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# *Phragmites australis* and *Typha orientalis* in removal of pollutant in Taihu Lake, China

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**Abstract**

Two plant populations of *Phragmites australis* and *Typha orientalis* grown in gravel and sediment substrate were studied to assess their capabilities for purifying polluted water in Taihu Lake, China. The substrate displayed most significant effects on the suspended matter ($P < 0.01$), with the reduction of 76%–87% and 52%–63% for *P. australis*, and 83%–86% and 45%-62% for *T. orientalis* in gravel substrate and sediment substrate, respectively. Both species and substrates significantly decreased the N and P concentrations of water body ($P < 0.01$). *P. australis* showed higher total N and P concentrations in tissues than *T. orientalis* and had a greater potential to remove nutrients from the lake. Phosphate was easily to concentrate in the belowground tissues, while nitrate concentration was higher in leaf and stalk. Therefore, harvesting the aboveground tissues could take most of nitrate out of the sediment. The saturate photosynthetic rate ($A_{sat}$) of *P. australis* was higher than that of *T. orientalis* when grown in sediment substrate. But instance water-use-efficiency ($WUE_i$) ($A/E$) and intrinsic water use efficiency ($A/g_s$) showed the maximum values of two species grown in river water. With significant difference in $g_s$, however, intercellular $CO_2$ concentration ($C_i$) had no obvious difference in two species which indicated that high $A_{sat}$ value of *P. australis* might result from the increased carboxylation capacity of the mesophyll, because of the central role of N in photosynthetic enzymes. Our findings suggest that the plants could absorb most of nitrogen in polluted water, while gravel displayed a high capacity for absorbing the suspended matters and phosphate salts. Therefore, biological and physiological pathways for pollutant removal should be integrated.

**Key words**: *Phragmites australis*; *Typha orientalis*; nutrient removal; gas exchange; Taihu Lake

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## Introduction

The nutrients, especially nitrogen and phosphorus, which could determine the water quality, had been recognized decades ago (Vollenweider, 1968). The topic of nutrient biogeochemistry in freshwater lakes, and the interrelation between biota and chemical environment had been investigated in many countries (Carrera *et al*., 2003). It is worth to mention that a sound physical-chemical approach has been introduced into this research field (Stumm and Morgan, 1970).

Taihu Lake, with the whole area 2338 km$^2$, is the important role for tourism, shipping, irrigating and drink water resources for nearby cities, i.e., Wuxi and Suzhou (Chen *et al*., 2003). With the rapid development of economy around Taihu Lake since 1980s, the water pollution of main rivers and lake areas has been worsening by lack of efficient protections and control measurements, especially the eutrophication of water body. It has been extensively used that the constructed wetlands grown with aquatic plant for nutrient removal from polluted lakes or other water bodies and is widely recognized as the lowest cost method for wastewater treatment (William, 1995; Clevering, 1998; Annadotter *et al*., 1999; Jing *et al*., 2001). For example, wetland filtration could reduce up to 30%–67% total phosphorous and 30%–52% total nitrogen for the hypereutrophic lake water (Coveney *et al*., 2002).

Studies of the eutrophication relations and monthly monitoring to find remedies against eutrophication in Taihu Lake began in October 1991 (Cai *et al*., 1994). However, the pollution is still serious, and affects the life of local people and economy development. Therefore, it is urgent to apply effective approaches to treat the water pollutions in Taihu Lake, and restore the lake ecosystems. Local plant species should be firstly considered for their high adaptation capacity for environment. Six ponds were constructed with different substrates to simulate the wetland systems to purify the eutrophic lake water with indigenous major emerging plant species, *Phragmites australis* and *Typha orientalis* in west Taihu Lake, China. In this study, the nutrients removal efficiency of different

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substrates was compared and plant biomass contributions to nutrient removal processes were evaluated in the constructed ponds.

The following three questions are addressed: (1) if *P. australis* would exhibit favorable gas exchange traits compared with *T. orientalis*; (2) if *P. australis* showed the higher ability to absorb phosphate and nitrogen than *T. orientalis*; (3) if the different substrates affect the efficiency of plant to absorb nutrients.

