Do Aquatic Macrophytes Configuration Mode Impact Water Quality?
(Adakah Mod Konfigurasi Akua Makrofit Mengesan Kualiti Air?)

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ABSTRACT

*This paper had selected watermifoil (*Myriophyllum veticillatum *Linn*.*), softstem bulrush (*Scirpus validus *Vahl) and yellow-flowered iris (*Iris wilsonii*), in showing the water purification through different configuration. AFIs with different combination of aquatic plants were set up to purify the water quality for 50 days. This paper aimed to evaluate chemical and vegetative characteristics of each type of plant and also to find configuration of aquatic plants to maximize the contaminants removal efficiency by artificial floating island (*AFI*). The result indicated that the trophic waterbody promote the growth of plants and all of the AFIs have the ability to purify water and reduce contaminants. However, the most effective way is by combination of these three aquatic plants which has strong capacity to remove COD, NO₃⁻, total nitrogen, total phosphorous and improve pH levels. Watermifoil (*Myriophyllum verticillatum *Linn*.*) is better than yellow-flowered iris (*Iris wilsonii*) and softstem bulrush (*Scirpus validus *Vahl) in disposing water pollutants.*

Keywords: Aquatic plants; configuration; water purification

ABSTRAK

*Kertas ini telah memilih tumbuhan watermifoil (*Myriophyllum veticillatum *Linn*.*), softstem bulrush (*Scirpus validus *Vahl) dan yellow-flowered iris (*Iris wilsonii*) yang menulenkan air melalui konfigurasi berbeza. AFI dengan kombinasi berbeza tumbuhan akuatik disediakan bagi menulenkan air selama 50 hari. Kajian ini bertujuan menilai ciri kimia dan vegetatif setiap tumbuhan yang dikaji di samping mencari konfigurasi tumbuhan akuatik bagi memaksimumkan kecekapan penyingkiran bahan cemar melalui pulau terapung buatan (*AFI*). Keputusan kajian menunjukkan jasad air trofik menggalakkan pertumbuhan tumbuhan dan semua kombinasi AFI berupaya untuk menulenkan air dan mengurangkan bahan cemar. Kombinasi yang paling berkesan adalah kombinasi ketiga-tiga tumbuhan kerana mempunyai kapasiti yang tinggi untuk menyingkirkan COD, NO₃⁻, jumlah nitrogen, jumlah fosforus dan memperbaiki aras pH. Watermifoil (*Myriophyllum verticillatum *Linn*.*) adalah lebih baik berbanding yellow-flowered iris (*Iris wilsonii*) untuk digabungkan dengan softstem bulrush (*Scirpus validus *Vahl) dalam menyingkirkan bahan cemar.*

Kata kunci: Konfigurasi; penulenan air; tumbuhan akuatik

INTRODUCTION

The main objective in wastewater treatment process is to eliminate or reduce contaminants to the level that cause no adverse effect on human or the receiving environment (Okia 1993). Various conventional methods are in practice for purification of water and removing eutrophic water. Many traditional approaches are non-eco-friendly, time-consuming and expensive. Artificial floating island (AFI) is an efficient and eco-friendly way to purify the water quality. It relies on nature process to mechanically and biologically filter water as it passes slowly through shallow areas of dense aquatic vegetation, and through permeable bottom soil (Stewart et al. 2008).

Nakamura and Mueller (2008) reported water quality enhancement is the most important feature of AFI, especially in Asia where their installation over large surface areas (10 to 30%) of lakes and reservoirs help mitigate the effects of eutrophication. De Stefani et al. (2011) developed an experiment which was conducted in a channel receiving aquaculture effluents and found that median chemical oxygen demand (COD) in water passing through the floating wetland system was reduced by 66%, biochemical oxygen demand by 52% and total phosphorus by 65%. Zhao et al. (2012) indicated that average removal rates for total nitrogen (TN), NH_4^+-N, NO_3^--N NO_2^--N, total phosphorus (TP) and chlorophyll a in summer–autumn season were 36.9%, 44.8%, 25.6%, 53.2%, 43.3% and 64.5%. In addition, it also effectively reduced the concentrations of total suspended substance (TSS), *Escherichia coli* and heavy metals.

