_1 to C_5, D_1 to D_5 and E_1 to E_5 are the five duplicated experiments.

36.1 to 81.4% of that of the unvegetated control wetland (Jing and Hu, 2009). Song et al. (2009) also reported 8.95 and 20.16% removal of TN and TP from eutrophic waters due to the presence of vegetation. Furthermore, *Zizania caduciflora* had a better effect on phosphorous removal than nitrogen removal in constructed wetlands (Song et al., 2009).

In the current study, we investigated the effectiveness of AFIs for water treatment in Beijing and neighboring areas. The aims were to; 1) select certain emerging plants effective at purifying water and enhancing the aquatic environment in Beijing and, 2) give top propriety to appropriate vegetations employed in the application of wetlands primarily in Beijing. The study provides theoretical foundation and technological support for the restoration projects of Beijing's wetlands and aquatic eco-systems.

MATERIALS AND METHODS

Experimental materials

Four kinds of plants were selected in this experiment and they are the softstem bulrush (*Scirpus validus* Vahl), spiked loosestrlfe (*Lythrum salicaria* Linn.), yellow-flowered iris (*Iris wilsonii)* and dwarf cattail (*Typha minima*), respectively.

Experimental design

This experiment was conducted in five ways, four of these contained each kind of emerging plant mentioned above with one AFI respectively, while the other one was only substrate without any vegetation, thus acting as a control experiment (Table 1). The total number of the whole experiment was twenty-five water jars and each type consisted of five same groups of repeated trial marked A, B, C, D and E. In order to guarantee the data integrity and accuracy, all groups were placed in the same external environment outside and inspected regularly.

Data measurements

At the initiation of the experiment, pH, chemical oxygen demand (COD), nitrate, total nitrogen (TN), and total phosphorous (TP) was measured in each water jar. At 10-day intervals, the chemical parameters were measured again. All data were analyzed by SPSS13.0 and Sigmaplot 10.0 software. In addition, the biomass was determined for each plant at the initiation and completion of the experiment.

RESULTS

Plant growth

The growth characteristics of the plant species after 50 days of growth on the AFI is presented in Figure 1. All the species had a similar amount of aboveground biomass (7.34 to 81.94 g) at the end of the study, with exception of spiked loosestrlfe (*L. salicaria* Linn.*)* that had approximately ninth as much as the other species. Dwarf cattail (*T. minima*) also had the second highest mean biomass of nearly 12 g. Softstem bulrush *(S. validus* Vahl*)* and yellow-flowered iris (*I. wilsonii*) had the smallest biomass of the four plants. Spiked loosestrlfe (*L. salicaria* Linn.*)* had the greatest amount of underground biomass (87.08 g), followed softstem bulrush (*S. validus* Vahl) (19.28 g) and yellow-flowered iris (*I. wilsonii*) (10.28 g). The dwarf cattail (*T. minima*) had lest underground biomass (8.2 g).

The four vegetations therefore showed excellent growth in AFI, with extensive development of roots beneath the water (Figure 1). The average depth of growth of roots for the four experimental plants was between 20 and 35 cm, with maximum depths of up to 55 cm recorded for dwarf cattail (*T. minima*). In contrast, spiked loosestrlfe (*L. salicaria* Linn.*)* had the shortest roots, the majority of which were less than 19 cm long. Softstem bulrush (*S. validus* Vahl), spiked loosestrlfe (*L. salicaria* Linn.*)* and yellow-flowered iris (*I. wilsonii*) had more biomass above than below-mat. In particular, softstem bulrush (*S. validus* Vahl) due to its relatively longer root growth, developed over twice times as much biomass aboveground than underground. In case of this AFI, the root under the body was poorer than aboveground growth.