## 1 Materials and methods

### 1.1 Study site

The investigation was conducted at Linzhuang River, being one of the main river channels of Taihu Lake, in Yixing City, Jiangsu Province, which is the Research Station of Chinese Academy of Environmental Sciences (42°23′N, 112°23′E). The research site is located in the downstream of residential area, being 200 m away from the Taihu Lake. Wastewater from domestic, factories and agricultural activities around the region are mostly discharged into Linzhuang River (Table 1). We monitored the water quality of river water in August and September, 2003, at that time the eutrophication is just became serious in Taihu Lake. The blue-green algae are blown into the river by the southeast wind, accompanied with the nitrogen salt from the sediment of lakeshore. Water in most area is V class water according to the environmental quality standards for surface water (GB 3838-2002) (Table 2).

### 1.2 Experimental design

Seeds were collected from the west Taihu Lake, China, in November 2003, and sowed in greenhouse at the Research Station of the Chinese Academy of Environmental Sciences in Dapu in March 2004. When they grow large enough, we transfered them into the ponds (L × W × H, 10 × 3.4 × 1.1 m) which are constructed by the cement near the Linzhuang River. The density is about 30 × 30 cm of individual spacing. We pumped 3000 L water from the river into depositing pond (L × W × H, 7.6 m × 3.4 m × 2 m) daily to deposit the solid particles and other dirt. Then the water will be flowing into each pond about 10 h each day at a uniform speed, which is controlled by the mounted valve at the entrance. The water will stay in ponds for three days. The depth of water in pond remains 60 cm by a unique outlet. Two kinds of substrate were applied, one is sediment and the other is gravel. The river water was set as the control in this experiment. The plants were established through the foam material, which floats on the water surface. Three replications are performed for each treatment.

**Table 1** Pollutant discharge in the Taihu Lake region in 2001–2005 (ton/year)

| Pollution sources | Waste water ($\times 10^4$) | COD | TN | TP |
|---|---|---|---|---|
| Industrial wastewater | 53901 | 111061 | 12545 | 591 |
| Domestic wastewater | 32290 | 119029 | 19948 | 3394 |
| Village area source | 145247 | 28138 | 29842 | 852 |
| Aquiculture | 83774 | – | 13195 | 533 |
| Lakeside domestic wastewater | 216 | 417 | 21 | 3 |
| Lake precipitation | 3341 | 23595 | 2760 | 60 |
| Dust laying | – | – | 421 | 33 |
| Shipping | – | 164 | 22 | 2 |
| Water and soil erosion | – | – | 800 | 192 |
| Total | 318769 | 282404 | 79552 | 5660 |

–: Data are unavailable; COD: chemical oxygen demand; TN: total nitrogen; TP: total phosphate.

### 1.3 Sampling and chemical analysis

Water samples were taken every three days in entrance and water outlet of each pond to measure some relative indexes from 19 September to 24 November 2004. The total nitrogen (TN), total phosphorus (TP), pH and transparency were measured. Plant samples were collected on 20 November 2004. In each pond, 8–10 plant individuals of *P. australis* and *T. orientalis* were respectively collected and divided the tissues into three parts as leaf, stalk, and root. All tissues of each sample was dried at 70°C in an oven for 48 h to constant mass, then weighted, grounded to 80 mesh and stored for chemical analysis. For each plant species 1 g dry weight of tissue, the total N was analyzed according to Auto-Kjeldahl method (Kjektec System 1026 Distilling Unit, Sweden) by Zhang *et al.* (2004) and Lowther (1980) and using the ammonium molybdate method for P content mesurement (Rice, 1964; Bradstreet, 1965; Horwitz, 1975).

