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RESEARCH ARTICLE

# Effects of *Spartina alterniflora* invasion on biogenic elements in a subtropical coastal mangrove wetland

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**Abstract** The invasion by exotic cordgrass (*Spartina alterniflora*) has become one of the most serious and challenging environmental and ecological problems in coastal China because it can have adverse effects on local native species, thereby changing ecosystem processes, functions, and services. In this study, 300 surface sediments were collected from 15 stations in the Jiulong River Estuary, southeast China, across four different seasons, in order to reveal the spatiotemporal variability of biogenic elements and their influencing factors in the subtropical coastal mangrove wetland. The biogenic elements including carbon, nitrogen, and sulfur (C, N, and S) were determined by an element analyzer, while the phosphorus (P) was determined by a flow injection analyzer. The concentrations of biogenic elements showed no significant differences among four seasons except total phosphorus (TP); however, our ANOVA analyses revealed a distinct spatial pattern which was closely related with the vegetation type and tidal level. Values of total carbon (TC) and total nitrogen (TN) in the surface sediment of mangrove vegetation zones were higher than those in the cordgrass and mudflat zones. The concentrations of TC, TN, TP, and total sulfur (TS) in the high tidal zones were higher than those in the middle and low tidal zones. Redundancy analysis (RDA) revealed that tidal level, vegetation type, and season had some significant influence on the distribution of biogenic elements in the Jiulong River Estuary, by explaining 18.2, 7.7, and 4.9 % of total variation in the four biogenic elements, respectively. In conclusion, *S. alterniflora* invasion had substantial effects on the distributions of biogenic elements in the subtropical coastal wetland. If regional changes in the Jiulong River Estuary are to persist and much of the mangrove vegetation was to be replaced by cordgrass, there would be significant decreases on the overall storage of C and N in this coastal zone. Therefore, the native mangrove reforestation and exotic cordgrass elimination should be a priority in mangrove sustainable management for coastal ecosystem health.

**Keywords** C · N · P · S · Mangrove · Cordgrass · Invasion · Jiulong River Estuary

## Introduction

Coastal wetlands act as transition zone buffering the interactions between the marine and the terrestrial ecosystems (Bianchi et al. 2013; Chmura et al. 2003) and may function as carbon, nitrogen, and phosphorus sinks reducing the organic matter runoff into the sea and serving as source of marine nutrients (Cai 2011; Feller et al. 2010; Valiela and Teal 1979). Coastal wetlands are fragile and sensitive to human activities, and the physical, chemical, and biological factors of coastal wetlands change strongly at spatial and temporal scales. In recent years, coastal wetlands have been undergoing rapid economic development and population increase; thus, they will potentially face growing problems with environment quality because large amount of pollutants input to the estuaries. This can have a profound negative impact over primary productivity, biodiversity, and ecosystem function of the local wetland ecosystems (Vitousek et al. 1997). The biogeochemical cycles of carbon, nitrogen, phosphorus, and sulfur in coastal wetlands have been an important focus for research into global change for several decades (Adams et al. 2012).

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However, information on the biogenic elements of biogeochemical cycling in subtropical estuarine mangrove wetlands is still very limited.

Mangroves are composed of species of halophytic intertidal trees and shrubs derived from tropical genera and have unique ecological functions and important social economy values (Saintilan et al. 2014). They have a complex food web, high species diversity, and net primary productivity (Lin 1999; Lovelock et al. 2009). The Jiulong River Estuary wetland in Fujian Province is a typical mangrove wetland reserve in southeast coastal areas of China. The dominant species in this wetland was *Kandelia obovata*. The best pure *K. obovata* mangrove forests were only distributed in Taiwan and Jiulong River Estuary in Fujian globally (Yang 2004). However, due to intense aquaculture and agricultural activities, rapid urban development, and biological invasion, many mangroves have suffered disturbance and degradation (Holguin et al. 2006; Hopkinson et al. 2012). Over the last decades, the *Spartina alterniflora* has invaded the coastal wetlands. *S. alterniflora*, as an invasive C4 perennial grass, was first intentionally introduced to the coastal wetland of China from its native range, the USA in 1979 (Liao et al. 2007). *S. alterniflora* invasion has not only threatened biodiversity of native ecosystems, but also altered ecosystem process, function, and service (Ehrenfeld 2003; Mack et al. 2000), thereby resulting in changes of carbon, nitrogen, phosphorus, and sulfur cycles in the invaded ecosystem (Jackson et al. 2002; Liao et al. 2008; Zhou et al. 2007). Many studies have shown the effects of plant invasion on carbon and nitrogen cycles (Bianchi et al. 2013; Hibbard et al. 2001; Jackson et al. 2002; Johnson and Wedin 1997; Li et al. 2009; Liao et al. 2007); however, the results of these studies suggest that the response of ecosystem to plant invasion is variable due to different invasion species and diverse native ecosystems. Therefore, quantitative analysis from independent studies across species and ecosystems is necessary for evaluation of ecosystem response to plant invasion (Liao et al. 2008). Mangrove–salt marsh ecotones offer an exceptional window onto the changes in biogenic elements in such dynamic transitional regions, including responses to *S. alterniflora* invasion.

