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The effect of biomass variations of *Spartina alterniflora* on the organic carbon content and composition of a salt marsh in northern Jiangsu Province, China

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A B S T R A C T

The relationship of the organic carbon content and surface sediment composition to the litter mass of *Spartina alterniflora* was analyzed to investigate the responses of organic carbon content and composition to biomass changes in a salt marsh after the introduction of *S. alterniflora*. The vertical distribution of sediment organic carbon and its relationship with *S. alterniflora* underground biomass was also examined. The results show that the total organic carbon (TOC), recalcitrant carbon (RC) and labile carbon (LC) contents were significantly greater in the surface sediments of the *S. alterniflora* flat, which showed different intra-annual variation trends compared to a bare flat. In particular, the majority of *S. alterniflora*-derived organic carbon was LC in the *S. alterniflora* flat sediments, indicating that the introduction of *S. alterniflora* resulted in a significant increase in surface sediment LC content. In addition, the results of *S. alterniflora* litter decomposition revealed a rapid decrease of 40% in the organic carbon stocks within the first 2 months, and the TOC and LC contents showed intra-annual variation trends similar to the surface litter mass but with a two-month "phase difference" in time. Further analysis indicated, *S. alterniflora* litter controlled the content and proportion of the *S. alterniflora*-derived TOC input, and it ultimately affected the TOC content variations in the sediments. However, due to the LC mainly originated from *S. alterniflora*, the surface litter exerted more significant impact on the variation of LC content. In the bare flat core, the relatively low TOC, RC and LC content values were significantly influenced by the grain control effect, and the origins of these components were mainly derived from non-*S. alterniflora* sources. However, in the *S. alterniflora* flat cores, the relationships between organic carbon content, grain size and underground biomass, together with the analysis of the organic carbon origins, indicated that the *S. alterniflora* underground biomass significantly affected the origin of organic carbon. In addition, *Spartina alterniflora* introduction significantly increased the carbon sequestration capacity of the tidal salt marsh in North Jiangsu. Furthermore, the TOC, LC and RC accumulation rate analyses also indicated that *S. alterniflora* introduction improved the salt marsh soil and was beneficial to long-term carbon sequestration of the organic carbon pool.

1. Introduction

Salt marsh ecosystems are highly productive and play a critical role in coastal and marine carbon cycles (Bauer et al., 2013). Organic carbon is the basis for maintaining high productivity and biomass in tidal salt marsh ecosystems (Odum, 1984; Costanza, 1997; Childers et al., 2002). Carbon sequestration rates in global salt marshes range from 18 to 1713 $g\,C\,m^2\,a^{-1}$, which are several orders of magnitude higher than those in terrestrial forests (Elsey-Quirk et al., 2011). It is estimated that salt marshes and other coastal ecosystems (including seagrasses, macroalgae and mangroves) occupy 0.2% of the ocean surface but contribute 50% of carbon burial in marine sediments (Duarte et al., 2013), which is termed "blue carbon" (Chmura, 2011). Therefore, studying the carbon cycle in salt marshes and investigating the soil carbon pool dynamics of salt marshes is beneficial to scientifically assessing the role of salt marshes in linking land and ocean carbon cycles.

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Vegetation has a central role in the organic carbon cycle throughout the entire salt marsh ecosystem (Schalles and Shure, 1989; Negrin et al., 2011), and plants are the major origin of organic matter in most salt marshes (Bull et al., 1999; Gao et al., 2012). However, because of the invasion of exotic species, the original dominant species and plant community has greatly changed, which inevitably leads to alterations in the material cycles of salt marsh ecosystems (Chen et al., 2012; Hopkinson et al., 2012). In particular, when exotic species have substantially different productivity than the original species, both the ecosystem productivity and organic carbon input into the soil will be substantially altered by the invasion of exotic species (Ehrenfeld, 2001; Windham and Ehrenfeld, 2003), which results in variations in the stock and composition of the original salt marsh carbon pool (Zhang et al., 2010). This situation not only influences estimates of the global carbon balance but also directly affects any accurate evaluation of the status and role of salt marshes in the global carbon cycle (McLeod et al., 2011a,b; Guo et al., 2009).

Vegetation biomass and litter mass are recognized as two critical factors affecting the accumulation and output of organic carbon in salt marsh ecosystems (White and Howes, 1994; Simões et al., 2011). In addition, the fractions of organic carbon (which are collectively referred to as the "organic carbon composition" in the present study) are complex in salt marshes and can be divided into two components in terms of biochemical recalcitrance: recalcitrant carbon (RC) and labile carbon (LC) (Rovira and Vallejo, 2002). Recalcitrant carbon generally accounts for a higher proportion of organic carbon and is retained in soil for longer, thereby exerting greater importance in terms of the long-term carbon sequestration of the organic carbon pool (Casals et al., 2010). Despite its lower proportion in organic carbon, LC is characterized by higher bioactivity and has a higher sensitivity to changes in external environmental factors, such as vegetation types (Belay-Tedla et al., 2009; Huang et al., 2011), thereby controlling ecosystem productivity in the short term.