### 1.4 Gas exchange measurement

Gas exchange was measured using a portable gas exchange fluorescence system (GFS-3000, Heinz Walz GmbH, Effeltrich, Germany) in current foliage from each species in 9:00–11:00 from 20 to 24 Sept. 2004. Three individuals of plant were chosen to determine the gas exchange in each pond. The GFS-3000 system measurements and formulae were used for the determination of photosynthetic rate ($A_{\text{sat}}$, μmol/(m$^2$·s)), stomatal conductance ($g_s$,

**Table 2** Water quality in Linzhuang River measured during Aug. and Sep. in 2003

| Parameter | 17 Aug. | 19 Aug. | 22 Aug. | 24 Aug. | 26 Aug. | 29 Aug. | 31 Aug. | 2 Sep. | 4 Sep. | 6 Sep. |
|---|---|---|---|---|---|---|---|---|---|---|
| TN (mg /L) | 1.32 | 1.132 | 3.27 | 1.207 | 1.693 | 1.508 | 0.969 | 1.1 | 2 | 5.41 |
| TP (mg/L) | 0.114 | 0.118 | 0.139 | 0.176 | 0.129 | 0.161 | 0.134 | 0.17 | 0.14 | 0.54 |
| $NO_3^-$-N (mg/L) | 0.229 | 0.247 | 1.481 | 0.228 | 0.126 | 0.358 | 0.129 | 0.26 | – | – |
| $NH_4^+$-N (mg/L) | 0.575 | 0.668 | 10.43 | 0.615 | 0.731 | 0.556 | 0.407 | 0.56 | 1.15 | 3.77 |
| DO (mg/L) | 2.6 | 2.4 | 0.1 | 1.2 | 2.8 | 1.8 | 1.0 | 2.0 | 0.7 | 0.3 |
| pH | 9.44 | 9.44 | 10.12 | 7.52 | 8.01 | 7.82 | 7.93 | 7.78 | 6.37 | 6.46 |
| Water temperature (°C) | 26.5 | 29.3 | 31.5 | 29.7 | 29.7 | 29.5 | 26.7 | 30.5 | 29.9 | 30.6 |

–: Data are unavailable; DO: dissolved oxygen.

mmol/($m^2$·s)), internal $CO_2$ concentration ($C_i$, μmol/mol) and transpiration ($E$, mol/($m^2$·s)). Instantaneous water-use-efficiency (WUE) ($A/E$) and intrinsic water-use-efficiency ($A/g_s$) were also calculated.

### 1.5 Statistical analysis

Statistical analyses were performed using SPSS 10.0 software. Multiple comparisons were used to separate the means of plant N, P and physiological characteristics ($A_{sat}$, $E$, $g_s$, $C_i$ and WUE) in every species for each treatment. The differences were tested by a one-way ANOVA (Duncan test) at $P < 0.05$ or $P < 0.01$. Student's $t$-test was used to determine the differences in plant N and P concentrations, and the physiological characteristics between *P. australis* and *T. orientalis* grown under different sediments. SigmaPlot 9.0 (SPSS Inc.) was used to fit and statistically test regression lines for all photosynthesis data.

## 2 Results

### 2.1 Removal of suspended matter of water

The suspended matter content of river water was in the range of 2–4 mg/L. The values significant decreased in ponds with substrate of gravel and sediment in three months ($P < 0.05$). For *P. australis* community, the suspended matter content was in the range 0.6–2.5 mg/L in river water (Fig. 1a, 1b, 1c). It was reduced by 76%–87% and 52%–63% in gravel substrate and sediment substrate, respectively. For *T. orientalis* community, the suspended matter content was 0.5–2.3 mg/L (Fig. 1a, 1b, 1c). It was reduced 83%–86% in gravel substrate, while it was 45%–62% in sediment substrate. For the same substrate, two species did not display significant differences in effects on the suspended matter, but the different sediments significantly affected the suspended matter in water ($P < 0.01$). The suspended matter was higher in September, but decreased in November.

### 2.2 Removal of N and P

The N content of river water was about 2.0–2.9 mg/L and decreased through treatment. The N content of water was about 0.78–2.0 mg/L in ponds growing *P. australis* with substrate. It was reduced by 45%–61% and 25%–50% in gravel substrate and sediment substrate, respectively. The N content of water was 0.6–1.9 mg/L in ponds planting *T. orientalis*. The value declined 44%–61% and 25%–61% in gravel substrate and sediment substrate, respectively.

