Physics and Chemistry of the Earth xxx (2017) 1–6

Contents lists available at ScienceDirect

Physics and Chemistry of the Earth

journal homepage: www.elsevier.com/locate/pce

Effects of soil abiotic factors on the plant morphology in an intertidal salt marsh, Yellow River Delta, China

Shanze Li [a], Baoshan Cui [a,*], Junhong Bai [a], Tian Xie [a], Jiaguo Yan [a], Qing Wang [a], Shuyan Zhang [b]

[a] School of Environment, Beijing Normal University, State Key Joint Laboratory of Environmental Simulation and Pollution Control, Beijing 100875, China
[b] Yellow River Delta Management Station, The Yellow River Delta National Nature Reserve Administration, Shandong 257500, China

ARTICLE INFO

Article history:
Received 5 December 2016
Received in revised form
5 February 2017
Accepted 1 April 2017
Available online xxx

Keywords:
Biogeography
Estuary
Sediment
Suaeda salsa
Plant trait

ABSTRACT

Plant morphology plays important role in studying biogeography in many ecosystems. *Suadea salsa*, as a native plant community of northern China and an important habitat for diversity of waterbirds and macrobenthos, has often been overlooked. Nowadays, *S. salsa* community is facing great loss due to coastal reclamation activities and natural disturbances. To maintain and restore *S. salsa* community, it's important to address the plant morphology across marsh zones, as well as its relationships with local soil abiotic conditions. In our studied intertidal salt marsh, we found that less flood disturbance frequency, softer soil conditions, rich soil organic matter, total carbon and total nitrogen, lower water depth and water content, less species competition will benefit *S. salsa* plant in the morphology of high coverage, above-ground biomass, shoot height and leaf length. Lower soil porewater salinity will benefit the below-ground biomass of *S. salsa*. Thus, we recommend managers help alleviate soil abiotic stresses in the intertidal salt marshes, making the soil conditions more suitable for *S. salsa* growth and succession.

1. Introduction

Plant morphology plays important role in studying biogeography in many ecosystems and have been well studied in forestry (Ambrose et al., 2015) and agricultural (Berding and Hurney, 2005; Fielder et al., 2015) ecosystems. However, plant morphology in coastal salt marshes usually have gained few attentions, except nonnative plant species (Atwood and Meyerson, 2011; Liu et al., 2016). In coastal region, especially in estuarine area where the river merge into the open sea, the salinity lie on an increased gradient from landward to seaward and the sea surface temperature varied seasonally (He et al., 2009; Wang and Castelao, 2016). Maintaining and restoring the regional specific native species is facing great challenges from both anthropogenic and natural stresses like coastal reclamations (He et al., 2014; Li et al., 2016a) and herbivore (He and Silliman, 2016; Pennings et al., 2001). Invasive species is another difficult issue which has great threats on native species. *Spartina alterniflora* has been regarded as an important invasive species in almost the entire coast of China (Liu et al., 2016), which reduced the coverage of native species and brought great challenges in restoring native plants. Climatic changes and geographic variation in abiotic drivers would cause different responses of plant morphology (Abdala-Roberts et al., 2016; Ambrose et al., 2015). A major obstacle to successful maintain and restore native species is studying and matching the plant morphology to the regional conditions.

Coastal salt marshes is usually composed of relatively few plant species, making it possible to study one plant community thoroughly even within region or across different latitudes (Chapman, 1974; Pennings et al., 2001). Perennial species, *Spartina alterniflora*, as a native plant species in the southeastern of the United States have been distinguished regionally by its morphology as "tall Spartina" (>100 cm height), "medium Spartina" (50–99 cm height), and "short Spartina" (<50 cm height) (Li and Pennings, 2016; Schalles et al., 2013). Additionally, *Spartina alterniflora*, as an invasive plant species in China, its growth and relationships with abiotic factors have been studied across large scale of latitudes (Liu et al., 2016). In contrast, annual species, *Suaeda salsa*, as a specific native plant species of northern China have often been overlooked. *S. salsa*, as the only marsh dominant vascular plant species, covers most coastal salt marsh ecosystems in the Yellow River Delta,

* Corresponding author. School of Environment, Beijing Normal University, State Key Joint Laboratory of Environmental Simulation and Pollution Control, No. 19 Xinjiekouwai Street, Beijing 100875, China.
E-mail address: cuibs@bnu.edu.cn (B. Cui).

http://dx.doi.org/10.1016/j.pce.2017.04.004
1474-7065/

Shandong province, China (He et al., 2009), thus, *S. salsa* provides important primary production in the ecosystems. In addition, *S. salsa* community is an important habitat for waterbirds (Li et al., 2011) and diversity of macrobenthos like Mollusca and Crustacea (Li et al., 2014, 2016a). However, *S. salsa* community is facing great shrink due to coastal reclamation activities, invasive species threats and herbivores (Cui et al., 2011, 2016; He et al., 2015).

To maintain and restore *S. salsa* community, it's important to address the plant morphology across gradient of elevations, as well as its relationships with regional abiotic factors in marsh zones (Abdala-Roberts et al., 2016; Tessier et al., 2000). Hence, in this study we tested the hypotheses that (1) the plant morphology would vary across marsh zones; (2) the abiotic factors would also vary across marsh zones; and (3) the plant morphology was varied with abiotic drivers.