Water quality effects

pH

The pH value reflects a measure of the acidity or alkalinity of a solution. AFIs without emerging plants showed a trend of ascending pH from the beginning (pH = 8.49) to the end (pH = 9.90) (Figure 2). After 10 days, AFI with softstem bulrush (*S. validus* Vahl), AFI with spiked loosestrlfe (*L. salicaria* Linn.*)*, AFI with yellow-flower iris (*I. wilsonii*), and AFI with dwarf cattail (*T. minima*) presented a declining trend from 8.49 to 8.28, 8.49 to 8.09, 8.49 to 8.11 and 8.49 to 8.36, respectively but they rose after the 20 days from 8.28 to 8.57, 8.09 to 8.29, 8.11 to 8.40 and 8.36 to 8.60, correspondingly.

Chemical oxygen demand (COD)

The COD displayed no clear trends in all the experiment. AFI without vegetation rose and fell dramatically on 10th and 30th June, respectively from 39.1 to 58.9 mg/L and the to 36.4 mg/L, but it turns out to be flat in the end, which was approximately the same trends as AFI with

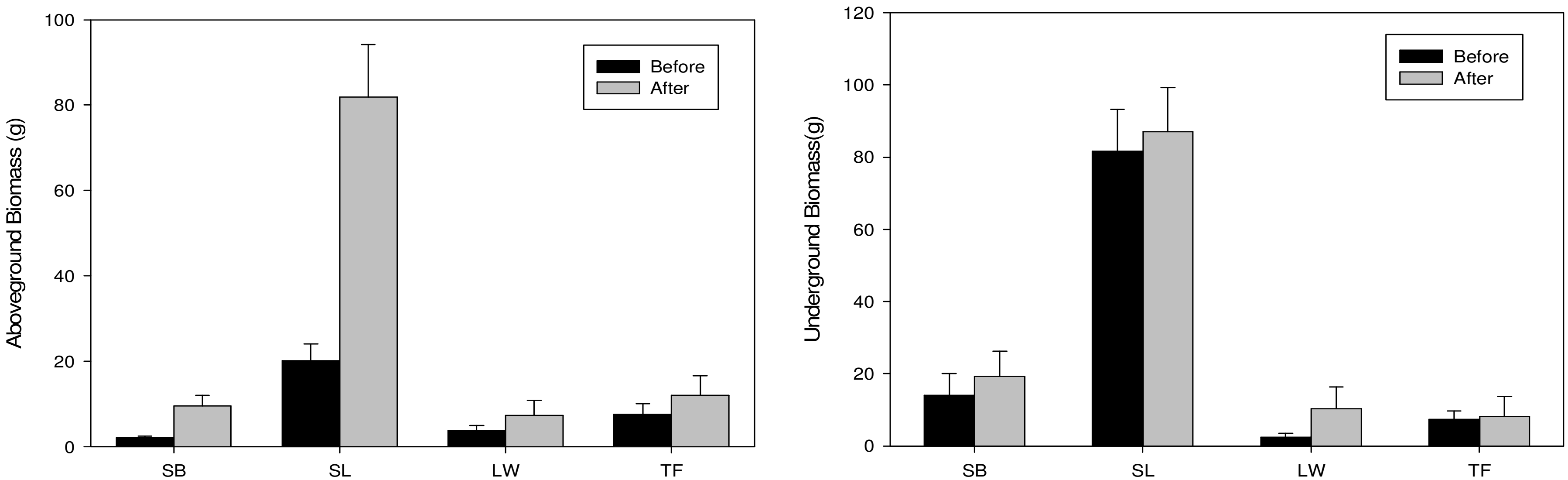


Figure 1. Growth characteristics of four different species measured in June 2011 after 50 days growth. Values in parentheses are standard deviations. SB = Softstem bulrush (*Scirpus validus* Vahl), SL = spiked loosestrlfe (*Lythrum salicaria* Linn.), LW = yellow-flowered iris (*Iris wilsonii*) and TF= dwarf cattail (*Typha minima*).

