

Nutrient retention in plant biomass and sediments from the salt marsh in Hangzhou Bay estuary, China

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Abstract Nutrient load into the ocean can be retained during the process of plant uptake and sedimentation in marshes along the bay zone. Seasonal variations of biomass and nutrient concentration in three dominated plant assemblages and associated sediments were monitored in this study area to determine effects of salt marsh on nutrient retention. Results showed that plant aboveground biomass displayed a unimodal curve with nutrient concentration generally decreased from spring to winter. Belowground biomass was relatively low during the rapid growth period with nutrient concentration tending to decrease and then increase during this period. Plant total nitrogen (TN) pools are higher than total phosphorus (TP) pools, and both pools showed significant seasonal variations. Water purification coefficients (WPC) of nutrients by plant assimilation were 34.4/17.3, 19.3/24.0, and 5.14/6.04 t/(m² year) (TN/TP) for *Phragmites australis*, *Spartina alterniflora*, and *Scirpus mariqueter*, respectively. Overall, these results suggest that higher annual plant biomass and nutrient assimilation contribute to greater nutrient retention capacity and accumulation in sediments, thereby enabling reduced eutrophication in transitional waters.

Keywords Estuaries · Eutrophication · Salt marshes · Primary production · Nutrients · Retention

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Introduction

In coastal areas, population growth and rapid economic development contribute to many point and nonpoint source nutrient inputs, both directly or indirectly, which largely lead increases in nutrient concentration in ocean waters. Nitrogen (N) and phosphorus (P) are essential nutrient elements in ecosystems, and P is a limiting nutrient for phytoplankton growth (Redfield 1958; Boers et al. 1998). Eutrophication in aquatic ecosystems caused by excessive input of N and P is recognized as a major water quality problem globally (Smith 2003; Schindler 2006).

Coastal wetland is one type of wetlands, which is located between ocean and terrestrial land, and is composed of a complex and assemblage of swamps, marshes, mudflats, etc. (Bai et al. 2012a). Salt marsh is typically dominated by halophytic (salt-tolerant) plants such as herbs, grasses, or low shrubs, with daily tidal flow that occurs and continuously floods the area (Adam 1990). As a transitional zone between terrestrial and marine ecosystems, salt marshes are one of the most biologically productive habitats that drive nutrient cycles and food webs supporting estuarine and coastal ecosystems (Marinucci 1982).

Plants and sediment nutrient pools may greatly affect nutrient cycles in salt marshes. Salt marsh plants have high assimilative capacity for N, P, and heavy metals (Quan et al. 2007; González-Alcaraz et al. 2012; Negrin et al. 2012). Sediment N mineralization, nitrification, and denitrification are critical processes of the N cycle (Bai et al. 2010, 2012a; Gao et al. 2012). Nitrification is an important source of NO₃⁻ for denitrification, while denitrification was the main mechanism associated with removal of nitrate in wetlands (DeLaune et al. 2005; Bai et al. 2010; González-Alcaraz et al. 2011). There was a higher contribution of *Spartina maritima* marshes and cypress swamps to N removal through denitrification, highlighting the role of the wetlands in this ecosystem service (Lindau et al. 2008; Sousa et al.

2012). Sediments play an important role in P retention by sorption and precipitation reactions (Pant and Reddy 2001; Lai and Lam 2008). Under oxic and anoxic conditions, Ca compounds were the main inorganic soil components contributing to P retention in the salt marsh, except in sites with low CaCO₃ concentration, where Fe and Al oxides contribute more to P retention (Álvarez-Rogel et al. 2007). Retention of suspended particles in sediment colonized by marsh vegetation also acts as a trap for nutrients and contaminants (Cartaxana and Catarino 1997; Palomo et al. 2004; Quan et al. 2007; Sousa et al. 2010). Differences in nutrient accumulation levels occur among plant species as well as between sediments (Cartaxana and Catarino 1997; Palomo et al. 2004). Considering the role of plants in this process, salt marshes are crucial to N and P remediation. Nutrient cycling and accumulation processes partitioned by salt marsh halophytes have been found to reduce eutrophication and lower atmospheric CO₂ (Sousa et al. 2010).

There are several threats to existence and functioning of salt marshes, particularly direct and indirect anthropogenic impacts such as leveeing of rivers, beach reclamation, aquaculture and marine construction, and other activities (DeLaune et al. 2005; Bromberg-Gedan et al. 2009). Notably, these effects have resulted in the sharp decline of natural intertidal beach and increased pollutant loads to intertidal and coastal waters in the vicinity of Hangzhou Bay, adjacent to the East China Sea.