Aquatic plants are essential for getting the good ecological status of aquatic ecosystems, and it is therefore necessary to preserve such communities in freshwaters (Bornette & Puijalon 2011). Aquatic plants are suitable for wastewater treatment because they have tremendous capacity of absorbing nutrients and other substances from the water (Boyd 1970) and hence bring the pollution load down. Macrophytes play key functions in biochemical cycles, through, for example, organic carbon production, phosphorous mobilisation and the transfer of other trace

elements (Jeppesen et al. 1998; Murphy 2002). Zhu et al. (2011) studied seven species, especially *Salix babylonica*, *Gypsophila* sp. whereby *Oenanthe javanica* had an ideal effect on TN and TP removal and could be widely utilized for the treatment of wastewater in rural areas. Nakai et al. (2010) found that *T. angustifolia, S. tabernaemontani* and *P. australis* have the potential beneficial species for vegetation on artificial floating islands. These species may enhance the water purification owing to anti-cyanobacterial allelopathic effects. Elankumaran et al. (2003) established a comparative study between *Hydrilla verticillata* and *Salvinia* sp. and concluded that removal efficiency of *Hydrilla verticillata* is higher in lower concentration of (at 5 ppm) compared to *Salvinia*, but in higher concentration removal efficiency of *Salvinia* is more. Juwarkar et al. (1995) have reported 78% to 91% removal of BOD, nitrogen reduction from 30.8 to 9.8 mg/L and phosphate reduction from 14.9 to 9.6 mg/L using the emergent macrophytes *Typha latiofolia* and *Phragmites carka*. According to Dunabin and Bowmer (1992) these emergent plants influence metal storage indirectly by modifying the substratum through oxygenation, buffering and pH and adding organic matter. Hu et al. (2010) also reported plant eco-island system had remarkable purification ability to remove pollutants from hypereutrophic water and mixed planting of *O. javanica* D.C. with *N. officinale* on the FEIS may enhance nutrient removal and water quality improvement of eutrophic water bodies, especially at low temperature season. Yao et al. (2011) also reported that AFI with plants had a strong capacity for the removal of nitrogen and phosphorus. In particular, softstem bulrush (*S. validus* Vahl) and spiked loosestrife (*L. salicaria* Linn.) were excellent aquatic plants in Beijing wetland restoration.

Until recently, we only selected certain aquatic plants which have efficient removal rate. There is some lake of knowledge about configuration of aquatic plants. While in the current study, AFIs with different combination of aquatic plants were used to do the reaserch. The aims were to find the best optional floating island configuration to enhance the water quality; find the best plant or combination to match with softstem bulrush (*Scirpus validus* Vahl) and confirm a floating island which is qualify enough to dispose the pollutants and provide scientific evidence for ecological restoration in Beijing.

Meterials and Methods

EXPERIMENTAL MATERIALS

Three kinds of plants were selected in this experiment and they are watermifoil (*Myriophyllum veticillatum* Linn.), softstem bulrush (*Scirpus validus* Vahl) and yellow-flowered iris (*Iris wilsonii*), respectively.

EXPERIMENTAL DESIGN

Four kinds of AFI were made, three of these all contain softstem bulrush (*S. validus* Vahl). They were assembled with watermifoil (*M. veticillatum* Linn.), yellow-flowered iris (*I. wilsonii*), the combination of watermifoil (*M. veticillatum* Linn.) and yellow-flowered iris (*I. wilsonii*), respectively. The last AFI was only substrate without any vegetation, thus acting as a control experiment (Table 1). The total number of the whole experiment was twenty water jars and each type consisted of five same groups of repeated trial marked A, B, C, D and E. Only in this way, the data integrity and accuracy can be guaranteed.