Understanding of spatiotemporal variability of biogenic elements in the subtropical coastal mangrove wetland is crucial to explaining ecosystem processes and functions and modeling their responses to *S. alterniflora* invasion. Such an understanding will help us to better value the vulnerable ecosystems and to manage the mangrove wetland. Several studies have examined the biology and biogeochemistry in these mangrove wetlands (Alongi et al. 2005; Lin 1999; Yu et al. 2014), but little is known about the influence of vegetation, tide, and season on the distribution of biogenic elements. The aims of this study were to investigate the spatial and temporal variations of biogenic elements across four seasons, four vegetation types, and three tidal zones in the Jiulong River Estuary wetland and to reveal the effects of *S. alterniflor*a invasion on the biogenic element distributions in the subtropical wetland.

## Materials and methods

### Study area and sampling

This study was conducted in a subtropical coastal wetland that is located in the Jiulong River Estuary (117° 53′–117° 55′ E, 24° 25′–24° 29′ N) in Fujian, southeast China. *K. obovata* is the dominant mangrove species, and *S. alterniflora* has invaded the large area over the last few decades (Yu et al. 2014). The climate in this area is subtropical maritime monsoon, the mean annual rainfall is 1,200 mm, and the mean annual mean temperature is 21 °C. The Jiulong River Estuary has a strong semidiurnal tide with an average tidal level of 2 m.

Three hundred surface sediment samples were collected from 15 stations during spring (April 2010), summer (August 2010), autumn (November 2010), and winter (January 2011) (Fig. 1). Samples were collected from 15 stations, which comprised four different habitat types, i.e., unvegetated bare mudflat, native mangrove zone, full *S. alterniflora* invaded zone, ecotone area with exotic *S. alterniflora* and native mangrove growing mixed together in the same area; three blocks were considered under different tidal levels, i.e., high-, middle-, low-level zones. The vegetation and tide type of 15 stations are presented in Table 1. Five parallel samples were collected from the four corners and center of a 1-m × 1-m quadrat at each site. All samples were collected from the top 0–10-cm layer in sediment using polyvinyl chloride (PVC) pipe (7 cm in diameter) and were packed in airtight plastic bags and transferred to the laboratory in a car refrigerator for further processing and analysis.

## Chemical analysis

The sediment samples were freeze-dried at −80 °C, powdered with an agate mortar, and sieved through a standard sieve of 150 μm. The powered sediments of total carbon (TC), total nitrogen (TN), and total sulfur (TS) contents (as % dry weight of the sediment) were directly determined using Elemental Vario MAX CNS Analyzer (Germany), while the TP contents were measured by LACHAT QC 8500 Flow Injection Analyzer (USA) after digested with $HClO_4$–$H_2SO_4$ and diluted with ultrapure (Mill-Q) water. Salinity of sediment pore water was measured in situ by an ATAGO digital salt meter (Japan). The pore water pH was measured using a Starter 2C pH meter (China). The grain size (D50) was analyzed by a Malvern 2000 laser granulometer (UK).