In recent years, increased delivery of N and P resulting in severe eutrophication of Hangzhou Bay has been documented in various government reports (MEPC 2010; OFBZ

2011), which indicate that the bay's environmental quality is below Grade IV Sea Water Quality Standard of China (0.50 and 0.045 mg/kg for inorganic N and orthophosphate, respectively). In addition, land reclamation is decreasing the size of Hangzhou Bay area. For example, 70 % of the total land area (1,154 km²) in Cixi County, located in south Hangzhou Bay, was reclaimed from salt marshes (Feng and Bao 2006). The decline in salt marshes minimizes the buffer zone between the continent and the ocean that acts as a biological filter, thereby accelerating the eutrophication process as the marsh nutrient retention capacity is reduced.

To date, limited studies have been conducted to evaluate the role of N and P cycling in the impacted salt marshes of Hangzhou Bay. Hence, the aims of this study were to evaluate the nutrient (N and P) pools and the seasonal changes in plants (*Phragmites australis* (Cav.) Trin. ex Steud., *Spartina alterniflora* Loisel., and *Scirpus mariqueter* Wang et Tang.) and sediments of the Hangzhou Bay salt marsh.

Material and methods

Study site

Hangzhou Bay is in the northern Zhejiang Province of China (Fig. 1). The bay is situated in the outer part of the Qiantang River Estuary, adjacent to the East China Sea, which is the world's largest tidal bore. Hangzhou Bay is characterized by a north subtropical maritime monsoon climate, with four distinct seasons, a mean annual temperature

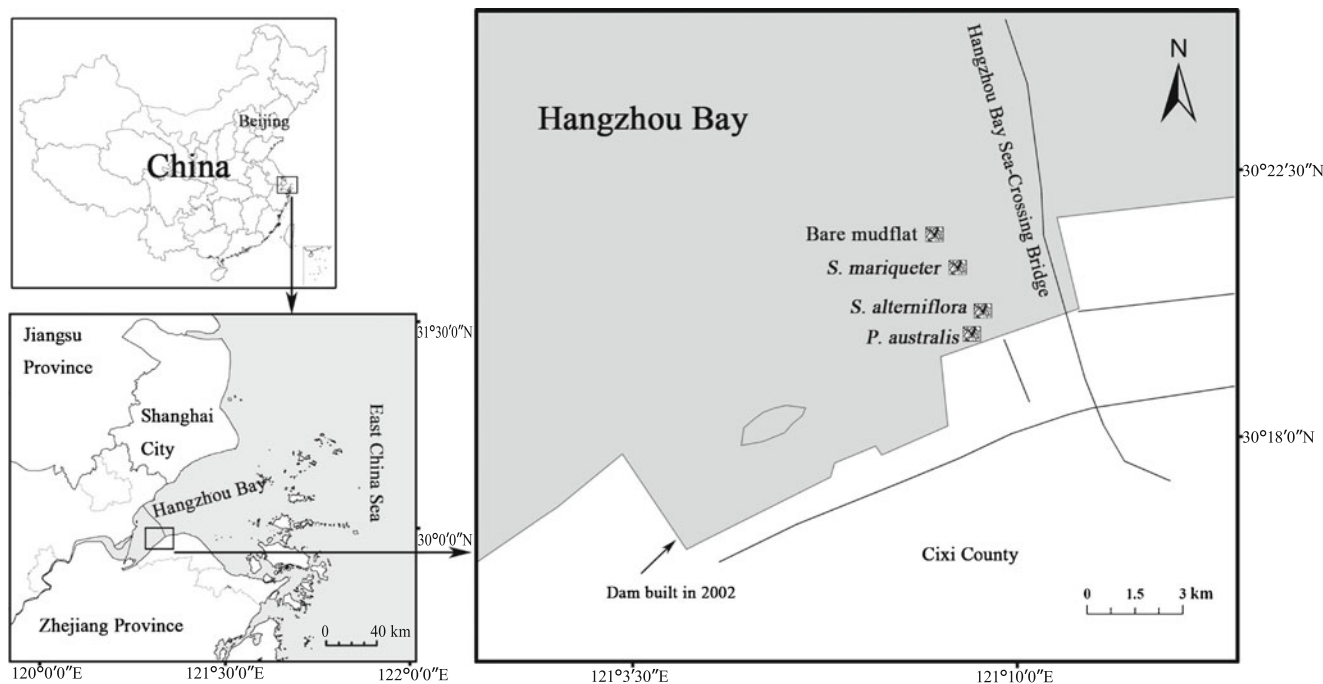


Fig. 1 Location of salt marsh study area in Hangzhou Bay, China

of 16 °C, annual rainfall of 1,273 mm, and water depth of 8–10 m. The study area is located in the south Hangzhou Bay. The area's strong tidal currents have a high carrying capacity for suspended sediments that were carried downstream from the Yangtze River and Qiantang River (Zhou and Gao 2004) and allow rapid accumulation of sediments that extend the shoreline at a velocity of 292 m/year (Yang et al. 2004). Semidiurnal tides regularly flood the low marsh and mudflat zones, while the high marsh is irregularly inundated, and spring high tides may also flood the entire salt marsh area.