DATA MEASUREMENTS

pH levels, chemical oxygen demand (COD), nitrate, total nitrogen (TN) and total phosphorous (TP) was measured in each water jar at the begin of the experiment. At 10-day intervals, the chemical parameters were measured again. SPSS 13.0 and Sigmaplot 10.0 software were used to process data. Moreover, the biomass at the initiation and completion of the experiment were also measured.

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 (12.58 to 14.25 g) at the end of the study. The configuration of these three plants had the greatest amount of aboveground biomass (14.25 g), followed by the configuration of Softstem bulrush (*S. validus* Vahl) and watermifoil (*M. verticillatum* Linn.) (13 g). The configuration of yellow-flowered iris (*I. wilsonii*) and Softstem bulrush (*S. validus* Vahl) had the least aboveground biomass (12.58 g). The configurations of these plants also had the greatest amount of underground biomass (14.21 g), followed by the configurations of yellow-flowered iris (*I. wilsonii*) and Softstem bulrush (*S. validus* Vahl) (14.08 g). The configuration of Softstem bulrush (*S. validus* Vahl) and watermifoil (*M. verticillatum* Linn.) had the smallest underground biomass (8.4 g) of the three configurations.

The four vegetations therefore showed excellent growth in AFI, with extensive development of roots beneath the water (Figure 1). The scope of root length for the three experimental configurations was between 24.58 and 30.14 cm, with minimum depths of up to 24.58 cm recorded for the configuration of Softstem bulrush (*S. validus* Vahl) and watermifoil (*M. verticillatum* Linn.). In contrast, yellow-flowered iris (*I. wilsonii*) and Softstem bulrush (*S. validus* Vahl) had the longest roots, the majority of which were more than 30.14 cm. The height of the configurations of these plants ranged from 89.25 to 108.25 cm. The configuration of Softstem bulrush (*S. validus* Vahl) and watermifoil (*M. verticillatum* Linn.) are the highest (108.25 g), followed by the configuration of these three plants (90.15 g). The value of configurations of yellow-flowered iris (*I. wilsonii*) and Softstem bulrush (*S. validus* Vahl) (89.25 g) are very close to the value of these three plants' configuration.