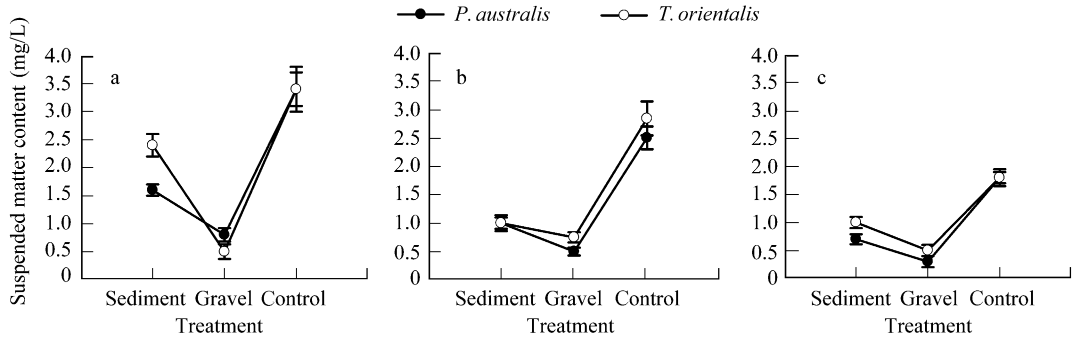

**Fig. 1** Suspended matter content of water in the river and outlet water ponds with sediment and gravel substrate with *P. australis* and *T. orientalis* plant community respectively in September (a), October (b) and November (c). Each data point represents the mean and S.E. for three repetitions.

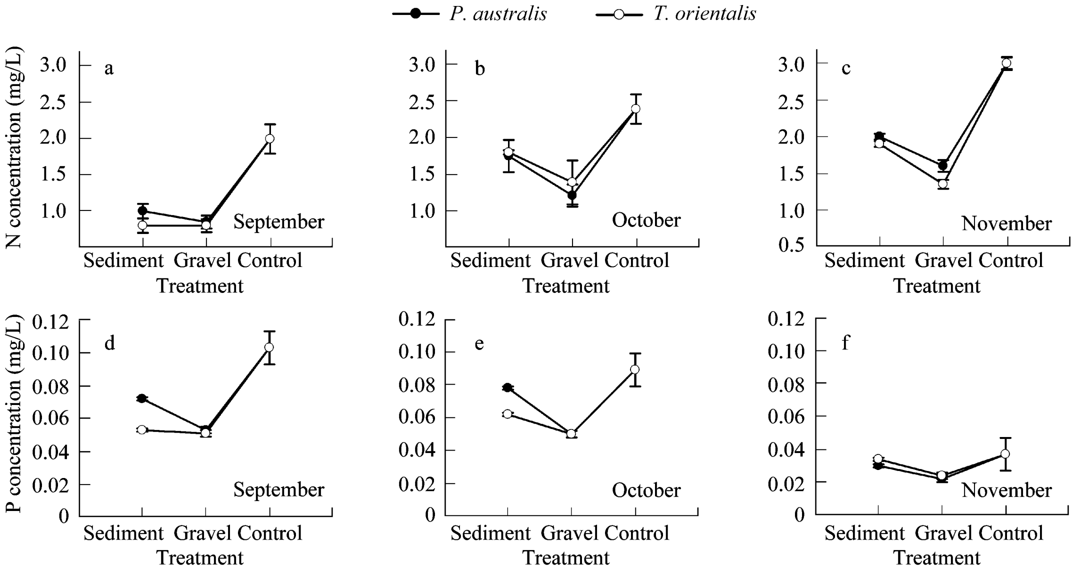

**Fig. 2** Total N and P concentration of water in the river and outlet water ponds with sediment and gravel substrate with *P. australis* and *T. orientalis* respectively. Each data point represents the mean and S.E. for three repetitions.