The main characteristics of the sediment indicated by a previous investigation in the research area were shown in Table 1. The water in Hangzhou bay estuary is a mixture of seawater and fresh water and its salinity can range from 5 to 15 g/kg. There are only a few plant species in natural marsh. Native dominant plant species includes *P. australis* and *S. mariqueter*, each of which can form a dense monoculture in the marsh zone (Shao et al. 2011). Monocultures of *P. australis* are often found around the high marsh zone, while *S. mariqueter*, a pioneer plant that is endemic to China, dominates the low marsh zone. *S. alterniflora* often invades the midmarsh zone and then quickly expands toward the high and low marsh zones (Quan et al. 2007).

Sampling strategy

Three randomly selected 0.5×0.5 plots representative of *P. australis*, *S. alterniflora*, and *S. mariqueter* were located at the high, mid, and low marsh separated by at least 100 m. Plant biomass was collected bimonthly in March, May, July, September, and November 2009, and these months generally corresponded to the four seasons in our research area. During each sampling event, live aboveground plant was clipped at the ground level. Belowground samples (roots and rhizomes) were collected from the same plots using a 0.5×0.5×0.6-m box corer. Sediment cores were washed over a 2-mm mesh screen and retained roots and rhizomes were collected for analysis. Additionally, three sediment cores with two layers (0–5 cm as surface sediment and 5–20 cm as rooted sediment) were sampled using an Eijkelpkamp gouge auger (50 cm length by 6 cm diameter)

from each plant species. Sediment in bare mudflat that was located near the plots of *S. mariqueter* was taken as control.

Analytical procedures

Plant samples were rinsed thoroughly with tap water and then cleaned with deionized water. Samples were first dried at 105 °C for 30 min and then dried at 60 °C to constant weight for approximately 48 h. The above- and below-ground biomass of the three salt marsh plants were calculated on a dry weight basis (grams per square meter), respectively. Sediment was dried at room temperature. Each of the dry sediment and plant samples was homogenized by grinding to powder for analysis of total N (TN) and total P (TP) concentration. TN concentration of the sediment and plant was determined by the Kjeldahl method (Nelson and Sommers 1980). TP was measured using a molybdophosphoric blue colorimetric method after acid digestion (Murphy and Riley 1962).

Calculation of nutrient pools and production

Elemental concentration and above- and belowground biomass were multiplied to yield total amounts of above- and belowground nutrient pools for each plant species, respectively. Annual net primary production for aboveground was estimated by peak live aboveground biomass, and belowground was calculated based on the differences between the maximum and minimum belowground biomass recorded during the study period (De la Cruz and Hackney 1977). Annual net nutrient primary production (ANNPP) was estimated similarly.

Data analysis

Repeated ANOVA (analysis of variance) measurements were carried out in order to compare the evolution over time and among different sampling plots for the parameters analyzed in sediment and plant samples, separately, using SPSS 16.0. Dependent variables were above- and belowground biomass, plant and sediment nutrient concentrations, and plant nutrient pools. Data were log-transformed, when

Table 1 Main characteristics of the sediment in research area. The values are average±SD

	pH ^a	Salinity ^a (g/kg)	OC ^a (g/kg)	TN ^a (g/kg)	TP ^a (g/kg)	PSC ^b (g/kg)
Value	8.42±0.15	5.17±1.45	5.86±1.45	0.56±0.22	0.60±0.03	0.33±0.12
	Sand ^a (%)	Silt ^a (%)	Clay ^a (%)	Ca ^a (g/kg)	Fe ^a (g/kg)	Al ^a (g/kg)
Value	5.55±2.72	81.8±1.46	12.6±2.89	33.5±5.00	26.5±3.88	42.4±13.1

^a n=24

^b Phosphate sorption capacity (PSC) (n=4). Estimated by nonlinearly fitting the sorption data obtained from batch incubations into the Langmuir adsorption isotherm according to the method of Lai and Lam (2008)

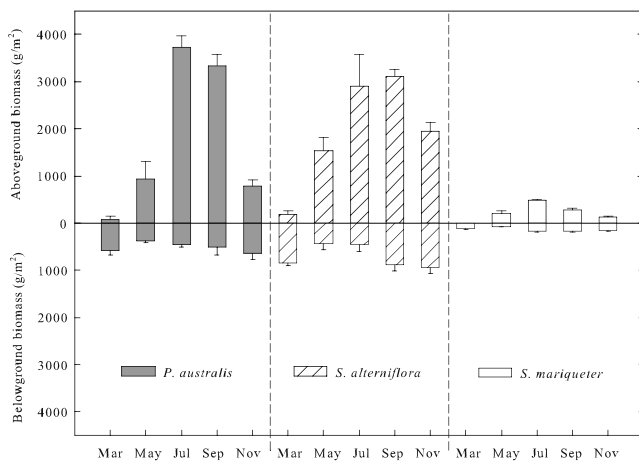


Fig. 2 Above- and belowground plant biomass (average±SD, n=3, g/m²) in salt marsh

necessary, to achieve homogeneity of variance (Levene's test). When data did not fulfill the sphericity requirement for Mauchly's sphericity test, univariate *F* statistics using a corrector index of epsilon were applied, based on Greenhouse–Geisser, Huynh–Feldt, or lower-bound corrections. Pearson's correlation analyses were performed among plant biomass, nutrient concentrations, and nutrient pools. Differences were considered significant if probabilities for nonsignificance were <0.05.