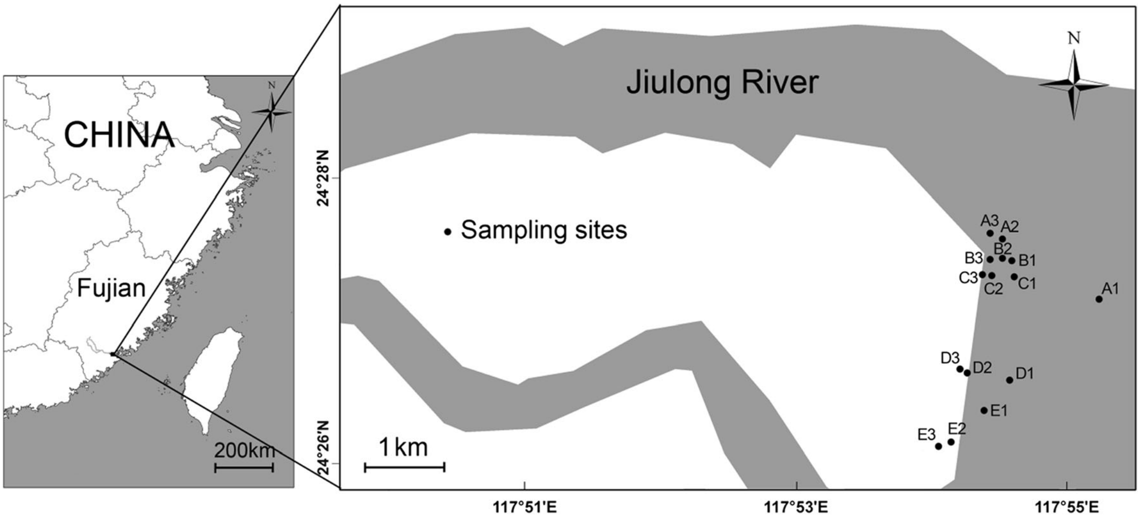


**Fig. 1** Location of 15 sampling stations in the subtropical coastal wetland from the Jiulong River Estuary

Due to the low inorganic carbon (<0.1 g kg$^{-1}$) analyzed by SHIMADZU Total Organic Carbon Analyzer SSM-5000A (Japan) in the study area, TC can be considered roughly equivalent to total organic carbon (TOC) (Cheng et al. 2006).

### Data analysis

We investigated the mean, standard error, and distribution of C, N, P, and S among 15 stations, 4 seasons, 4 vegetation types, and 3 tidal levels. One-way and three-way analyses of variance (ANOVA) were, respectively, performed on C, N, P, and S concentrations to test for differences among the different stations, seasons, vegetation types, and tidal levels after the data were Ln transformed to normal distribution. Where significant difference occurred, the Tamhane post hoc test was used to reveal the differences ($P<0.05$). These statistical tests were performed by the SPSS 19.0.

Preliminary detrended correspondence analysis (DCA) on the C, N, P, and S data revealed that the longest gradient length was shorter than 3.0; thus, a redundancy analysis (RDA) was applied for exploring the variations in the contents of C, N, P, and S by constraining ordination axes to linear combinations of environmental factors. To explore the relationships between spatiotemporal variability of biogenic elements and environmental factors, RDA was performed using the CANOCO 4.5 (ter Braak and Smilauer 2002).Vegetation profiles were transformed into binary code, scoring each position as 1 (presence) or 0 (absence), i.e., mudflat (0, 0), cordgrass (1, 0), mangrove (0, 1), and mangrove-cordgrass ecotone (1, 1). Tidal profiles were transformed into gradient code, i.e., low tide (1), middle tide (2), and high tide (3). RDA with forward selection was initially employed as an iterative process to explore correlation within the environmental dataset, prior to final selection of significant variables. The forward selection procedure was first applied to all environmental variables. Only factors statistically significant at $P<0.05$ confidence level were selected for the final analysis. The statistical significance of environmental factors was tested by using a Monte Carlo permutation test with 999 permutations. The final constrained model examined the response of TC, TN, TP, and TS contents to the 10 significant environmental variables defined by forward selection.

With three subsets of environmental data (season, vegetation, and tide), the total variation of TC, TN, TP, and TS contents was partitioned into seven components including covariance terms. The variation explained by these subsets was subtracted from the total variation (1.0 in case of RDA) to obtain the unexplained variation. The environmental variables are represented in the figures by arrows pointing in the

**Table 1** Characteristics of vegetation and tide in the sampling sites from coastal wetland of the Jiulong River Estuary

| Station | Tide | Vegetation | Station | Tide | Vegetation | Station | Tide | Vegetation |
|---|---|---|---|---|---|---|---|---|
| A1 | Low | Unvegetated mudflat | A2 | Middle | Unvegetated mudflat | A3 | High | Unvegetated mudflat |
| B1 | Low | Cordgrass | B2 | Middle | Cordgrass | B3 | High | Cordgrass |
| C1 | Low | Mangrove-cordgrass ecotone | C2 | Middle | Mangrove-cordgrass ecotone | C3 | High | Mangrove- cordgrass ecotone |
| D1 | Low | Cordgrass | D2 | Middle | Mangrove | D3 | High | Mangrove |
| E1 | Low | Mangrove | E2 | Middle | Cordgrass | E3 | High | Cordgrass |

direction of maximum change, and the arrow length is indicative of the importance of each environmental variable.