The N content increased from September to November (Figs. 2a, 2b, 2c). The dissolved P content of river water was 0.04–0.11 mg/L. The dissolved P content of water was 0.02–0.08 mg/L in ponds planting *P. australis* with substrate. Comparing with the control, it was reduced by 42%–49% in ponds with gravel substrate, with average value 45%, while it was 14%–29% in ponds with sediment substrate, with average value 21% (Figs. 2d, 2e, and 2f). For *T. orientalis* community, the dissolved P content was about 0.02–0.06 mg/L. It was reduced by about 37%–51% in gravel substrate, with average value being 45%. It was about 12%–47% in sediment substrate, with average value being 29%. The dissolved P content was higher in September, and decreased in November.

### 2.3 Total N and P concentration of plants

For *P. australis*, N content in the decreasing sequence: leaf > stalk > root. The total N content in aboveground tissue was more than 67%–85% in both treatments and control. N content of tissues were higher in plants growing in ponds with sediment than that in gravel and river water ($P < 0.05$) (Fig. 3a). The gravel substrate did not significantly affect the N content in tissue. The similar trends were found in *T. orientalis* (Fig. 3b). But P concentration in root was basically higher than that of stalk and leaf in both species (Figs. 3c and 3d). Total P and N concentrations in all tissues were larger for *P. australis* than that of *T. orientalis* (Fig. 4a).

### 2.4 Gas exchange of plants

$A_{sat}$ of *P. australis* was the highest in sediment substrate, while the lowest value was recorded in river water (Fig. 5a). Similar trends were recorded in $E$ (Fig. 5c). The value of $g_s$ was the higher in plant growing in sediment than that in gravel and river water (Fig. 5b). The trends of $C_i$ were similar to $g_s$ (Fig. 5d). But WUE$_i$ showed the maximum value of *P. australis* growing in river water, the lowest value in ponds with sediment (Fig. 5e). $A/g_s$ presented the maximum value of *P. australis* growing in river water (Fig. 5f). For *T. orientalis*, the maximum value of $A_{sat}$ was in ponds with sediment (Fig. 5a), and $g_s$, $E$ and $C_i$ showed the similar trends with that of $A_{sat}$ (Figs. 5b, 5c, and 5d). But WUE$_i$ and $A/g_s$ displayed the maximum value of *T. orientalis* in the individuals growing in river water (Figs. 5e and 5f).

## 3 Discussion

### 3.1 Removal of suspended matters of water

The suspended matter can be caught or stuck by the roots of plants or the stalks when water flows through ponds. Also the suspended matter can be deposited by itself due to the reduced kinetic energy in the vegetated water bodies. In this study, gravel showed a larger ability to absorb the suspended matter than the sediment, while two species did not show significant decreases in