TABLE 1. Schematic representation of the experimental design

A1	B1	C1	D1
A2	B2	C2	D2
A3	B3	C3	D3
A4	B4	C4	D4
A5	B5	C5	D5

A = AFI; B = AFI with softstem bulrush (*Scirpus validus* Vahl) and watermifoil (*Myriophyllum veticillatum* Linn.); C = AFI with softstem bulrush (*Scirpus validus* Vahl) and yellow-flowered iris(*Iris wilsonii*) and D = AFI with softstem bulrush (*Scirpus validus* Vahl), watermifoil (*Myriophyllum veticillatum* Linn.) and yellowflowered iris (*Iris wilsonii*). A1 to A5, B1 to B5, C1 to C5 and D1 to D5 are the five duplicated experiments for data analysis
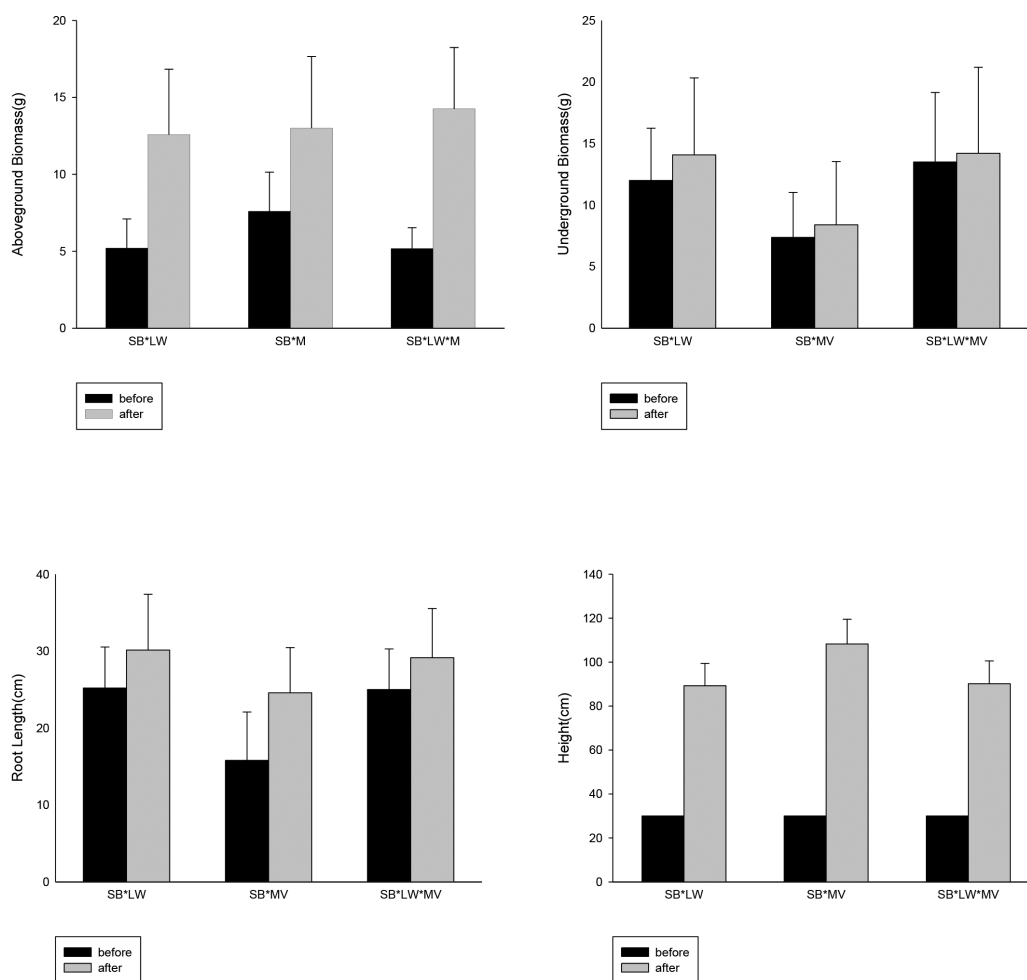

FIGURE 1. Growth characteristics of three different configurations measured in June 2011 after 50 days growth. Values in parentheses are standard deviations

SB=Softstem bulrush (*Scirpus validus* Vahl), LW=yellow-flowered iris (*Iris wilsonii*), MV=watermifoil (*Myriophyllum verticillatum* Linn.)

WATER QUALITY EFFECTS

Figure 2 shows the graphs for mean concentrations for chemical oxygen demand (COD), pH levels, NO_3^--N, PO_4^{3-}-P total nitrogen (TN), total phosphorus (TP) and for each treatment throughout the batches.

CHEMICAL OXYGEN DEMAND (COD)

The top left graph illustrated AFI without vegetation rose and fell dramatically on 20th June to 20th July, went up from 38.15 to 58.9 mg/L and then descended to 36.43 mg/L and it went up again to 45.97 mg/L and then descended until turns out to be flat in the end (42.4 mg/L). While the rest of the three groups decrease modestly, the configurations of yellow-flowered iris (*I. wilsonii*) and Softstem bulrush (*S. validus* Vahl) had the greatest amount of COD (22.36 mg/L), followed the configuration of Softstem bulrush (*S. validus* Vahl) and watermifoil (*M. verticillatum* Linn.) (15.25 mg/L). The configuration of these three aquatic plants had lest amount of COD (10.25 mg/L).

pH LEVELS

A measure of the acidity or alkalinity of a solution was reflected by the pH value as shown on the top right graph. AFIs without plants showed a trend of ascending pH from the beginning (pH = 8.4) to the end (pH = 9.90) (Figure 2). After 50 days, AFI with yellow-flowered iris (*I. wilsonii*) and softstem bulrush (*S. validus* Vahl), AFI with softstem bulrush (*S. validus* Vahl) and watermifoil (*M. verticillatum* Linn.) and AFI with these three aquatic plants presented a wave trend from 8.4 to 8.54, 8.4 to 8.45, 8.49 to 8.11 and 8.49 to 8.64, respectively.