## Results

### General distributions of C, N, P, and S

The values of TC, TN, TP, and TS across the 15 stations (75 sites) from 4 seasons were significantly different ($P<0.001$) (Fig. 2). The TC ranged from 8.40 to 23.87 g kg$^{-1}$, with a mean±standard deviation (SD) of 14.84±3.42 g kg$^{-1}$; the lowest and highest values were recorded in stations A1 (summer) and E3 (winter). The TN ranged from 0.85 to 2.57 g kg$^{-1}$, with a mean±SD of 1.50±0.33 g kg$^{-1}$; the lowest and highest values were recorded in stations A2 (summer) and E3 (summer). The TP ranged from 0.25 to 0.84 g kg$^{-1}$, with a mean±SD of 0.46±0.09 g kg$^{-1}$; the lowest and highest values were found in stations E2 (summer) and E3 (winter), respectively. TS ranged from 0.22 to 6.77 g kg$^{-1}$, with a mean±SD of 2.40±1.07 g kg$^{-1}$; the lowest and highest values were found in stations E3 (summer) and B3 (spring), respectively.

### C, N, P, and S difference among four seasons, four vegetation types, and three tidal levels

The results of the three-way ANOVA indicated that vegetation, tide, and season had the most significant effects on TC, TN, TP, and TS contents. Further, there were significant effects on C, N, P, and S concentrations from interaction of vegetation, tide, and season with each other, except that tide that interacted with season had no significant effects on the distributions of TC and TN (Table 2).

Distributions of TC and TN concentrations varied significantly with vegetation and tidal level, and the Tamhane post hoc test revealed that mangrove>ecotone≈cordgrass>mudflat; high tidal level>middle tidal level>low tidal level (Fig. 3a, b). The TP differed significantly among vegetation types and tides: mangrove≈ecotone≈cordgrass>mudflat; high tide>middle tide>low tide (Fig. 3c). TS varied

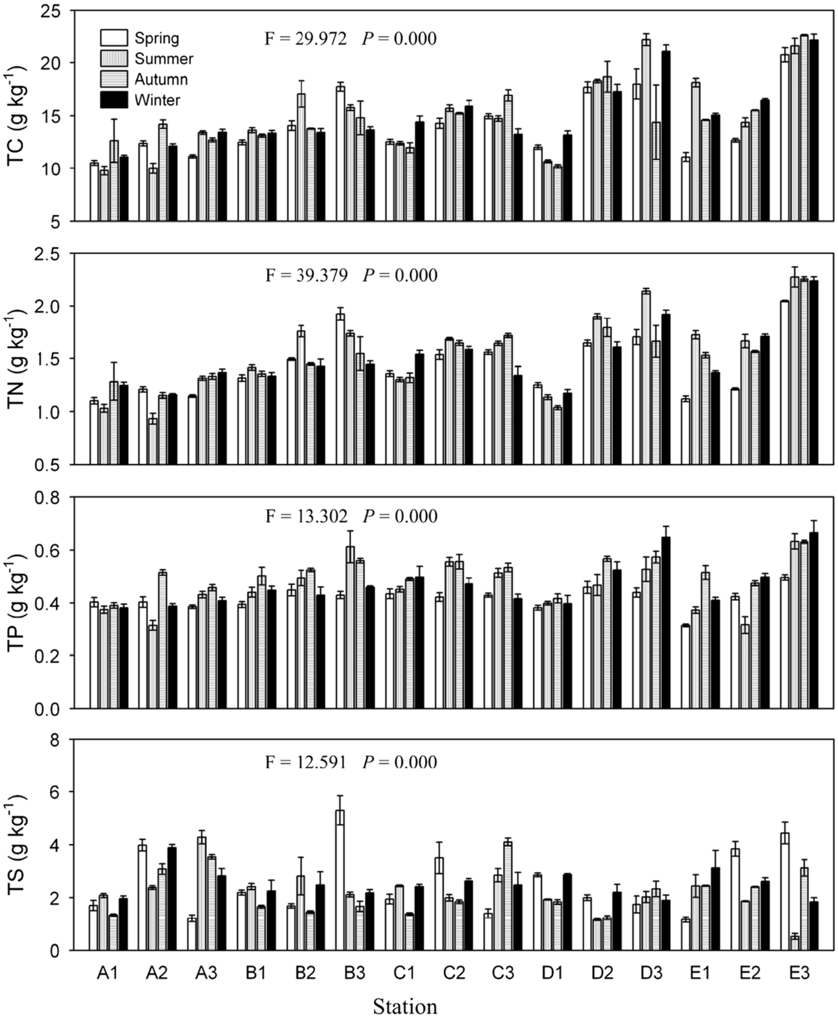


**Fig. 2** Concentrations of biogenic elements in the subtropical coastal wetland in the Jiulong River Estuary. *Error bars* indicate±standard error, $n=5$

