Catena 128 (2015) 144–154

Contents lists available at ScienceDirect

Catena

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

Flood regime affects soil stoichiometry and the distribution of the invasive plants in subtropical estuarine wetlands in China

Weiqi Wang [a,b,*], Chun Wang [a,b], Jordi Sardans [c,d,**], Chuan Tong [a,b], Ruixia Jia [a,b], Congsheng Zeng [a,b], Josep Peñuelas [c,d]

[a] Institute of Geography, Fujian Normal University, Fuzhou 350007, China
[b] Key Laboratory of Humid Subtropical Eco-geographical Process, Ministry of Education, Fujian Normal University, Fuzhou 350007, China
[c] CSIC, Global Ecology CREAF-CSIC-UAB, Cerdanyola del Valles, 08193 Barcelona, Catalonia, Spain
[d] CREAF, Cerdanyola del Valles, 08193 Barcelona, Catalonia, Spain

ARTICLE INFO

Article history:
Received 12 July 2014
Received in revised form 29 December 2014
Accepted 19 January 2015
Available online 6 February 2015

Keywords:
China
Climate change
Ocean level
Plant invasion
Stoichiometry
Wetland

ABSTRACT

Projections of climate change impacts over the coming decades suggest that rising sea levels will flood coastal wetlands, moving the range of wetlands inland from the current coastline. The intensity of flooding in wetland areas will thus increase, with corresponding impacts on soil properties and coastal ecosystems. We studied the impacts of two levels of water inundation on the concentration and stoichiometry of soil carbon, nitrogen, phosphorus and sulfur in areas dominated by the native C_3 species *Scirpus triqueter* L., the native C_4 species *Cyperus malaccensis* var. *brevifolius* Boecklr. and the invasive Gramineae C_3 species *Phragmites australis* (Cav.) Trin. ex Steud in the Shanyutan wetland areas of the Minjiang River estuary in China. Comparison of the communities dominated by these three species in high- and low-water flood habitats showed that flooding enhanced anaerobiosis and salinity and altered the carbon and nitrogen plant–soil cycles. Higher flooding favored the invasive species more than the two native species. The invasive *P. australis* accumulated more carbon (65% increase in aboveground biomass), and took up more nitrogen under high flooding than did *C. malaccensis* and *S. triqueter*. The more conservative use of soil resources, particularly the limiting nutrient N, appeared to underlie the higher capacity of the invasive species to tolerate higher flooding intensity. Increases in flooding may thus enhance the success and expansion of the invasive *P. australis* to the detriment of the native plant species in these Chinese wetlands.

1. Introduction

Global change can affect ocean levels (Schewe et al., 2011; Mendelsohn et al., 2012; Piecuch and Ponte, 2014), river flows (Bueh et al., 2003; van Vliet et al., 2013; Grafton et al., 2013) and water stoichiometry (Sardans et al., 2012; Sardans and Peñuelas, 2014) that in turn can affect community structure and function (Peñuelas et al., 2012, 2013). Rising sea levels could be especially critical for wetland ecosystems (Ramsar, 2013). In China, a higher sea level would flood the current coastal wetlands and create new wetlands farther inland. However, most coastal areas in China, including the studied estuary, are protected by seawalls, so wetland areas cannot increase in size, and this is why the areas of these wetlands will only decrease as the sea level rises (Yang et al., 2014). As an example, with a 0.5 m rise in sea level, the Liaohe delta would lose 3530 km^2 (Xiao et al., 2003) and the Changjiang River estuary would lose 20% of its area (Ji et al., 1994).

Flooding can also alter the soil contents and the stoichiometric relationships of carbon (C), nitrogen (N), phosphorus (P) and sulfur (S) by changing the aerobic/anaerobic biogeochemical equilibrium, nutrient inputs and outputs and/or the structure of plant communities (Steinman et al., 2012; Recha et al., 2013). Moreover, flooding shifts can also interact with other impacts of global change such as success of invasive species (Sardans and Peñuelas, 2012). Invasive plant species, such as *Phragmites australis*, are increasing in several Chinese wetland areas (Tong et al., 2011; Wang et al., 2014). The success of *P. australis* has been associated with changes in its nutrient-use efficiency (Wang et al., 2014), so we hypothesize that increased flooding could have an impact on its invasive success.