NO$_3^-$ CONCENTRATION

The middle left graph illustrated the reduction process of the NO$_3^-$. The curve of the AFI without vegetation came up to the summit (2.59 mg/L) in the third measurement and then fell in the end noticeably. The other three curves declined obviously. Starting at the same point (1.29 mg/L), the values of AFI with yellow-flowered iris (*I. wilsonii*) and Softstem bulrush (*S. validus* Vahl), the configuration of softstem bulrush (*S. validus* Vahl) and watermifoil (*M. verticillatum* Linn.) and AFI with these three aquatic plants dropped to 0.15, 0.08 and 0.05 mg/L. If we concentrate on the initial and final data, no more than one curve of AFI with these three aquatic plants decreases to below 0.05 mg/L.

PO$_4^{3-}$

AFIs without plants went up from 1.35mg/L separately to 1.68 mg/L and then descended ultimately (Figure 2). In addition, the other four experiments overall tend descended. All the configuration had a similar amount of PO$_4^{3-}$ (0.08 to 0.1 mg/L) at the end of the study as shown on middle right graph. AFI with yellow-flowered iris (*I. wilsonii*) and softstem bulrush (*S. validus* Vahl) had the greatest amount of PO$_4^{3-}$ (0.1 mg/L), followed AFI with these three aquatic plants (0.09 mg/L). The configuration of softstem bulrush (*S. validus* Vahl) and watermifoil (*M. verticillatum* Linn.) had lest amount of PO$_4^{3-}$ (0.08 mg/L). Total nitrogen (TN)

Bottom left graph illustrated a reduction process of the total nitrogen. AFIs without plants fluctuate greatly. It went up from 2.75 mg/L separately to 3.62 mg/L and then descended to 2.24 mg/L. AFI with yellow-flowered iris (*I. wilsonii*) and softstem bulrush (*S. validus* Vahl), AFI with Softstem bulrush (*S. validus* Vahl) and watermifoil (*M. verticillatum* Linn.) and AFI with these three aquatic plants showed evenly declining trends from 2.75 to 0.82, 2.75 to 0.78 and 2.75 to 0.70, respectively. If we concentrate on the initial and final data, no more than one curve of AFI with these three aquatic plants decreases to below 0.75 mg/L (0.70 mg/L).

TOTAL PHOSPHOROUS (TP)

The bottom right graph illustrated the reduction process of the total phosphorous. AFI without vegetation ascended slightly in the first and second sampling. In detail, they rose from 0.49 to 0.60 mg/L and then kept steady declining trends. AFI with yellow-flowered iris (*I. wilsonii*) and softstem bulrush (*S. validus* Vahl), AFI with Softstem bulrush (*S. validus* Vahl) and watermifoil (*M. verticillatum* Linn.) and AFI with these three aquatic plants showed evenly trends of decling from 0.49 to 0.07, 0.49 to 0.06 and 0.49 to 0.05, respectively. Obviously AFI with these three aquatic plants had lest amount of Total phosphorous.