Results

Above- and belowground biomass

The ANOVA of repeated measures indicated that plant aboveground and belowground biomass differed significantly across seasons (Fig. 2, *p*<0.05). The aboveground biomass of all species showed similar seasonal patterns with a unimodal curve. *P. australis* and *S. maritima* reached the highest average aboveground biomass (3,731.7 and 487.4 g/m², respectively) in July, whereas *S. alterniflora* achieved its highest level (3,105.9 g/m²) in September. Overall, the belowground biomass was relatively high in the early stage of plant growth or in the fall during wilting and decreased during the rapid growth phase.

The aboveground biomass of the three species was relatively low compared to belowground biomass during the first sampling. Subsequently, the aboveground biomass was higher than belowground biomass (*p*<0.05), accounting for more than 60 % of total plant biomass between May and September. In November, the trend was the same for *P. australis* and *S. alterniflora*, while for *S. maritima*, the aboveground biomass was lower than belowground as it withered earlier than the other two species. The mean belowground/aboveground biomass ratios during the

growing season for *P. australis*, *S. alterniflora*, and *S. maritima* were 2.44, 1.38, and 0.62, respectively. However, the mean ratios were 0.38, 0.31, and 0.62, respectively, if we don't include the date of the early stage in March.

Plant biomass showed a significant difference between plants (*p*<0.05). The aboveground biomass of *P. australis* and *S. alterniflora* was significantly greater than those of *S. maritima* (Fig. 2, *p*<0.05), while there was no significant difference between the native plant (*P. australis*) and invasive plant (*S. alterniflora*). Belowground biomass displayed a trend of *S. alterniflora*>*P. australis*>*S. maritima* during the entire study period.

Nitrogen and phosphorus concentrations in plants

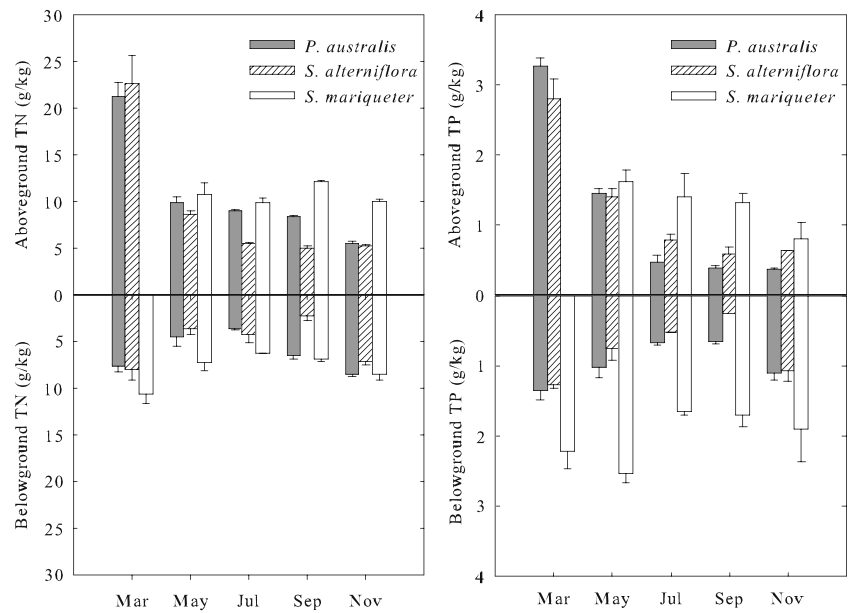
Seasonal patterns of TN and TP concentrations in plant of three species are shown in Fig. 3. TN and TP concentrations in aboveground part of *P. australis* and *S. alterniflora* were highest at the early period of growth and gradually decreased along the study period. The variation of *S. maritima* is similar for TP concentration, while the changes were not significant for TN concentration. The concentrations of TN and TP in the belowground part showed a decreasing and then an increasing tendency over the year. The concentrations in the belowground part of *P. australis* and *S. maritima* were lowest (3.64 and 6.20 g/kg for TN, 0.655 and 1.65 g/kg for TP, respectively) in July when the aboveground biomass was highest. The turning point for *S. alterniflora* was in September (2.26 and 0.25 g/kg for TN and TP, respectively) when its aboveground biomass reached the highest value (Fig. 2).

The TN concentration of the three plant species was much greater in the aboveground than the belowground part (Fig. 3), and the TP concentration had varying trends between above- and belowground parts across seasons (Fig. 3). The ANOVA of repeated measures indicates significant differences of plant TN and TP concentrations among the species (*p*<0.05). Both TN and TP concentrations were significantly greater in *S. maritima* than in *P. australis* and *S. alterniflora* (Fig. 3, *p*<0.05), except in March when *S. maritima* had no burgeoned aboveground growth.