Recent stoichiometric ecological studies have shown that S can be more sensitive than N or P to stoichiometric shifts in response to environmental changes (Kirkby et al., 2013). The strong link between C and S justifies the study of S and its stoichiometric relationships with other nutrients (Kirkby et al., 2011), particularly in wetland ecosystems.

* Correspondence to: W. Wang, Institute of Geography, Fujian Normal University, Fuzhou 350007, China.
** Correspondence to: J. Sardans, CREAF, Cerdanyola del Valles, 08193 Barcelona, Catalonia, Spain.
E-mail addresses: wangweiqi15@163.com (W. Wang), j.sardans@creaf.uab.cat (J. Sardans).

http://dx.doi.org/10.1016/j.catena.2015.01.017
0341-8162/

Water fluxes during tides and the differences of daily flooding time generate nutrient shifts in wetland soils (Tong et al., 2010, 2011; Wang et al., 2012b), but the degree of the impacts on soil stoichiometry and its relationships with other soil properties in wetlands and their possible influence on the success of alien species are poorly known. Because estuarine wetlands are influenced by changes in both river flows and tides, their elemental ratios are likely to be the most variable of the terrestrial ecosystems worldwide. The impact of changes in *water fluxes* during tides and the differences of daily flooding time on the relative balance of soil C:N:P:S stoichiometry in wetlands remains unclear.

Coastal wetlands occupy 5.7×10^6 km^2 globally (Ramsar, 2013; Mitsch and Gosselink, 2007) and 1.2×10^4 km^2 in China (Shen and Zhu, 1999; Huang et al., 2006). They are cradles of biodiversity upon which countless species of plants and animals depend for survival (Ramsar, 2013). Furthermore, wetlands are among the world's most productive environments and provide a wide array of benefits, such as mitigation of pollution (Destandau et al., 2013), provision of bird habitats (Fairbairn and Dinsmore, 2001), and reduction of hurricane storm surges (Barbier et al., 2013). Coastal wetlands are also a sink of C as peat and plant matter (Ramsar, 2013; Mitsch and Gosselink, 2007). Wetlands continue to be among the ecosystems most affected by global change, and yet we lack information on the effect of water fluxes during tides and the differences of daily flooding time on their abiotic and biotic environments (Ramsar, 2013; Mitsch and Gosselink, 2007). A better knowledge of the resulting soil C, N, P and S ecological stoichiometries in wetlands would provide decision makers with the necessary information for developing effective methods to enhance the potential capacity of these ecosystems to fix C and reduce the emission of greenhouse gases (Peñuelas et al., 2013). Moreover, determining the cycles and balances of C, N, P and S and the fertility of the soil could improve our understanding of the impacts on potential wetland uses and regenerative capacities.

To further understand the effects of floodwater regime on soil C, N, P and S concentrations and stoichiometries in estuarine wetlands, we: (1) describe the changes in soil C, N, P and S concentrations and stoichiometries, as well as other chemical and physical soil properties associated with floodwater, and the relationships among these parameters at different depths in estuarine tidal wetlands; (2) analyze the relationships among these properties and the capacity of soil to store C; and (3) determine the impact of changes in flooding on the success of invasive plant species.

