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A model for the contribution of macrophyte-derived organic carbon in harvested tidal freshwater marshes to surrounding estuarine and oceanic ecosystems and its response to global warming

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ABSTRACT

The tidal freshwater marshes dominated by *Phragmites australis* (common reed) in the Chongxi Wetland are important components of the Yangtze River estuary in China. The litter from *P. australis* is exported to the surrounding estuarine area and the sea with the tidal flushing in the form of plant residue, particulate organic matter, and dissolved organic matter and is an important organic carbon resource of the East China Sea. A model was constructed using STELLA® software (version 9.1.3) to simulate the contribution of macrophyte-derived organic carbon to surrounding estuary and ocean ecosystems. The model is based on the monitoring and observational data from field surveys and published information on the Chongxi Wetland from 2008 to 2011, and the response of the total organic carbon flowing out of the wetland to global changes was also predicted in conditions of plant shoots that were annually harvested in winter. The results demonstrate the following: (1) the annual contributed organic carbon is 891 g C m^{-2}, of which 612 g C m^{-2} flows out of the wetland directly as plant residue; (2) total organic carbon continually increases after a short decrease at the start of April of 2010, retains a high value from mid-July to mid-November and rapidly decreases to approximately zero during the harvest of the aboveground plant organs; and (3) accumulated annual organic carbon contributions to the surrounding estuarine and oceanic ecosystems are predicted to increase as the global average temperature rises, and the sea level increases.

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1. Introduction

Tidal wetlands, such as salt, brackish, and freshwater marshes, form important links between terrestrial and oceanic ecosystems. Tidal marsh soils and vegetation naturally store water, filter sediments and pollutants from fresh water supplies, and help to stabilize shorelines by reducing erosion and storm surges associated with rising sea levels (Daily et al., 1997; Mitsch and Gosselink, 2000; Wang et al., 2013). Because they represent a large component of the terrestrial biological carbon pool, tidal marshes provide essential ecosystem services to society and play an important role in global carbon cycles (Craft et al., 2008).

The problems associated with the ecological functions of the organic detritus contribution of coastal salt marshes has received increasing attention in recent decades. Certain coastal salt marshes, such as the South Atlantic coastal salt marshes in the USA, exhibit "hot spots" of organic carbon contribution to the heterotrophic communities of the surrounding estuarine and oceanic ecosystems. However, in such regions as the Gulf of Mexico coast, this outwelling process is not important or occurs rarely (Odum, 2000). Most of the available information on the organic matter export of coastal salt marsh has been provided by studies in various regions, such as in Australia (Melville and Connolly, 2003), Japan (Kurata et al., 2001) and the USA (Gratton and Denno, 2006; Kwak and Zedler, 1997). Little is known regarding the contribution of macrophyte-derived organic carbon from estuarine tidal freshwater marshes to ocean ecosystems, especially for the Yangtze River estuary, which is a region severely impacted by human activities.

The tidal freshwater marsh dominated by *Phragmites australis* (common reed) in the Chongxi Wetland is an important component of the Yangtze River estuary in China. Because *P. australis* is

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perhaps the most productive macrophyte of temperate regions (Asaeda and Karunaratne, 2000; Westlake, 1963), the Chongxi tidal freshwater marsh has high aboveground biomass accumulation and productivity (Zhang et al., 2013). The litter from *P. australis* is exported to the sea with the tide flushing as plant residue, particulate organic matter and dissolved organic matter and is an important organic carbon resource of the East China Sea.

Many aspects of *P. australis* have been discussed. The growth of *P. australis* has been studied extensively in the field (Hocking et al., 1983; Karunaratne et al., 2003; Windham, 2001) and by modeling (Allirand and Gosse, 1995; Asaeda and Karunaratne, 2000; Asaeda et al., 2002). The decomposition and nutrition dynamics of *P. australis* litter are relatively well-described, such as by Mason and Bryant (1975),Hietz (1992), Longhi et al. (2008), and Chimney and Pietro (2006). Furthermore, several studies have documented the effects of biological factors on *P. australis* decomposition. For example, a mechanistic model of *P. australis* leaf decomposition in a Mediterranean coastal lagoon in Italy was presented by Alemanno et al. (2007) to assess the importance of the heterogeneity of leaf detritus and rules governing patch colonization of decomposing detritus by benthic macro-invertebrates. Romaní et al. (2006) discussed the interactions of bacteria and fungi on decomposing litter. Although *P. australis* in estuaries is a potentially large source of energy and carbon for ocean ecosystems, the dynamics of litter production has received little attention compared to trees, such as the dynamics in mangroves and tropical rainforests. Few studies have examined the organic carbon contribution from tidal freshwater marshes dominated by *P. australis* to ocean ecosystems on an ecosystem level.

As previously mentioned, a model must be built that can describe the processes of organic matter in Chongxi tidal wetland and answer the following questions: (1) what is the contribution of organic carbon from Chongxi tidal marsh to the surrounding estuary and the East China Sea? and (2) how will the contribution change when impacted by sea level increases and possible temperature increases?