**Table 2** Results of three-way ANOVA testing the effects of vegetation, tide, and season on the biogenic elements

| Element | Factor | *df* | MS | F | *P* |
|---|---|---|---|---|---|
| TC | Vegetation | 3 | 1.248 | 93.559 | 0.000 |
| | Tide | 2 | 1.339 | 100.369 | 0.000 |
| | Season | 3 | 0.073 | 5.465 | 0.001 |
| | Vegetation * Tide | 6 | 0.108 | 8.069 | 0.000 |
| | Vegetation * Season | 9 | 0.059 | 4.397 | 0.000 |
| | Tide * Season | 6 | 0.027 | 2.041 | 0.061 |
| | Vegetation * Tide * Season | 18 | 0.045 | 3.376 | 0.000 |
| | Error | 252 | 0.013 | | |
| | Total | 300 | | | |
| TN | Vegetation | 3 | 0.448 | 100.034 | 0.000 |
| | Tide | 2 | 0.484 | 108.164 | 0.000 |
| | Season | 3 | 0.029 | 6.573 | 0.000 |
| | Vegetation * Tide | 6 | 0.078 | 17.494 | 0.000 |
| | Vegetation * Season | 9 | 0.027 | 6.111 | 0.000 |
| | Tide * Season | 6 | 0.007 | 1.455 | 0.194 |
| | Vegetation * Tide * Season | 18 | 0.014 | 3.201 | 0.000 |
| | Error | 252 | 0.004 | | |
| | Total | 300 | | | |
| TP | Vegetation | 3 | 0.043 | 28.664 | 0.000 |
| | Tide | 2 | 0.067 | 44.634 | 0.000 |
| | Season | 3 | 0.052 | 34.565 | 0.000 |
| | Vegetation * Tide | 6 | 0.018 | 12.164 | 0.000 |
| | Vegetation * Season | 9 | 0.006 | 4.031 | 0.000 |
| | Tide * Season | 6 | 0.005 | 3.439 | 0.003 |
| | Vegetation * Tide * Season | 18 | 0.004 | 2.828 | 0.000 |
| | Error | 252 | 0.001 | | |
| | Total | 300 | | | |
| TS | Vegetation | 3 | 0.429 | 11.589 | 0.000 |
| | Tide | 2 | 0.260 | 7.026 | 0.001 |
| | Season | 3 | 0.126 | 3.406 | 0.018 |
| | Vegetation * Tide | 6 | 0.414 | 11.184 | 0.000 |
| | Vegetation * Season | 9 | 0.350 | 9.438 | 0.000 |
| | Tide * Season | 6 | 0.466 | 12.592 | 0.000 |
| | Vegetation * Tide * Season | 18 | 0.394 | 10.642 | 0.000 |
| | Error | 252 | 0.037 | | |
| | Total | 300 | | | |

significantly with vegetation and tidal level, peaking in the mudflat and the high tidal zones, respectively (Fig. 3d). No significant difference was detected between four seasons for any of the biogenic elements except TP, which showed the lowest values in spring and the highest values in autumn.

### Relationship between C, N, P, S, and environmental factors

The ten environmental variables identified by forward selection in RDA were all significant in explaining a portion of the variation in TC, TN, TP, and TS concentrations ($P<0.05$). Eigenvalues for axes 1 and 2 were 0.338 and 0.029, respectively (Fig. 4). The first axis was significantly positively correlated with tide, mangrove, and cordgrass ($P<0.01$) and showed a negative significant correlation with pH, D50, spring, and salinity ($P<0.01$). The second axis was significantly positively correlated with tide and pH ($P<0.01$) and showed a negative significant correlation with autumn ($P<0.05$).

Tide was the primary factor that affected the distributions of TC, TN, TP, and TS. The unique variance explained by tidal level (18.2 %) was substantially higher than that explained by vegetation (7.7 %) or season (4.9 %) (Table 3).