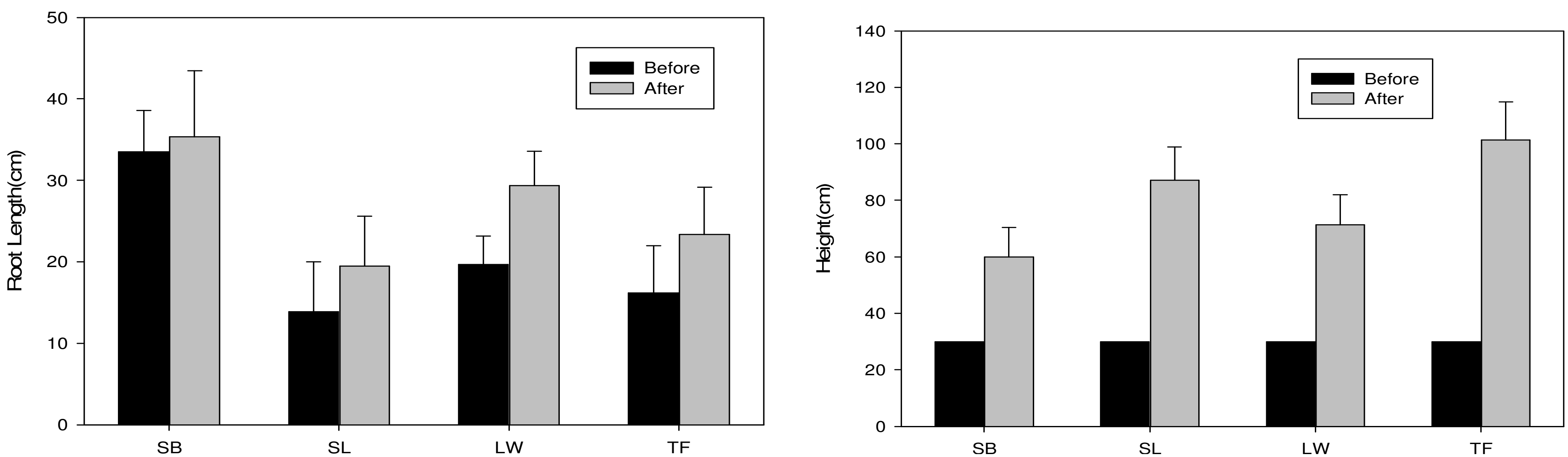