2. Description of the modeled ecosystem

The Chongxi Wetland comprises than 300 hm^2 area and is located at the west end of Chongming Island (31°42′N–31°44′N, 121°12′E–121°16′E; Fig. 1), which is the largest island at the mouth of the Yangtze River estuary in eastern China. The Yangtze River estuary is an irregular, semidiurnal tidal estuary draining into the East China Sea; it has a twice-diurnal tide, seasonal spring and neap tide. The total duration of the flood and ebb currents is approximately 12.4 h. The area is characterized by a subtropical monsoon climate that has a dry season and flood season, annual mean temperature of 15.3 °C and annual average precipitation and evaporation of 1049 mm and 718 mm, respectively (Ma et al., 2012). The salinity of the area for most of the year is below 0.5‰, and the highest values are less than 1.5‰, even in the dry season (Shen et al., 2003).

At this site, native monospecific stands of *P. australis* are found on the upper portions of the intertidal zone at an elevation from 3.6 m to 4.2 m. The stands have been cut annually between November and December for non-food commodity production, such as papermaking, craft manufacturing and fodder production for livestock (Xiong et al., 2010). *P. australis* is a highly productive plant in the study area that can reach 4 m in height at the end of September and produce an average total biomass of more than 9000 g m^{-2}. The high density and production of the plants provide a good habitat and significant amount of nutritional resources for herbivore consumers, especially macrobenthic invertebrates.

As a key element of macro-benthic fauna in the coastal wetland ecosystem, crabs play a large role in the energy budgets and nutrient cycling. Crabs consume a tremendous variety of plant materials, such as foliage, seeds, fruits and leaf litter of vascular plants (Monakov, 1972; Nakasone et al., 1983; Seiple, 1981), and practice many modes of herbivory (Wolcott and O'Connor, 1992). In addition, the burrowing and foraging by crabs significantly enhances the productivity of the plants (Bertness, 1985) and influences the structure of the infaunal benthic community (DePatra and Levin, 1989). *Chiromantes dehaani* is the dominant crab species of the studied tidal marsh, and it is primarily distributed in the high and middle tidal zone in common reed and wild rice (*Zizania latifolia*) vegetation. From field observation, we found that it is common for *C. dehaani* to climb up the plants for grazing fresh foliage or escaping the tide, and this results in the breakdown of the aboveground plant organs. *C. dehaani* is also harvested by local people for food production in the study area.

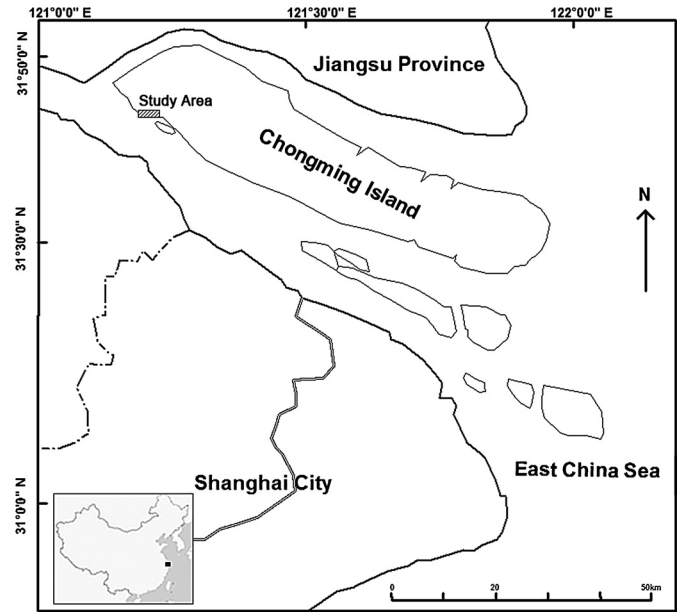

Fig. 1. The location of the study area.

The tidal activity exports part of the freshly fallen litter and also litter from the aboveground parts of *P. australis* from the marsh directly to the estuary. The other part undergoes decomposition and enters the detrital pool. Contributing to the particulate and dissolved organic matter pools of the wetland are the aboveground organs and belowground litter of *P. australis* and crab feces.

3. Materials and methods

3.1. Data collection and processing

The dynamics of the aboveground, belowground and litter fall biomass of *P. australis* were investigated based on data obtained from monthly sampling during April 2010–March 2011. Five quadrants of 0.25 m × 0.25 m (i.e., 0.0625 m^2) were harvested for aboveground standing shoots and belowground material. The fractions of fallen leaf, sheath, stem and panicle litter on the ground were then collected. The belowground materials were sampled from the stand to a depth of 0.8 m below the soil surface and separated into live and dead parts after washing. All plant materials were oven-dried at 60 °C and weighed by an electronic balance with precision of 0.1 g. Data were standardized to 1 m^2 plots and published by Zhang et al. (2013). The data for April were used as the initial value and the remaining data were used for calibration.

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