## Discussion

### Spatiotemporal variability of biogenic elements

The distributions of TC, TN, TP, and TS in surface sediments from coastal areas are key issues in the circle of Land-Ocean Interactions in the Coastal Zone (LOICZ) program (Marchand et al. 2003; Yu et al. 2012). In Jiulong River Estuary, the concentrations of biogenic elements are intermediate on a global scale compared with previously reported data (Alongi et al. 2005; Yu et al. 2012). The TC and TN values in this study were similar to previous data from the Zhangjiangkou mangrove wetland in Fujian province of China, but they were slightly lower than mangrove coast in French Guiana (Marchand et al. 2003; Zhang et al. 2008). The TP in the study was similar to that reported for mangrove wetland in Zhangjiangkou, while the TS values were lower than Guiana mangrove coast (Marchand et al. 2003; Zhang et al. 2008). Although range of TOC, TN, and TS contents in French Guiana Mangrove were high, the young mangrove forest in Guiana was similar with that of Jiulong River Estuary wetland because TOC fluctuated from 1 to 2 %; total N values ranged from 0.1 to 0.2 % (Marchand et al. 2003).

There was no significant difference in the season for TC, TN, and TS concentrations, but TP showed higher values in autumn and lower values in spring. This distribution pattern of TP was probably due to different forms of phosphorus in the sediments (Zhou et al. 2007). Recently, Pan et al. (2010) found that organic P was the main part of TP in this area, which accounted for 50–60 % of TP. So, the concentration of TP was higher in autumn than that in spring, because the amount of litter contributing organic P was abundant in autumn.

### Vegetation and tidal control of organic matter

The spatial and temporal variations of organic matter were found to vary significantly across different sedimentation