Nitrogen and phosphorus concentrations in sediment

The TN and TP concentrations and seasonal dynamics in vegetated and unvegetated sediments are shown in Fig. 4. Study results indicate that sediment TN and TP concentrations varied significantly across seasons (*p*<0.05) but did not differ significantly between depths. The sediment TN concentration had significant variation among plant species and bare mudflat (*p*<0.05). TN concentration was significantly greater in the plots of *P. australis*, *S. alterniflora*, and *S. maritima* than in the plots of bare mudflats (Fig. 4, *p*<

Fig. 3 Above- and belowground plant TN and TP concentrations (average±SD, n=3, g/kg) in salt marsh



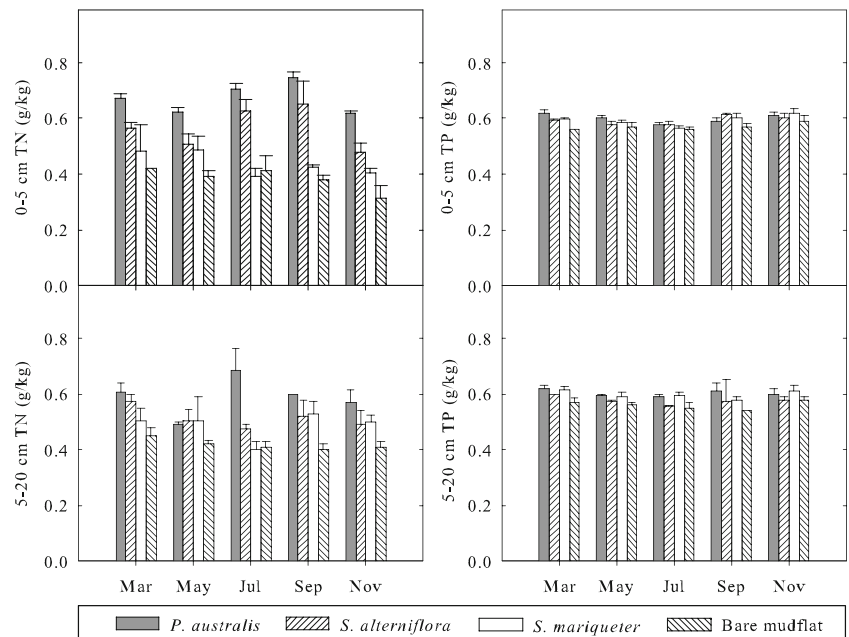
0.05). The sediment TN variation among plots of plant species was in conformity to the variation of plant aboveground biomass ($r=0.59, p<0.01$) than aboveground concentration ($r=-0.00, p>0.05$). Sediment TP concentration also showed variation among plant species. While these differences were not constant over time, there were several repetitive trends with TP concentration in sediment of *P. australis*>*S. maritima*>*S. alterniflora*>bare mudflats.

The coefficients of variation of TN and TP in 0–5 cm sediment between different plant species and bare mudflat were 18.2–29.1 and 1.9–3.9 %, respectively. The coefficients of variation of TN and TP in 5–20 cm sediment were 12.9–25.7 and 2.9–6.8 %, respectively. Overall, the change of TP in wetland sediment was not as apparent as that for TN.

Allocation of nitrogen and phosphorus in salt marsh

Pool allocation of TN and TP in plant above- and belowground parts is shown in Fig. 5. Generally, the TN pools are higher than TP pools in salt marsh. Both TN and TP pools showed significant ($p<0.05$) and similar seasonal variation patterns throughout the growing season in plants. Both nutrient pools of the aboveground part were lowest in March and highest in July at the peak of the growing season. For the pools belowground, the highest values were often in March or November. The seasonal variation patterns of total TN and TP pools (above- and belowground) of these plants were similar to that of the aboveground part.

Fig. 4 TN and TP concentrations in 0–5 and 5–20 cm sediment (average±SD, n=3, g/kg) in the study area



For different parts of the two native species, the aboveground part contained significantly more TN and TP than belowground during the growing season, except in March when the plants began to sprout or November when wilting. This trend was similar for the invasive plant *S. alterniflora*, except in November which pools in the aboveground part were still higher than belowground.