DISCUSSION

The AFI stocks nutrients inside the aquatic plants and base meterials. The trophic condition of the waterbody promotes the growth of plants. It seems there is a proportional relation between the biomass and the nutrients in the water. Phosphorous and nitrogen are both key parameters for aquatic plant life. The ammonium ion is the preferred nitrogen source for plant growth (James et al. 2004; Smolders et al. 2002). The capacity to absorb COD, NO$_3^-$, total nitrogen and total phosphorous of AFI with these three aquatic plants was better than other aquatic plants. Therefore, the configuration of these three plants had the greatest change value of aboveground biomass. In contrast to aboveground biomass, length of roots and underground biomass of AFI with these three aquatic plants reach the least change value. On the other hand, non-rooted macrophytes absorb their nutrients from water, and are consequently usually found in aquatic ecosystems where the nutrient level in the water column is high (Lacoul & Freedman 2006). In addition, rooted plants can use nutrients both in the water column and in the substrate (Madsen & Cedergreen 2002). Watermifoil (*M. verticillatum* Linn.) is a kind of submerged plant. It almost do not have any roots let alone underground biomass. Denny (1980) observed that tendency to use shoots as sites of heavy metal uptake instead of roots increases with progression towards submergence and simplicity of shoot structure.

Some other researches also illustrated the water purification characteristics of the aquatic plants, especially softstem bulrush (*S. validus*). Hunter et al. (2001) had demonstrated the importance of softstem bulrush (*S. validus*), an obligate wetland plant that is used regularly in wetlands for wastewater treatment, on removal of ammonium, orthophosphate and total organic carbon (TOC) from microcosms receiving synthetic municipal wastewater. Average percent removal of NH^{4+}-N was significantly greater in microcosms containing plants (67%) than in those without plants (29%). Percent removal of PO$_4^{3-}$-P was also significantly greater in microcosms with plants (42%) than in microcosms without plants (20%). Yao (2011) had showed 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 means that the AFI with the plants has big potential as a nutrient stock room. Gersberg et al. (1986) demonstrated investigations using artificial wetlands which quantitatively assess the
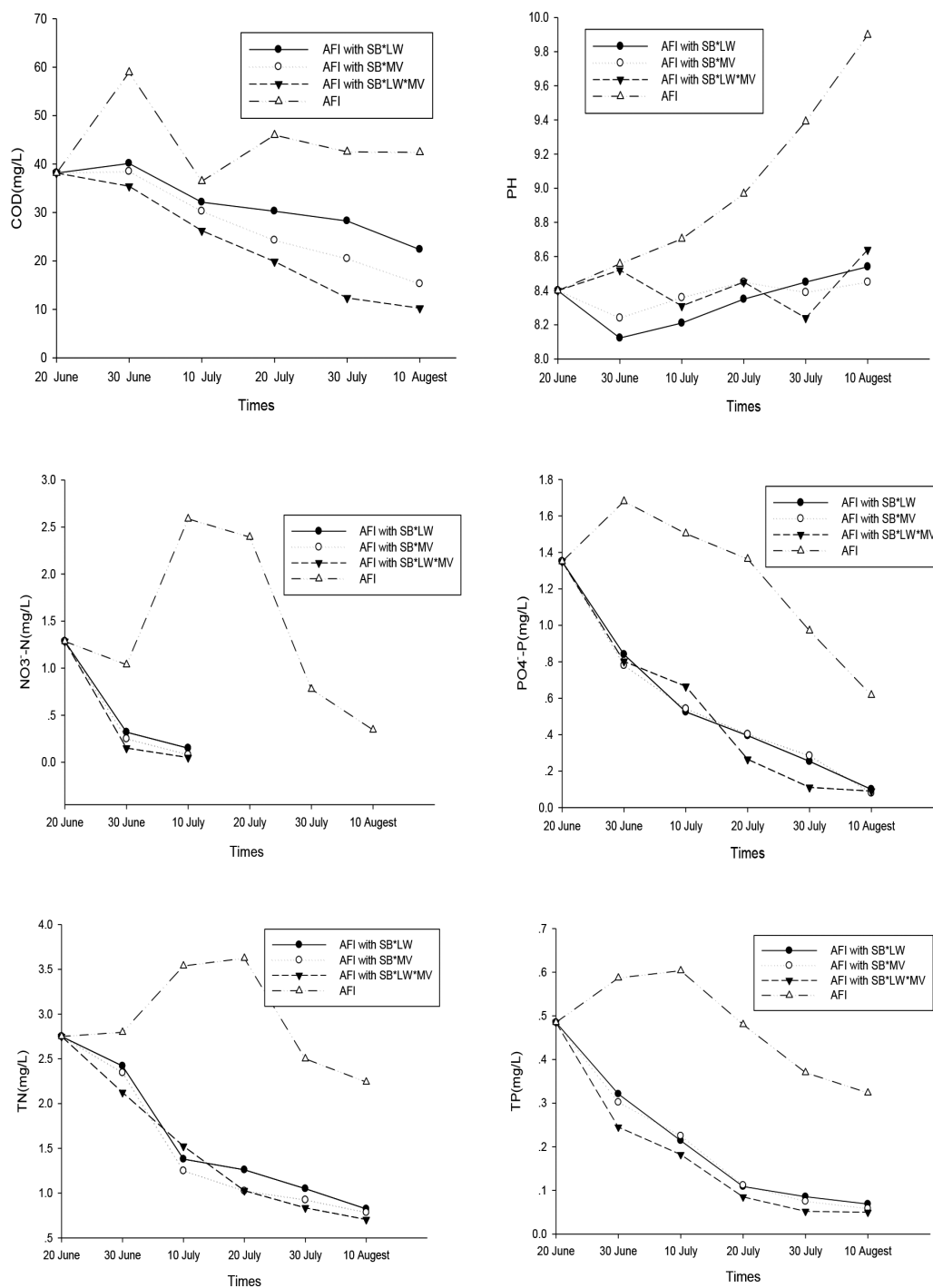
FIGURE 2. Mean concentration for PH, COD, PO43-P, NO3-N, TN, TP, for each treatment throughout the batches (*n*=5). Initial concentrations (PH, COD, PO$_4$^{3}-P, NO$_3$-N, TN, TP) are 8.4,38.15, 1.35, 1.285, 2.75 and 0.485 mg/L. Error bars represent +/-one standard error of the mean. Fifty days samples were only collected for some treatments (SB, LW and MV)