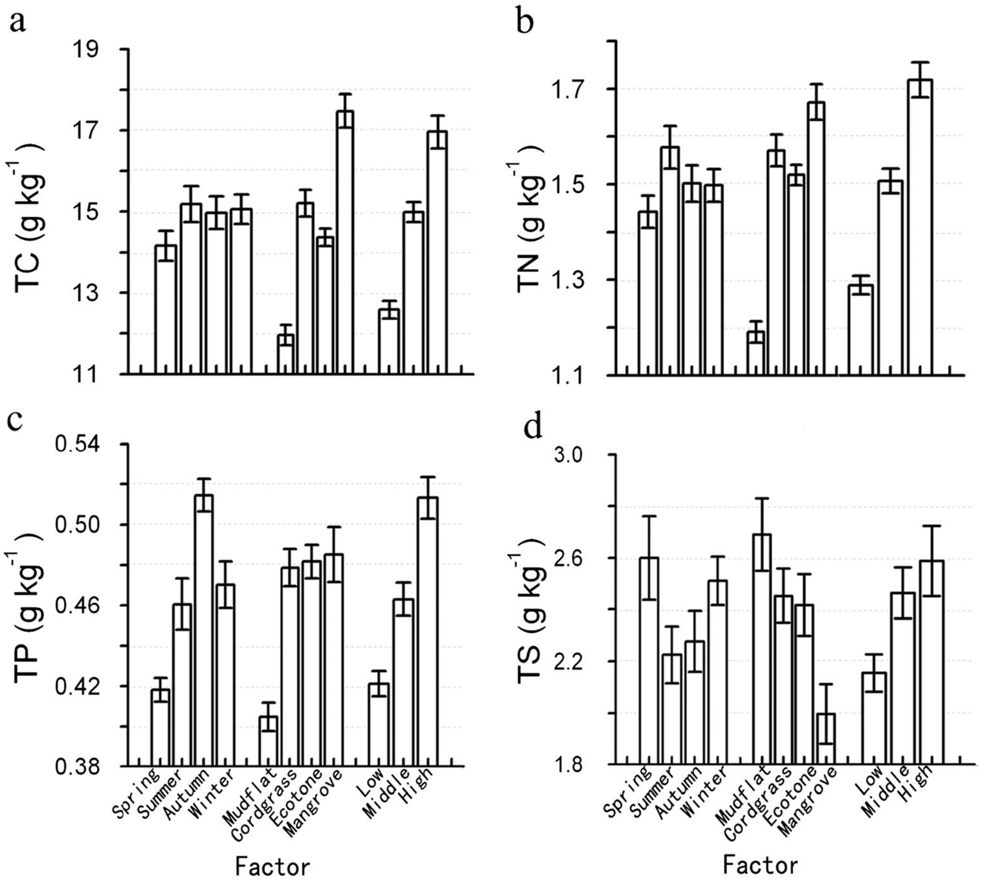


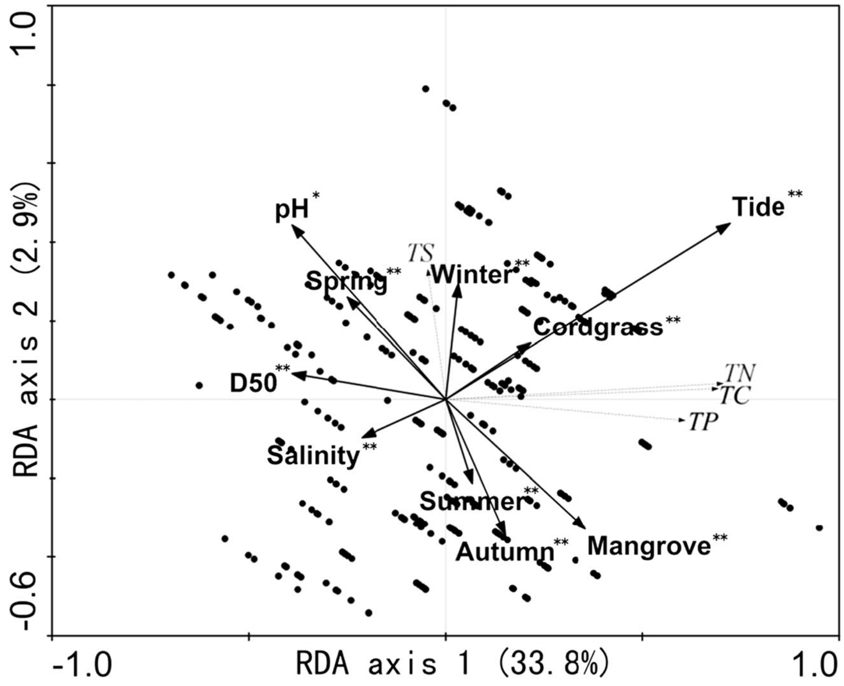
**Fig. 3** Concentrations of biogenic elements for the three study factors (season, vegetation, tide) in the 300 surface sediment samples. Values are means± standard error

environments, vegetation types, tidal levels, and industrial discharge (Wang et al. 2003; Zhou et al. 2007). However, this issue has received little integrative attention. Wang et al. (2003) found that mash vegetation contributed significant amounts of organic matter to the sediment. The organic matter in surface sediments of the Yangtze Estuary marsh was mainly controlled by the chemical composition of the suspended particulate matter (Zhou et al. 2007). In the present study, factors including tidal level, vegetation type, and season on the distribution of biogenic elements were all considered.

Interestingly, we found that values of TC and TN in the mangrove vegetation zones were higher than those in invasive plant zones and mudflat zones. These results were similar with previous reports in the Zhangjiangkou and the Jiulong River Estuary mangrove wetland in Fujian province of China (Pan et al. 2010; Zhang et al. 2008) and the Gulf of Mexico (Bianchi et al. 2013). However, the results were inconsistent with the Mornington Peninsula temperate mangrove and salt marsh systems in the southern hemisphere, because mangrove sediments from a cooler and drier temperate latitude may store less C than mangroves in warmer and wetter tropical latitudes (Livesley and Andrusiak 2012). Normally, mangroves have high productive, high decomposition rate, and short return time (Lin 1999). According to Clark et al. (2001) and Alongi (2009), the mean of net primary productivity (NPP) for mangrove ranged from 2 to 50 Mg C ha$^{-1}$ year$^{-1}$, rivaling some of the most productive old growth tropical forests (Reef et al. 2010). Mangroves can fix and store more carbon than marshes on regional and global scale, and the contents of organic matter in mangroves are higher than mudflat; thus, they are consistent with the recent reports on blue carbon sinks (Cai 2011; Hopkinson et al. 2012; Bianchi et al. 2013).

Our results clearly indicated that all biogenic elements increased significantly from the low tidal zones to the high tidal zones in the Jiulong River Estuary. In fact, the grain size distribution can influence the spatial characteristics of C, N, P, and S, which were significant negative correlation with D50. There are a number of reasons for this. First, the sediment particles tended to become finer from the low-tide level to the high-tide level, while the highest concentration of biogenic elements was closely associated with the finer fractions (Ashagrie et al. 2005; Zhou et al. 2007). Second, the middle- and high-tide regions have more vegetation and litter which are rich in organic matter. Third, TOC and N stocks in soils of a marine and a brackish marsh increased with decreasing inundation frequency (Spohn and Giani 2012). High tidal zones have shorter duration of tidal inundation, which affects salinity, oxidation state, and nutrient availability, thereby resulting in less loss of organic matter. Finally, coastal wetlands receive significant organic matter inputs as a direct result

**Fig. 4** Redundancy analysis (RDA) ordination showing the biogenic elements in relation to seasons, vegetation types, tidal level, and environmental properties (**$P<0.01$, *$P<0.05$)



of intense human activity, and the impact of land-based pollution in high tidal zone is stronger (Alongi et al. 2005; Pan et al. 2011).