Discussion

Capacity of nutrient retention in different plants

Biomass is an important parameter in evaluating ecosystem structure and function. Capacity of nutrient retention in salt marshes is directly related to plant biomass production and nutrient levels in the ambient environment. Compared with other results (Quan et al. 2007; Li et al. 2009), this study found that the peak aboveground biomass of *P. australis* and *S. alterniflora* was significantly greater in the Hangzhou Bay wetland than in the Yangtze River estuary (3,731 vs. 1,246 g/m² for *P. australis* and 3,105 vs. 2,759 g/m² for *S. alterniflora*), while the trend was opposite for *S. mariqueter* (487 vs. 548 g/m²), even though both sites have similar climates. There was also a marked difference in the aboveground biomass between invasive plant *S. alterniflora* and native *P. australis* (*S. alterniflora* > *P. australis* in the Yangtze River estuary but no significant difference in this study site). The aboveground biomass of *S. alterniflora* was also higher than that in North American coastal wetlands, which was from 176 g/(m² year) in New Jersey to 938 g/(m² year) in Texas (Kirwan, et al. 2009). Therefore, aboveground primary production varies widely in salt marsh plants from various sites and may also result in a different nutrient retention capacity. Such findings may be related to different latitudes, varying growth years of plants as well as various salinity and nutrient levels in the ambient water in different estuaries (Brix, et al. 2001; Kirwan, et al. 2009).

S. alterniflora reached the highest aboveground biomass slightly later than *P. australis* and *S. mariqueter*. This is likely due to different phenology among these species, as *P. australis* and *S. mariqueter* burgeon only in spring, whereas *S. alterniflora* has a slow continuous growth in autumn and winter (Li et al. 2009). Plant aboveground biomass increased, while nutrient concentrations decreased during the growing season. Similar results also have been reported for other marsh species (Boyer et al. 2001; Neves et al. 2007). Nutrient pools were greatest when biomass was high but nutrient concentration was low in each plant. This study also found that for the aboveground part, although the nutrient concentration in *S. mariqueter* was higher than both *P. australis* and *S. alterniflora*, nutrient pools were lower for *S. mariqueter* than both *P. australis* and *S. alterniflora*. As

such, the nutrient pools of the aboveground part were mainly influenced by the biomass rather than the nutrient concentration itself for the salt marsh plants in this study area ($r=0.94$ and 0.85 for N and P, respectively, $p<0.01$).

Seasonal changes of TN and TP concentrations in the aboveground part adequately explain the pattern of nutrient transfer in salt marsh plants. Aboveground growth began in March with a high nutrient concentration in the newly burgeoned photosynthetic leaves and reached the highest aboveground biomass at the expense of rhizome resources. Subsequently, the plants started to senesce and a large portion of the aboveground nutrients were slowly translocated to the belowground part in winter (White and Howes 1994; Quan et al. 2007) and reserved for the next year's growth. Further evaluation of the *S. alterniflora* marsh indicated that recycling of N through translocation from aboveground to belowground parts and remineralization of dead belowground part are the major pathways in the sediment N cycle, equivalent to 67–79 % of the annual plant N demand (White and Howes 1994). In addition, belowground biomass and nutrient reserves of the marsh plants maintain a certain level throughout the year, while most of the aboveground biomass is broken down or brought off the coast by tide with a small amount of residue in the sediment (Howarth 1993). Consequently, the belowground part plays an important role in ecosystem nutrient cycling and energy conversion (Schalles and Shure 1989). This is particularly true for plants such as *P. australis* and *S. alterniflora*, which have significantly higher belowground biomass than that of *S. mariqueter*. However, the belowground/aboveground biomass ratios were lower in *P. australis* and *S. alterniflora* than *S. mariqueter*. This might be related to different flooding conditions and that the more unfavorable conditions in lower marsh of *S. mariqueter* caused greater investment in belowground biomass. Also, the belowground/aboveground biomass ratios were lower than that in European (Brix et al. 2001) and South American (Negrin et al. 2012). This might lie with the different physical characteristics among different research areas. The lower growth years of plants in our research area caused by intensive and rapid reclamation would be another reason that leads to relatively undeveloped roots system.

From this study, the salt marsh plant assimilated the greatest amount of nutrients during the growing season and lower amounts in the winter. All three species reached the highest nutrient pools in summer (July). Given that nutrients could be re-released through the decomposition of senescent plant materials at the end of the growing season with little residues remaining in the sediment (Howarth 1993), this would be an opportune time to remove excess nutrients from the salt marsh in summer through best management practices such as harvesting or grazing (Kang et al. 2002). Harvesting could also be a potentially useful and