role of each of three higher aquatic plant types, *Scirpus validus*, *Phragmites communis* and *Typha latifola*, in the removal of nitrogen, BOD and TSS from primary municipal wastewaters. During the period August 1983-December 1984, the mean ammonia concentration of 24.7 mg l^{-1} in the primary wastewater inflow (hydraulic application rate = 4.7 cm day^{-1}) was reduced to mean effluent levels of 1.4 mg l^{-1} for the bulrush bed, 5.3 mg l^{-1} for the reed bed

and 17.7 mg l^{-1} for the cattail bed, as compared to a mean value of 22.1 mg l^{-1} for the unvegetated (control) bed. The configuration of Softstem bulrush (*S. validus* Vahl) and watermifoil (*M. verticillatum* Linn.) was the best choice for removal of PO$_4$$^{3-}$ instead of the combination of three aquatic plants mainly because that sometimes in eutrophic situations, the filling in of the waterbody probably results from higher productivity and succession would lead more

rapidly to the dominance of competitive species, both rooted and floating (Arts 2002; Khan & Ansari 2005).

CONCLUSION

The result indicated that aquatic macrophytes configuration mode does impact water quality whereas AFIs with different combination of aquatic plants have different abilities to purify water. Watermifoil (*Myriophyllum verticillatum* Linn.) is better than yellow-flowered iris (*Iris wilsonii*) to combine with softstem bulrush (*Scirpus validus* Vahl) pollutants disposal. The most effective way is the combination of these three aquatic plants. Vegetative characteristics of each type also indicated the trophic condition of the water body promote the growth of plants. The presence of these three plants played a key role in the removal of pollutants, although other plants which are used to confirm AFI configuration is uncertain. So, further experiments are needed to verify the role of different combination of aquatic plants play in water purification. However, the effectiveness of these measures relies heavily on a better knowledge of AFI and aquatic plants, which would be of some support to environmentally friendly restoration in Beijing.

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