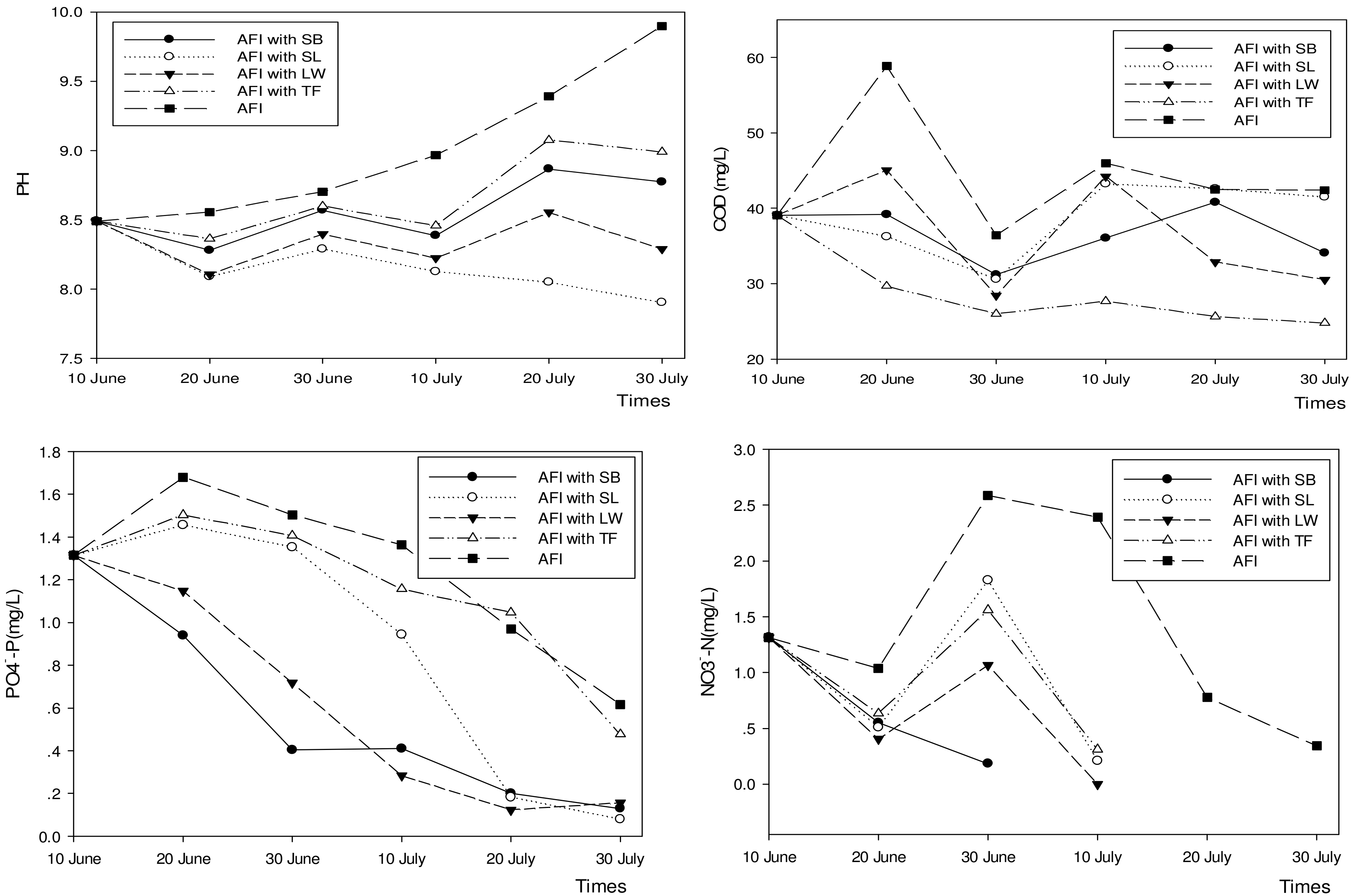