### Applications for mangrove ecosystem management and conservation

Plant invasion is recognized as a serious threat to native ecosystems, which can alter their biogenic element cycles, biodiversity, and ecosystem services (Lövei 1997). However, the high variability among the experimental results could stem from the differences in life forms of invasive and native plants. Liao et al. (2007) showed that *Spartina* invasion resulted in changes of net primary production and litter decomposition and enhanced C and N stocks in the *Scirpus* and *Phragmites*-dominated ecosystems. Bianchi et al. (2013) found significantly higher carbon sequestration in mangrove compared to marsh sites on Mud Island. Song et al. (2014) suggested that conversion from cropland to woodland could lead to significantly greater soil organic carbon accumulation than would the conversion of cropland to grassland. However, other studies have indicated that C and N can be lost from native ecosystem invaded by exotic plants (Jackson et al. 2002; Johnson and Wedin 1997). Jackson et al. (2002) reported that the C stock decreased with the invasion of woody plant into grassland ecosystem, while Johnson and Wedin (1997) observed that the N stock loss from a dry tropical forest invaded by grass. Our study focused on the invasion of a C4 grass into woody plant community, e.g., mangrove wetland invaded by *S. alterniflora*, and attempted to evaluate the ecosystem response to plant invasion. Values of TC and TN in mangrove vegetation zone were higher than those in the *S. alterniflora* in the top 30-cm layer, indicating that the *S. alterniflora* invasion into mangrove wetland caused ecosystem organic matter loss (Yu et al. 2012). If regional changes in the Jiulong River Estuary are to persist and much of the mangrove vegetation was to be replaced by cordgrass, there would be significant decreases in the overall storage of C and N in the coastal zone.

On the other hand, plant cover has notably effect on the local sediment heterogeneity. However, Prusty et al. (2009) showed that the distribution of some plant species across the different habitats could not result in significant differences of the major nutrients (i.e., C, N, P, and S). More importantly, our study found that TC, TN, TP, and TS concentrations in the mangrove-cordgrass ecotone zone were similar with cordgrass

**Table 3** The result of variation partitioning of biogenic elements ($n=4$) in sediments ($n=300$) explained by three sets of environmental variables, season (S), vegetation type (V), tidal level (T) in partial redundancy analysis (*p*RDA)

| Environmental variable | λ | P |
|---|---|---|
| S | 0.049 | 0.001 |
| V | 0.077 | 0.001 |
| T | 0.182 | 0.001 |
| S&V | 0 | |
| S&T | 0 | |
| V&T | 0 | |
| S&V&T | 0 | |
| Total explained | 0.308 | 0.001 |
| Unexplained | 0.692 | |

λ eigenvalue in RDA, the explanatory power of each component zone, due to *S. alterniflora* invasion reduced sediment biogenic elements heterogeneity in the mangrove wetland.

Significantly higher carbon sequestration in the mangrove zone was found compared to the cordgrass and mudflat zones, indicating that mangroves store more carbon than marshes. Higher carbon sequestration will stabilize the rates of organic carbon turnover in the coastal wetlands, may prove to have an ameliorating effect on regional atmospheric $CO_2$ increases (Bianchi et al. 2013). In summary, these studies have all let to the conclusion that *S. alterniflora* invasion into mangrove wetland can affect soil biochemical processes by means of decreased storage of C and N and reduced biogenic element heterogeneity. It appears that preserving and restoring mangrove are important and urgent, which will help to mitigate local climate change in the near future. Future work on changes in the sequestration of $CO_2$ on this regional scale is needed to further verify that mangrove conservation has an ameliorating effect on local atmospheric $CO_2$ increases.

## Conclusion

Our study describes and evaluates the spatiotemporal patterns of biogenic elements in surface sediments from Jiulong River Estuary mangrove wetland. The values of TC, TN, TP, and TS across the 15 stations from 4 seasons were significantly different. However, no significant difference was detected between four seasons for any of the elements except for TP. Values of TC and TN in mangrove vegetation zones were higher than those in mudflat and cordgrass. The concentrations of TC, TN, TP, and TS in the high tidal level regions were higher than those in the middle and low tidal levels.

Tidal level, vegetation type, and seasonality significantly affected the distribution of four biogenic elements in surface sediments of the Jiulong River Estuary, by explaining 18.2, 7.7, and 4.9 % of total variation, respectively. Further, the invasion of *S. alterniflora* in mangrove wetlands caused ecosystem C and N stocks loss and affected on the local sediment biogenic element heterogeneity. This suggests that it is essential to protect and restore mangrove wetland and to prevent and control the spread of *S. alterniflora*.

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