Many studies have demonstrated that the introduction of *Spartina alterniflora* greatly increases the accumulation of organic carbon in salt marshes (Cheng et al., 2006; Liao et al., 2007; Zhang et al., 2010). However, a thorough understanding is absent regarding the role of different components of *S. alterniflora* biomass (aboveground biomass, underground biomass and surface litter mass) in the output and accumulation of organic carbon and in controlling the dominant factors affecting the distribution patterns of sediment organic carbon in salt marshes and alteration in organic carbon composition while organic carbon accumulation rates increase. Such knowledge is important for obtaining in-depth knowledge of the accumulation mechanisms and dynamic variations of the organic carbon pool in *S. alterniflora* salt marshes, which is also critical to the scientific assessment of carbon pool changes in salt marshes after the introduction of *S. alterniflora*.

Smooth cordgrass (*S. alterniflora* Loisel) was introduced to the intertidal area of Jiangsu Province, China in 1982 (Chung, 1993). Because of its strong adaptability and high reproductive capacity, *S. alterniflora* has gradually replaced seepweed (*Suaeda salsa*) and become a dominant local species (Zhang et al., 2004; Wan et al., 2009; Gao et al., 2012). Thus, the introduction of *S. alterniflora* completely changed the condition of sparse large-scale aquatic vegetation cover in the intertidal zone of northern Jiangsu (Chen et al., 2004; Li et al., 2009). Therefore, the salt marsh of Northern Jiangsu Province provides a unique study opportunity to investigate the effect of biomass variations of *S. alterniflora* on organic carbon content and composition. In this study, we selected a typical salt marsh in North Jiangsu Province and aimed to (1) investigate intra-annual variations of *S. alterniflora* biomass and temporal variations of the litter decomposition rate, (2) analyze the relationship of the organic carbon content and the composition of surface sediments with the litter mass of *S. alterniflora*, (3) examine the vertical distribution of sediment organic carbon and its relationship with the underground biomass of *S. alterniflora* and (4) discuss the responses of the organic carbon content and composition relative to biomass changes in the salt marsh after the introduction of *S. alterniflora*.

2. Regional setting

Muddy coasts cover more than 90% of the coast in Jiangsu Province, which forms the largest muddy tidal flat in China. Common cordgrass (*S. anglica* Hubbard) was introduced to the coast of Jiangsu in 1963, and *S. alterniflora* was later introduced in 1982 (Chung, 1993). The latter is more competitive compared to the original vegetation and thus continuously invades the growth space of *S. anglica and S. salsa*. The *S. alterniflora* salt marsh is distributed from the upper region of the mid-tidal zone to the lower region of the high-tidal zone in northern Jiangsu (Chung, 2006). After the introduction of *S. alterniflora*, the *S. alterniflora* salt marsh areas along the coast of Jiangsu have rapidly expanded in the last two decades: the *S. alterniflora* vegetation only covered 2.3 km^2 in 1988 (Shen et al., 2002), but the area of *S. alterniflora* salt marshes increased to 187.1 km^2 in 2007 (Zuo et al., 2012). The average primary productivity of *S. alterniflora* is 1000–1500 $gm^2\,yr^{-1}$ (Mann, 1982) and can reach as high as 4000 $g\ m^2\,yr^{-1}$ in certain areas (Odum and Fanning, 1973). Because of the considerable community area and large primary productivity, *S. alterniflora* has significantly affected the tidal flat ecosystem of coastal Jiangsu (Qin et al., 1997).

The Wanggang River is one of the main local rivers flowing into the sea and is strongly influenced by tidal currents. The Wanggang tidal flat is characterized by typical semidiurnal tides with an average tidal range of 3.68 m, and it has a subtropical monsoon climate with an annual average temperature of 14.4 °C and an average annual rainfall of 1087.8 mm.

3. Data and methods

3.1. Sample collection

Surface sediment sampling and biomass surveying were conducted every two months from August 2012 to June 2013 (Fig. 1). Four transects were arranged in the study area, and one two-cm surface sediment sample was collected from two fixed sites (a bare flat and an *S. alterniflora* flat) in each transect (a total of eight sediment samples were obtained from each sampling). In addition, four 90-mm-diameter sediment cores (WG01-WG04) were acquired using a core sampler in August 2012:WG01-WG03 from the *S. alterniflora* flat in transects 01, 02 and 03 (with lengths of 93, 103 and 97 cm, respectively) and WG04 from the bare flat in transect 04 (with a length of 82 cm). The cores were sliced at 2.5 cm intervals for total organic carbon (TOC), total nitrogen (TN), LC, RC, $\delta^{13}C$ and grain size analyses, except that core WG03 were sliced at intervals of 3 cm. The surface sediment samples and core slices were returned to the laboratory and immediately frozen.

For the biomass survey, three 1 × 1 m quadrats were randomly selected each sampling, and the aboveground stems and leaves were harvested to obtain the aboveground biomass. Simultaneously, the *S. alterniflora* litter mass was also measured by collecting *S. alterniflora* surface litter at each quadrat. To obtain the vertical distribution profile of the underground biomass, three quadrats of 1 × 1 × 1 m were selected in August 2012, and underground roots at five depths (0–20, 20–40, 40–60, 60–80 and 80–100 cm) were collected.

Plant residue decomposition rates were measured using the litterbag method proposed by Wider and Lang (1982). Briefly, 15 g of