Figure 1. Contd.


AFI with SB
AFI with SL
AFI with LW
AFI with TF
AFI
PH
COD (mg/L)
PO4- -P(mg/L)
NO3- -N(mg/L)
10 June
20 June
30 June
10 July
20 July
30 July
Times

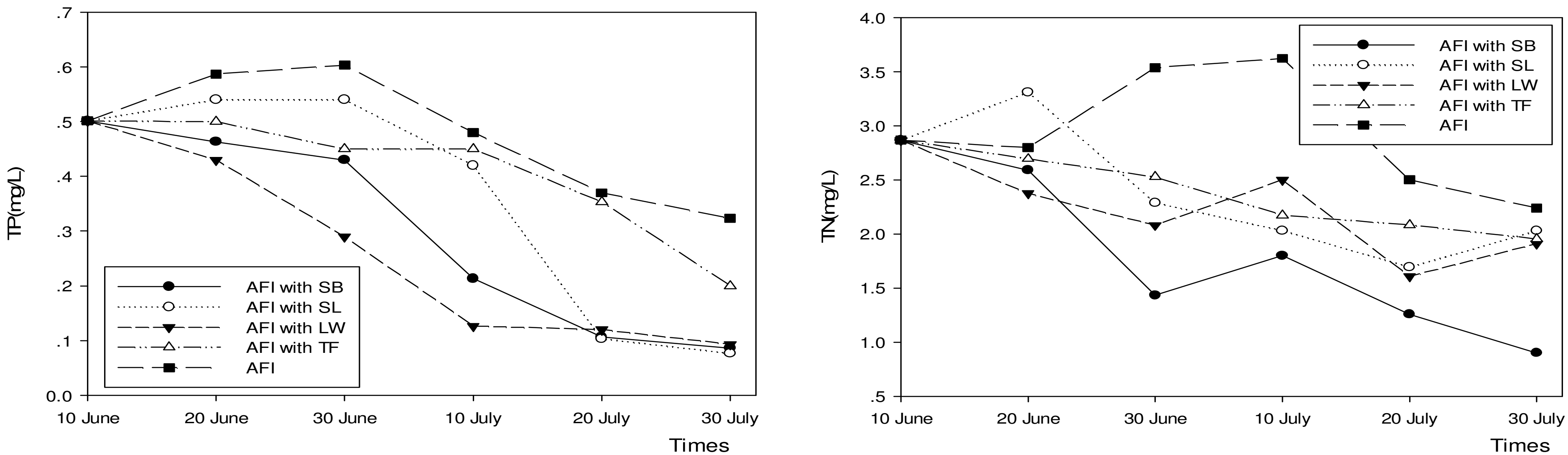


Figure 2. Mean concentration for PH, COD, PO_4^{3-}P, NO_3^-N, TN, TP, for each treatment throughout the batches (n = 5). Initial concentrations (PH, COD, PO_4^{3-}P, NO_3^-N, TN, TP) are 8.49, 39.07, 1.31, 1.31, 2.87 and 0.50 mg/L. Error bars represent +/-one standard error of the mean. Fifty days samples were only collected for some treatments (SB, SL, LW and TF). SB = Softstem bulrush (*Scirpus validus* Vahl); SL = spiked loosestrlfe (*Lythrum salicaria* Linn.); LW = yellow-flowered iris (*Iris wilsonii*) and TF= dwarf cattail (*Typha minima*).

yellow-flowered iris (*I. wilsonii*) (Figure 2). While two other curves of AFI with softstem bulrush (*S. validus* Vahl) and AFI with spiked loosestrlfe (*L. salicaria* Linn.) dropped to 31.2 and 30.6 mg/L in the third sampling and then one (AFI with softstem bulrush (*S. validus* Vahl)) goes up to 40.8mg/L in the fifth sampling and down to 34.1 mg/L at last. The other (AFI with spiked loosestrlfe (*L. salicaria* Linn.)) remained flat with the last three data being 43.2, 42.6 and 41.5 mg/L. The curve of AFI with dwarf cattail (*T. minima*) decreases modestly from 39.0 to about 24.8 mg/L.

PO_4^{3-}

Obviously the graph presented declining curves on all five experiments. Although, their overall changing trends are the same, three curves of only AFI without vegetation, AFI with dwarf cattail (*T. minima*) and AFI with spiked loosestrlfe (*L. salicaria* Linn.) went up from 1.31 mg/L separately to 1.68 mg/L, 1.50 mg/L and 1.46 mg/L in the first place, and then descended ultimately (Figure 2). In addition, different ending points meant that the final amount of PO_4^{3-} in AFI with yellow-flowered iris (*I. wilsonii*) (0.16 mg/L), AFI with softstem bulrush (*S. validus* Vahl) (0.13 mg/L) and AFI with spiked loosestrlfe (*L. salicaria* Linn.) (0.08 mg/L) are much lower than other two whose data are 0.62 mg/L (AFI without vegetation) and 0.48 mg/L(AFI with dwarf cattail (*T. minima*).

NO_3^-

The curves' overall tends descended first, came up to the pinnacle in the third measurement and then fell in the end noticeably, with the same starting points (1.31 mg/L) and peak value in the identical slot, apart from the curve of AFI with softstem bulrush (*S. validus* Vahl) that has no amount summit in the chart. The top amounts of four curves are 2.59 mg/L in the AFI without vegetation, 1.83 mg/L in the AFI with spiked loosestrlfe (*L. salicaria* Linn.), 1.56 mg/L in the AFI with dwarf cattail (*T. minima*) and 1.07 mg/L in the AFI with yellow-flowered iris (*I. wilsonii*) individually (Figure 2). The result to some degree demonstrated the high-quality of effects at removal of NO_3^- with the four emerging plants along with substrates.