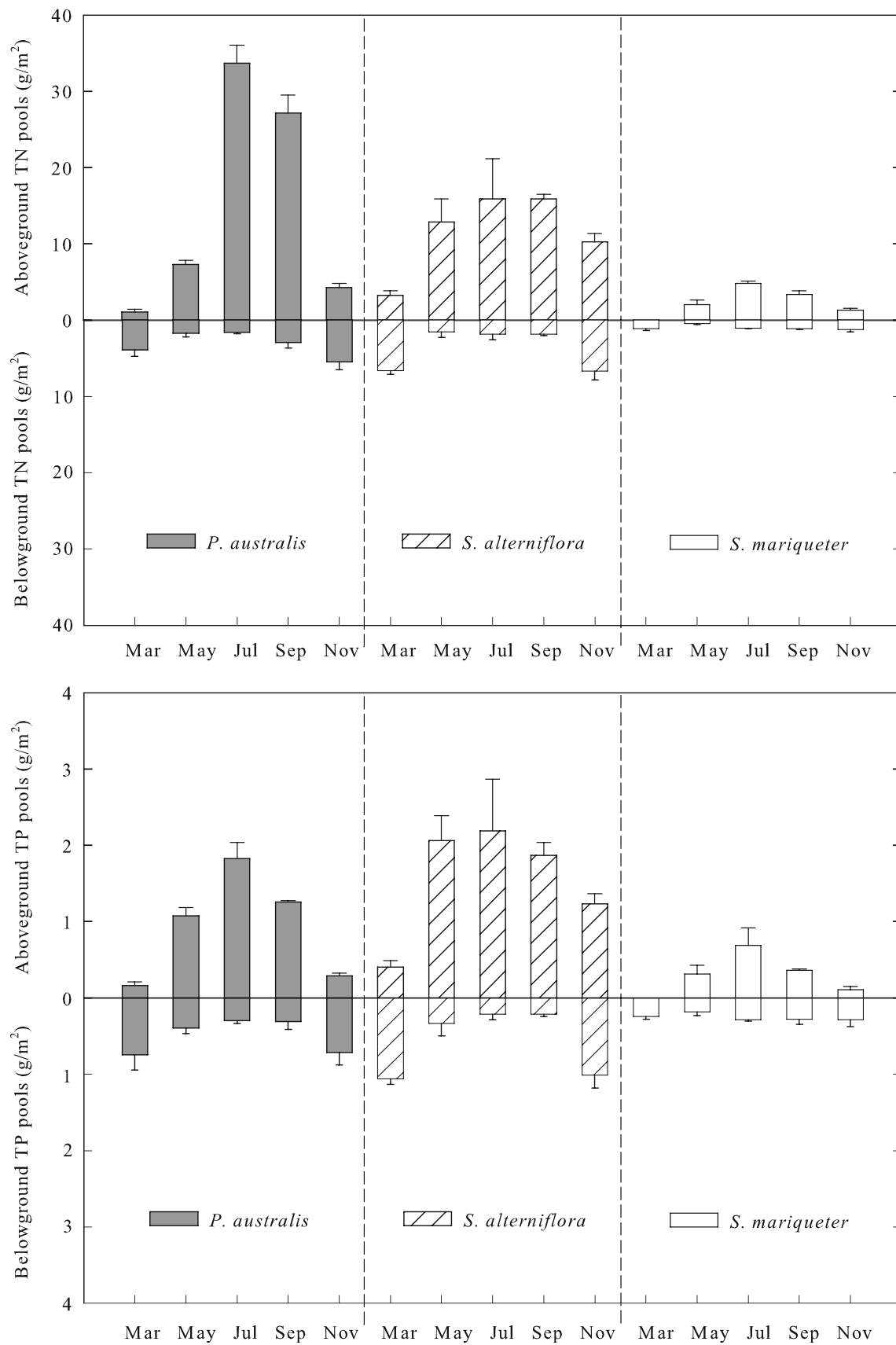


Fig. 5 Seasonal allocation of plant TN and TP pools (average \pm SD, $n=3$, g/m²) in salt marsh

effective approach for the control and management of the exotic and invasive plant *S. alterniflora*.

The influence of plants on sediment nutrient retention

Distribution and accumulation of N and P in sediment are related to allochthonous and autochthonous sources, sediment characteristics (composition, grain size, hydrology, Eh, and pH), and nutrient properties (Pant and Reddy 2001; Álvarez-Rogel et al. 2007; Song et al. 2007; Zhou et al. 2007; Bai et al. 2012b). Changes in species composition also may alter ecosystem structure (e.g., vertical root profile) and processes (e.g., nutrient cycling and carbon allocation) (Liao et al. 2008; Ehrenfeld 2010), suggesting that sediment nutrient concentration may consequently be changed with different plant species.

In this study, the variation of sediment TN concentration among plant species was more consistent for plant above-ground biomass, as plants remove N from water and enhance TN storage in sediment by increasing the organic fraction. Phosphorous concentration is affected less by plant species because it is dominated by sediment adsorption rather than biological processes (Picard et al. 2005). The variation of sediment TP concentration is more related to P fractionation and is affected by sediment characteristics such as grain size composition. Preliminary studies (Liang et al. 2012) in this area have shown that calcium carbonate-bound P was the main form of P, which was relatively evenly distributed in the sediment of different grain sizes. Therefore, the spatial variation of TP in sediment is not as apparent as TN.