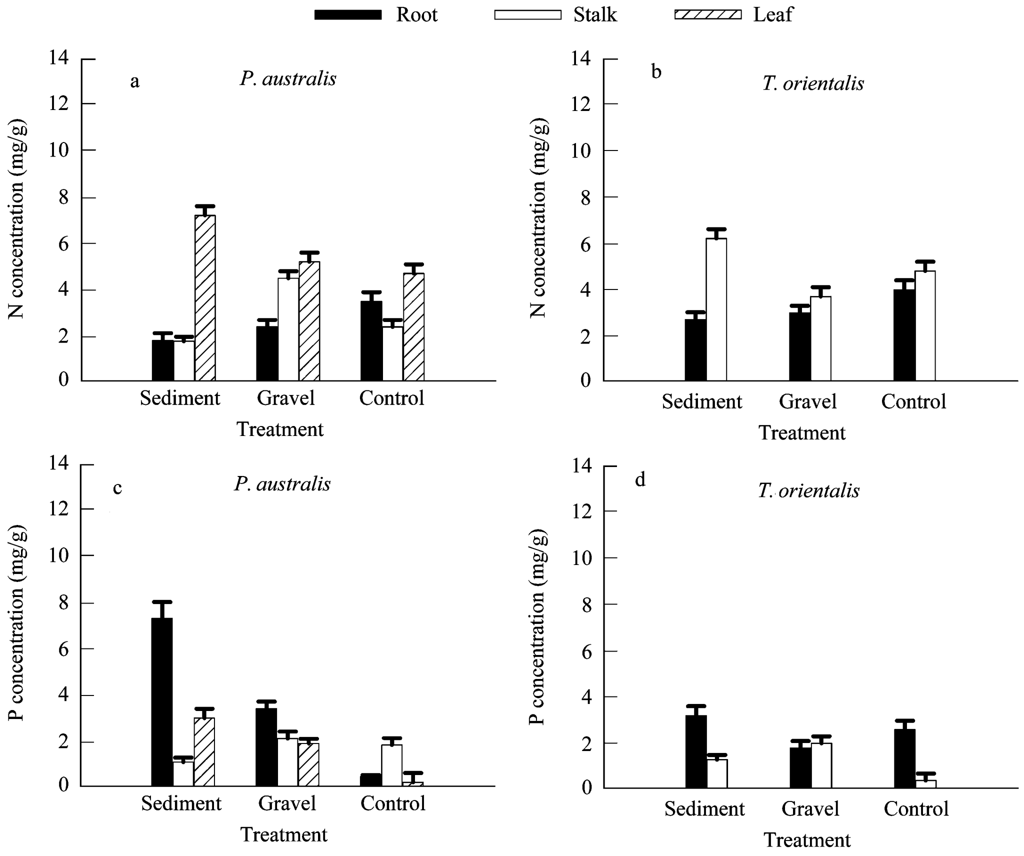

**Fig. 3** Total N and P concentration of tissues in *P. australis* (a, c) in *T. orientalis* (b, d) in the river water and ponds with sediment and gravel substrate. Each data point represents the mean and S.E. for three repetitions.

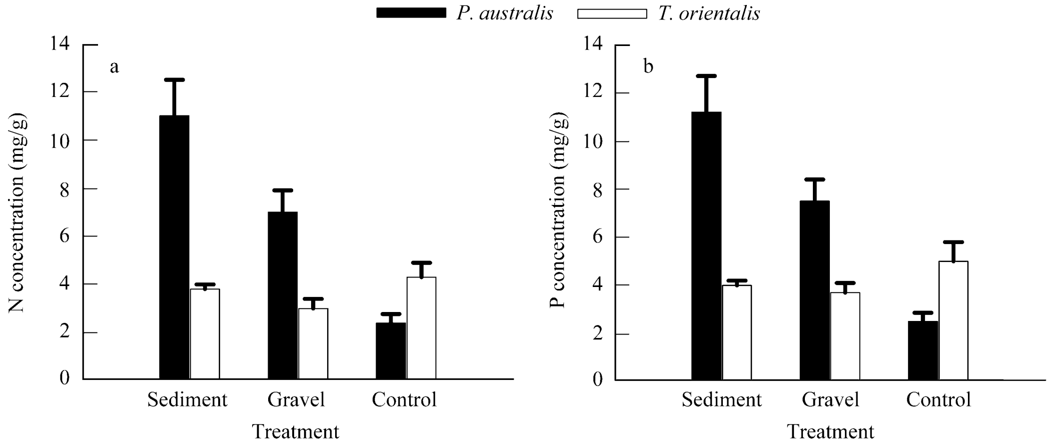

**Fig. 4** Total N (a) and P (b) concentration of whole plant in *P. australis* and *T. orientalis* growing in three different substrates. Each data point represents the mean and S.E. for three repetitions.