2. Material and methods

2.1. Study area

This study was conducted in the Shanyutan wetlands (26°01′46″N, 119°37′31″E; Fig. 1), the largest tidal wetland area (approximately 3120 ha) in the Minjiang River estuary. The climate in this region is relatively warm and wet with a mean annual temperature of 19.6 °C and a mean annual precipitation of 1346 mm (Zheng et al., 2006). The average salinity of the tidal water from May to December 2007 was 4.2 ± 2.5‰. *Scirpus triqueter* L. and *Cyperus malaccensis* var. *brevifolius* Boecklr. are the most widespread native plant species (Liu et al., 2006) in the area. *P. australis* has invaded the wetlands over the past 30 years and is now the most prevalent plant species. These three species can grow in both high-flood and low-flood habitats. Currently, *S. triqueter*, *P. australis* and *C. malaccensis* are the three primary plant species in the upper (mid to high) portions of mudflats in the Minjiang River estuary (Liu et al., 2006). *S. triqueter* is a native species, C_3 monocot. *S. triqueter* is short (0.6 m), has a vestigial leaves with marginal importance in photosynthetic function, a stick to aboveground base stem, and a belowground crawl stem. *P. australis* is an invasive species, C_3 monocot, a tall plant (2 m during last growth stage) with one leaf on each node of the aboveground stem. *C. malaccensis* is a native species, C_4 monocot, is shorter (1.5 m) than *P. australis*, and has a degenerated leaf, a stick to aboveground base stem and a belowground crawl stem. In our study, the high-flood habitats are located on average at 5.2 m above sea level and flooded by intermediate tides about 240 days per year and are submerged beneath 10–120 cm of water for 0.5–4 h during each tidal inundation. The low-flood habitats are located on average at 5.6 m above sea level and are flooded only during spring tides, about 80 days per year, submerged beneath 10–50 cm of water for 0.5–2 h during each tidal inundation. At low tide, the soil surfaces of both the low- and high-flood habitats of the entire estuarine wetlands are exposed, but the soil remains flooded in some low areas.

2.2. Collection and analysis of plant and soil samples

Samples were collected in October 2007 from *S. triqueter*, *P. australis* and *C. malaccensis* dominated community in the high- and low-flood habitats (Fig. 1). Three replicate plots were randomly established in each community at each flood regime. Plant samples were collected from a consistent height. Each replicate consisted of a large quadrat (10 × 10 m) in each plot and sampled the aboveground and belowground biomass from three randomly selected sub-quadrats (1 × 1 m). All plant material was gently washed with water and then oven-dried to a constant mass (80 °C for 24–36 h) and weighed. The plant biomass of each community was determined by summing the above- and below ground biomasses. The first 0.6 m of the soil profile in a 1× 1 m area was excavated. This depth was chosen because most root biomass of all studied species (>80%) is located in the first 60 cm of soil depth. Samples were collected with a small sampler (length, 0.3 m; diameter, 0.1 m) from each of six soil layers (0–10, 10–20, 20–30, 30–40, 40–50 and 50–60 cm) at the center and both sides of the soil pit. These three samples were combined to form one sample per layer. A total of 108 soil samples (three communities × two flood regime × six soil

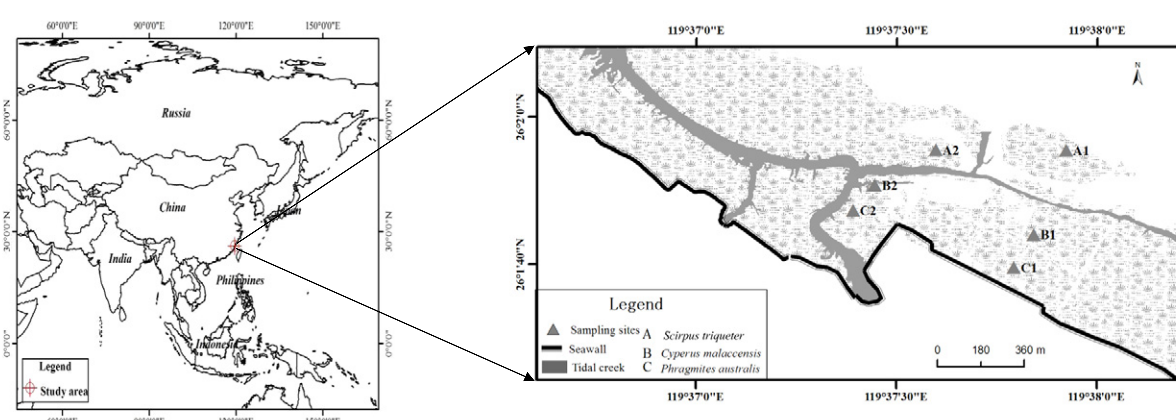

Fig. 1. Location of the six sampling sites for the high- and low-flood habitats.