Total phosphorous

This graph illustrated the reduction process of the total phosphorous. Contrary to the same starting content at 0.50 mg/L, the final results were especially evident among which the ultimate amounts of three curves of AFI with yellow-flowered iris (*I. wilsonii*), AFI with spiked loosestrIfe (*L. salicaria* Linn.) and AFI with softstem bulrush (*S. validus* Vahl) are 0.09 mg/L more or less, while two others were at 0.32 and 0.20 mg/L comparatively (Figure 2). Moreover, two curves of AFI with spiked loosestrIfe (*L. salicaria* Linn.) and only AFI without vegetation ascended slightly in the first and second sampling. In detail, they rose from 0.50 mg/L respectively to 0.54 mg/L and 0.59 mg/L and then kept steady declining trends. The whole chart revealed that the four emerging plants, as well as substrates play an eminent role in removal of TP.

Total nitrogen

This graph illustrated a variation process of the total nitrogen with passing time. On the whole, AFI with vegetations did not show the expected effects at removal of TN to some extent, not including the AFI with softstem bulrush (*S. validus* Vahl). Contrast to the curve of AFI with softstem bulrush (*S. validus* Vahl), the comparison of other curves between the beginning where the amount is 2.87 mg/L and the ending where they merely fell to about 2.00 mg/L is not very obvious (Figure 2). Besides the curves of amount of nitrogen in the figure, lack some certain regularity in the variation tends. Some curves alter gently and some fluctuate greatly. If we only concentrate on the initial and final data, no more than one curve of AFI with softstem bulrush (*S. validus* Vahl) deceases to below 1.0 mg/L (0.90 mg/L).

DISCUSSION

The length of roots under AFI generally seems to relate to the trophic condition of the water body. It seems there is a proportional relation between the length of roots under the AFI and the nutrients in the water (Nakamura and Shimatani, 1995). Softstem bulrush (*S. validus* Vahl), spiked loosestrIfe (*L. salicaria* Linn.*)*, yellow-flowered iris (*I. wilsonii*) and dwarf cattail (*T. minima*) were vegetated separately on AFI. The capacity of degradation of phosphorous by AFI with spiked loosestrIfe (*L. salicaria* Linn.*)* was better than others AFI with vegetation, while the capacity of removal nitrogen of AFI with softstem bulrush (*S. validus* Vahl) was better than others. This meant that the AFI with the plants has big potential as a nutrient stock room. This huge standing crop is mainly because of the rich nutrients and appropriate turbulence by wave that supplies oxygen (Nakamura and Shimatani, 1995). Based on the greater amount of biomass and capacity of removal observed for softstem bulrush (*S. validus* Vahl), spiked loosestrIfe (*L. salicaria* Linn.) and dwarf cattail (*T. minima*), these three species were selected to be used in the subsequent water quality improvement trials. Yellow-flowered iris (*I. wilsonii*) was also selected based on previous experience with this species and the fact that it has traditionally been one of the most commonly used species in wetlands treatment.

The purification characteristics of the AFI were clarified by some researches. Floating mats of Australian vetiver grass were grown in 20-L drums. Total nitrogen removal was monitored for four days, at which time total nitrogen was reduced from 99 to 6 mgL^{-1}(Hart et al., 2003), platforms with several species of wetland plants were floated in 160-gallon tanks, the experiments were run for 28 days, although nitrate was 80% removed by day 7 (Boutwell and Hutchings, 1999). A combination of microbes and actively growing macrophytes provides the best option for removing ammonium (Tanner, 1996). The basic idea of the purification of the AFI is the considerably different one. The AFI is a purification method by which the nutrient is not taken out outside the system. The point of this method is to stock nutrients inside the living creatures. The AFI can control the proliferation of phytoplankton like the water bloom (Nakamura and Shimatani, 1995)

This study indicates that the AFI with plants have excellent potential for removal of nitrogen and phosphorous. The results indicated that AFI with plants are capable of achieving dissolved nitrogen and phosphorous mass removal rates in the order of 2.87 to 1.91 g/L and 0.50 to 0.076 g/L, respectively. The presence of living plants played a key role in the removal of nitrogen and phosphorous, although this role is unclear. Further experiments are therefore needed to verify the role of plants and efficacy of field-scale. In addition to serving as effective tools for removal of excess nutrients, floating islands are useful for providing wildlife habitat, reducing biogas emissions, and improving the visual appearance of treatment areas.

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