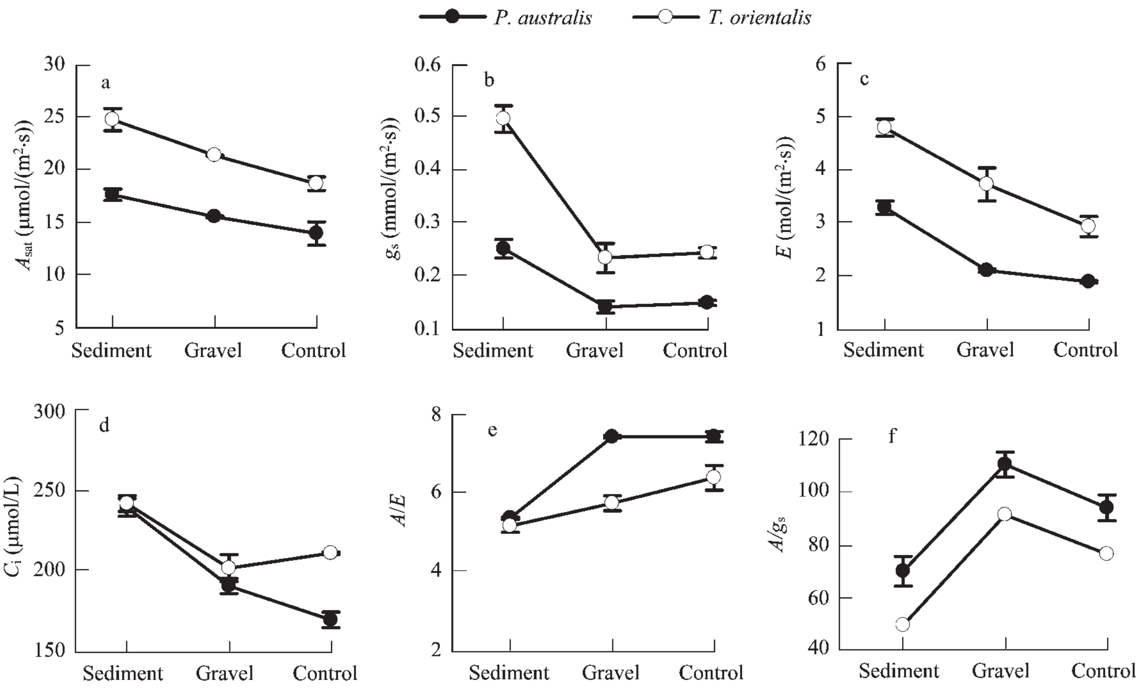

**Fig. 5** Saturate $CO_2$ assimilation ($A_{sat}$) (a), stomatal conductance ($g_s$) (b), internal $CO_2$ concentration ($C_i$) (c), transpiration ($E$) (d), instantaneous water-use-efficiency ($A/E$) (WUE$_i$) (e), and intrinsic water-use-efficiency ($A/g_s$) (f) of *P. australis* and *T. orientalis* in ponds with sediment, gravel substrate and the river water. Each data point represents the mean and S.E. for three repetitions.

suspended matter content in the same substrate (Fig. 1). This suggested that the caught of suspended matter mainly depended on the substrate, and the biological uptake was a very minor removal pathway in this experiment. For ponds with gravel substrate, the big hiatus between gravels offers the favorable space for suspended deposition and is not affected by the disturbance of water. Also the large surface area contributes the big decline of suspended matter in ponds with gravel. Our data indicated that one step should be designed to removal suspended matter by gravel when the water pollution was treated.

### 3.2 Removal of N and P content

The dissolved P content was decreased significantly in ponds with gravel comparing with the river water and sediments ponds (Figs. 2d, 2e, 2f). Dissolved phosphate is supplied to the Taihu Lake by the domestic wastewater and by the diffusion from bottom sediments. The P concentration of all tissues in *T. orientalis* was very similar among treatments and control (Fig. 4b). But the P content of water in corresponding ponds was significantly different (Figs. 2d and 2e). For *P. australis*, the P content was the highest in ponds with sediment, followed by gravel substrate (Figs. 2d, 2e, 2f). This may be related to the anoxic conditions of sediment ponds, which increases the solubility of phosphate associated with amorphous ferrous hydroxide and then enhances phosphate diffusive fluxes (Boyd, 1995). However, the removal of P from water was the best in ponds with gravel. This may be resulting from the high absorption ability of gravel to salt particles. P concentration of roots was higher than that leaf and stalk for both *T. orientalis* and *P. australis*. That is to say that harvesting the aboveground tissues after the end of growing season when the plants were applied for removing the nutrients in lake at a large scale, is not efficient to remove the phosphate from water body owing to the roots decomposing rapidly and $PO_4^{3-}$ will return to the lake again (Xie *et al*., 2004). Our data suggested that P concentration in Taihu Lake water column was controlled by physical and chemical factors, whereas biological uptake is likely to play a minor important role. Other possible removal pathways such as coprecipitation with authigenic aragonite and/or adsorption on colloidal particles should be also considered.