Sediment reflects historic accumulation of nutrient input and storage. The variation among plant species may be due to heterogeneity of sediments or external sources. Sedimentation rate in vegetated sediment should also be considered. Vegetated salt marshes often show rapid sediment accretion and growth of marshlands because of slow flow rate caused by especially short, stiff species and by directly trapping sediment on leaves and stems and within joints (Stumpf 1983; Leonard et al. 1995; Li and Yang 2009). For example, a 27-cm net accretion in 100 years for

an unstable Barataria Bay *S. alterniflora* marsh of Louisiana and a 45-cm net accretion in 100 years for a stable *S. alterniflora* marsh in Four League Bay have been estimated (Mitsch and Gosselink 2000). In Dongtai (China), *S. alterniflora* has accelerated natural land formation with vertical accretion rates of 48.5–52.1 cm compared to 10.5–16.9 cm in bare mudflat in 3.4 years (Chung et al. 2004). The contribution of vegetation-trapped sediment to the local total deposition rate was likely responsible for >10 % of the total depositional rate in the *S. alterniflora* marsh and <10 % of the total depositional rate in the *S. mariqueter* marsh (Li and Yang 2009). The retained P by increasing sedimentation of plant materials contributed up to 25 % of the total monthly P retention (Schulz et al. 2003). Although the sedimentation rate in this study was not investigated, it is speculated from the above reports that vegetated marshes have higher nutrient retention than bare mudflats.

Implication for reducing eutrophication in Hangzhou Bay

The N and P used by the plants ultimately come from the surface water. Therefore, N and P uptake from sediment interstitial waters and their incorporation in plant biomass imply nutrient sequestration and retention, thereby decreasing nutrient availability in the water column and potentially reducing eutrophication (Sousa et al. 2010). This study has a preliminary assessment of the contribution of yearly nutrient retention created by salt marsh growth in the system to reduce eutrophication by dividing the annual net TN and TP primary productions (ANNPP) by reduced nutrient concentration. The results (Table 2) indicate that the water purification coefficients (WPC) of dissolved inorganic N (DIN) and orthophosphate (DP) from water by plant were 34.4/17.3, 19.3/24.0, and 5.14/6.04 t/(m² year) for *P. australis*, *S. alterniflora*, and *S. mariqueter*, respectively. Although the TN pools are higher than TP pools in the salt marsh, the WPC of DIN is lower than DP in most cases. As P is a limiting factor for phytoplankton growth, these results further illustrate the importance of protecting salt marshes.

Table 2 Water purification coefficient (WPC) of three salt marsh plants

	ANNPP (g/(m ² year))		C _{in} (mg/kg)		C _{out} (mg/kg)		WPC (t/(m ² year))	
	N	P	N	P	N	P	N	P
<i>P. australis</i>	37.5	2.25					34.4	17.3
<i>S. alterniflora</i>	21.0	3.12	1.49	0.16	0.40	0.03	19.3	24.0
<i>S. mariqueter</i>	5.60	0.785					5.14	6.04

ANNPP annual net nutrient primary productions, C_{in} dissolved inorganic nitrogen and orthophosphate (taken as influent concentration) in seawater monitored in 2011, C_{out} an allowable concentration in this area according to the National Sea Water Quality Standard of China for Class III waters standard (taken as effluent concentration), WPC water purification coefficient=ANNPP/(C_{input}–C_{output})

Overall, salt marsh plants display high sequestration for N and P, thereby helping reduce eutrophication in the estuarine ecosystem. It should be pointed out that for TN, except plant uptake and immobilization in plant biomass, another major mechanism for reducing mineral N loading is denitrification (DeLaune et al. 2005; González-Alcaraz et al. 2011). González-Alcaraz et al. (2011) have compared denitrification considering the presence or absence of plant rhizosphere. Results indicated that in fine-textured basic wastes, the process is intense regardless of the existence of plant rhizosphere, while the role of vegetation is more relevant in sandier acidic wastes. However, according to the research done by Sousa et al. (2012), it seems that it cannot be concluded whether or not annual denitrification was significantly different between the vegetated sediment and the bare mudflats. N and P in water can also be absorbed by sediment. The maximal phosphate sorption capacity (PSC) is a useful measure of the P removal capacity of sediment–water system (Lai and Lam 2008). The PSC determined in our study area (shown in Table 1) reveals that the sediment can theoretically bind more P and could be about 1.5-fold higher than is currently reflected in sediment. Yet, considering the denitrification of nitrate and sorption of orthophosphate in sediment, the actual purification of water N and P by the whole system is expected to be even greater.

Conclusions

Our research showed significant distribution patterns and seasonal variations of N and P concentrations and pools in different parts of marsh plants. This can provide detailed information about changes in salt marsh retention capacity and contribute to explain seasonal variations in nutrient retention. It can also help to determine the optimal biomass harvesting time of salt marsh plants for maximum nutrient removal.

There was a significant relationship between plant net primary productivity and wetland nutrient retention, so the protection of localized wetlands would create more favorable environmental conditions for increasing plant biomass and help improve deteriorated water quality. However, in order to assess the nutrient retention capacity in the whole system, we should take into account of the nutrient quantities coming in and out of the salt marsh in water, the denitrification process of N cycling, and the maximal PSC in sediment.

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