2. Materials and methods

2.1. Study area

Our study area was located in the Yellow River Delta Natural Nature Reserve (119°09′ E; 37°46′ N) (Fig. 1), Dongying, Shandong Province. The Yellow River Delta has a warm-temperate climate and irregularly semidiurnal tides (Li et al., 2016a), and the Yellow River Delta is an important stopover for migratory waterbirds (Li et al., 2016b). Salt marsh is the main type of habitat which covers most of the Yellow River Delta. Salt marshes are mainly dominated by *Suaeda salsa* and *Salicornia europaea*, as well as forbs (Li et al., 2016a). Across the studied intertidal salt marsh, the high marsh zone is mainly covered by *S. salsa*, as well as covered by several interspersed patches of *S. salsa* and *S. europaea*. The middle and low marsh zones contain large bare areas interspersed with patches of *S. salsa* (Li et al., 2016a).

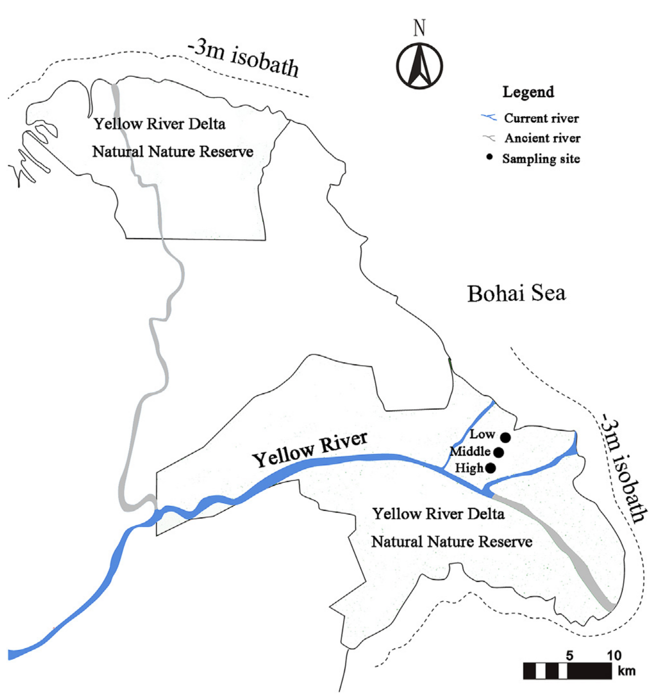

Fig. 1. Study area and sampling sites in the Yellow River Delta, China. We located three study sites in high, middle and low marsh zones of an intertidal salt marsh.

2.2. Sample collection and analysis

To give a comprehensive comparison for plant morphology across different zones of intertidal salt marsh, we located three study sites in high, middle and low marsh zones in the fall of 2012, respectively. In high marsh zone, we randomly set up 5 sampling plots in *S. salsa* community and 5 plots in interspersed patches of *S. salsa* and *S. europaea*. In middle and low marsh zones, we randomly set up 5 sampling plots in *S. salsa* community, respectively. At each sampling plot (1 m × 1 m) we recorded all the plant species (*S. salsa* and *S. europaea*) and their percent coverage (estimated by the same recorder), at the same time, collected above- and below-ground biomass in 3 replicate quadrats (1 m × 1 m for coverage estimating, and 0.5 m × 0.5 m in the center of the 1 m × 1 m quadrat for aboveground and belowground biomass collecting. The belowground biomass was collected at the depth of 20 cm) Soil was removed from cores (0.5 m × 0.5 m × 0.2 m, L × W × D) to collect live belowground biomass. Above- and below-ground biomass air-dried for 28 days (average 26.6 °C) and weighed. In each plot, we randomly selected 3 individuals of *S. salsa*, measured shoot height, stem-base diameter, leaf length, leaf width and leaf thickness as plant morphological characteristics.

We measured eight soil abiotic factors that might affect plant morphology (organic matter, total nitrogen, total carbon, porewater salinity, water content, bulk density, soil hardness and water depth). At each sampling plot, we collected three surface soil cores at 5 cm deep and 5.05 cm in diameter for soil abiotic factors. We analysed soil organic matter by using the Walkley and Black (Bai et al., 2012). We examined soil total nitrogen (TN) by using a continuous-flow analysis instrument (AA3, Europe), and soil organic carbon (TC) by using a total organic carbon (TOC) analyser (TOC-V, Japan). We collected the data of porewater salinity by measuring the resulting supernatant of a dry soil with deionised water (1:5 by volume) (Cui et al., 2011; Pennings et al., 2003). We determined soil water content and bulk density by weighing wet soil cores and re-weighing them after dried at 60 °C for 48 h (He et al., 2012). We measured soil hardness by using a soil penetrometer. We measured water depth by using a ruler, we dug a pit to locate the water table if it was below the soil surface (positive values indicate that the water level is above the soil surface, and negative values indicate that water level is below the soil surface).

2.3. Statistical analysis

We first compared plant morphological characteristics (plant coverage, above- and belowground biomass, shoot height, stem-base diameter, leaf length, leaf width and leaf thickness) and soil abiotic factors (organic matter, total nitrogen, total carbon, porewater salinity, water content, bulk density, soil hardness and water depth) across different marsh zones and between plant communities with one-way Analysis of Variance (ANOVA). Data were $\log_{10}(x+1)$ or square-root transformed when necessary. Second, we used Spearman rank correlation analysis to examine potential relationships between plant morphology and soil abiotic factors. We conducted these above analyses using SPSS 20.0.

Third, we used multivariate approaches to identify relationships between plant morphology (plant coverage, above- and belowground biomass, shoot height, stem-base diameter, leaf length, leaf width and leaf thickness) and soil abiotic factors (organic matter, total nitrogen, total carbon, porewater salinity, water content, bulk density, soil hardness and water depth). Preliminary analysis with detrended correspondence analysis (DCA) indicated that it was appropriate to analyze the dataset using redundancy discriminate analysis (RDA) because the largest value of gradient length was less than 3.0 (Lepš and Šmilauer, 2003). RDA was performed using