The sediment plays an important role in ponds as it is both an important source of various dissolved substances and a sink for particulate materials, nitrite, and nitrate etc. (Masuda and Boyd, 1994). Diffusion from the bottom sediments is a major source of ammonia to the lake (Dafner, 1992). The potential for N removal by denitrification is high when there is a large volume of reduced sediment. But the magnitude of N removal by this mechanism is low because nitrification and denitrification are tightly coupled in aquatic sediments (Hammer and Knight, 1994; Del Bubba *et al*, 2000). Also sediment nitrification is largely limited by the oxygen penetration of sediment, water exchange and circulation, aeration, pond depth and other management procedures (Rooth and Stevenson, 2000). *P. australis* is highly productive semi-aquatic plant and its contribution to the aquatic environment has been studied widely (Burian and Sieghardt, 1979; Neuhuber and Hammer, 1979; Gessner, 2000). In this article, the nitrate content in leaf and stalk was higher than that of root in both species (Figs. 3a and 3b). More than 50% nitrate of tissue are taken out of sediment by harvesting the aboveground parts of plants at the end of each growing season. Otherwise, the detritus stalk will deposit, and subsequently accumulate, decompose, and most of nitrate will enter the sediment (Polunin, 1984; Hocking, 1989a, b), which are the differences between the modes of phosphate and nitrate removal pathway. Also some allochthonous materials will deposit in the marshes. Walker (1970) documented that autochthonous matter dominates in reed marshes. Generally, a higher proportion of phosphorus than nitrogen was expected to remain trapped in the anaerobic layer. The model showed that the uptake of nitrogen and phosphorus of *P. australis* during the growing season exceeded the release during decomposition about 4–6 and 5–7 fold, respectively (Asaeda *et al*., 2002). In this study, leaf nitrogen contents of *P. australis* and *T. orientalis* were significantly higher in sediment ponds than that in gravel ponds and control ($P < 0.05$), with no significant difference between them (Figs. 3a and 3b).

### 3.3 Photosynthesis characteristics of two species

The photosynthetic capacity ($A_{sat}$) of *P. australis* was significantly higher than that of *T. orientalis* and decreased from sediment ponds, gravel ponds to control (Fig. 5a). $A_{sat}$ reflects the rate of diffusion of $CO_2$ to Rubisco, the activity of Rubisco, and/or the rate of regeneration of RuBP (Farquhar *et al*., 1980). Significant decreases in stomatal conductance with decreasing stability of N availability, because of the water will recede frequently in river water, namely the control and close relationships between $A$ and $g_s$ of *P. australis* ($P < 0.01$) (Figs. 5a and 5b) suggested the stomatal responses affected by stable N availability could increase the supply of $CO_2$ to the intercellular spaces. This may partially explain an increase in photosynthetic assimilation rate of *P. australis*. In general, the high values in $A$ with foliar N concentration can either be related with increased stomatal conductance or from increased carboxylation capability (Brown *et al*., 1996). With significant difference in $g_s$, however, $C_i$ had no obvious difference in two species which indicated that the high value of $A_{sat}$ for *P. australis* might also be a consequence of increased carboxylation capacity of the mesophyll because of the central role of N in photosynthetic enzymes, other proteins, and pigments (Smith *et al.*, 2004). $A_{sat}$ of *T. orientalis* is lower than that of *P. australis* might be caused by the low carboxylation capability related to the low conductance (Figs. 5a, 5b, 3a, 3b).

## 4 Conclusions

*P. australis* showed higher N and P concentration in tissues than *T. orientalis*, and may have greater potential to remove nutrients from the lake. Phosphate was easily to concentrate in the belowground tissues, while nitrate concentration was higher in leaf and stalk. Harvesting the aboveground tissues could take most of nitrate out of the sediment. Gravel displayed a high capacity to the absorption of suspended matters and phosphate salts. Therefore, biological and physiological pathways for pollutant removal should be integrated.

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