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Spatiotemporal patterns of the gross primary production in the salt marshes with rapid community change: A coupled modeling approach

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ABSTRACT

Coastal salt marshes are among the most productive ecosystems in the world. However, rapid changes in the vegetation communities of salt marshes caused by exotic species invasion and plant propagation requires a better understanding of how these shifts affect the landscape-scale variations of gross primary production (GPP). In the Yangtze Estuary of eastern China, we firstly compared 2-years GPP values obtained through eddy covariance measurements, satellite-based estimations and model simulations in two vegetation mixtures consisting of exotic *Spartina alterniflora* (C_4 plant) and dominant native *Phragmites australis* and *Scirpus* spp. (C_3 plants) The results indicated that the low-resolution remote sensing data with light-use efficiency method did not represent well the seasonal course of GPP relative to flux measurements and underestimated the annual amount GPP by 25–32%. In contrast, a detailed process-based vegetation model with species-specific parameterizations could identify the proportions of GPP from exotic C_4 and native C_3 vegetation and accurately reproduce the seasonal course and annual amount of GPP in the mixtures. The slopes of the linear regressions between the measured and modeled GPP were close (1.09 and 0.89 for the two mixtures, respectively) to the 1:1 line. To further evaluate the variations in GPP throughout the salt marshes, we coupled high-resolution remote sensing data to the vegetation model by transforming the vegetation index into the leaf area index (*LAI*) for different species. The coupled model reproduced the spatiotemporal dynamics of GPP in the salt marshes with rapid community change during the period of 2000–2008 and identified the variations of GPP from different species. The simulations indicated that the contribution rate of exotic *S. alterniflora* to GPP has been greater than that of native species since 2003–2004. Therefore, we suggest that this method is useful for high-resolution estimations of regional GPP in other coastal marshes with invasive *S. alterniflora* in China.

1. Introduction

Coastal salt marshes are among the most productive ecosystems in the world (Duarte et al., 2005; Mcleod et al., 2011; Kirwan and Megonigal, 2013). The gross carbon fixation by hydrophytes through photosynthesis, known as gross primary production (GPP), represents the largest flux in the carbon cycle. However, coastal vegetation communities exhibit complex spatiotemporal patterns because of sedimentary accretion, vegetation succession, plant invasion, and changes in salinity and flooding regime (Mitsch and Gosselink, 2007). Particularly, rapid changes in vegetation communities that result from exotic species invasion and plant propagation (vegetation expansion on mudflats) requires a better understanding of how these shifts affect the landscape-scale variations of GPP in coastal salt marshes.

A large amount of sediment is deposited in the Yangtze Estuary by the Yangtze River every year, which results in accretion at the seaward edge of the coastal salt marshes. This process also favors the propagation and expansion of vegetation (Ge et al., 2008; Xiao et al., 2010). However, the introduction of *Spartina alterniflora* (a grass with a C_4 photosynthetic pathway) from North America to Chinese coastal zones has resulted in a nationwide invasion since the 1980s (Li et al., 2009; Zuo et al., 2012). In the Yangtze

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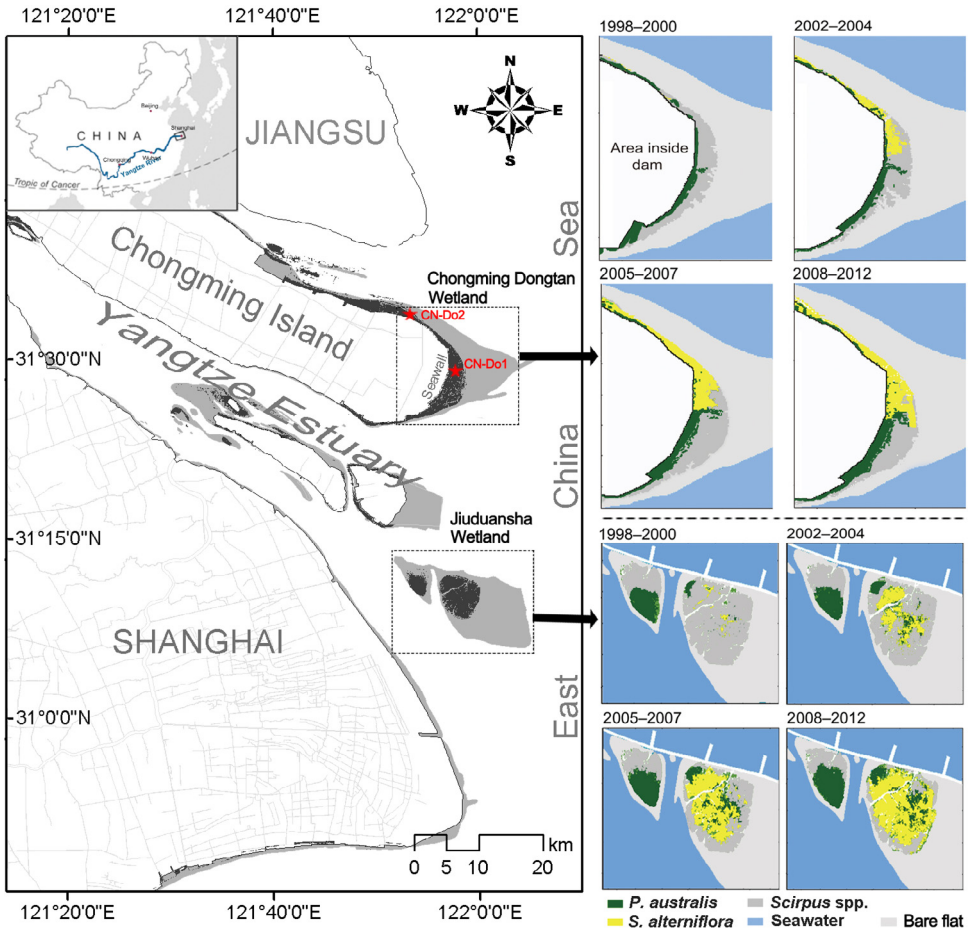

Fig. 1. Location of the salt marshes in the Chongming Dongtan wetland and Jiuduansha wetland (Yangtze Estuary) with the location of two eddy covariance sites (CN-Do1 and CN-Do2) in the Chongming Dongtan wetland. The right panel shows the spatiotemporal dynamics of the salt marsh vegetation after plant invasion.

Estuary, the expansion rate of *S. alterniflora* was much higher than the propagation rate of the native species of *Phragmites australis* and *Scirpus* spp. (including *Scirpus mariqueter* and *Scirpus triqueter*) (Ge et al., 2013, 2015a). As a result, the salt marshes in the estuary have become dominated by *S. alterniflora*, *Phragmites australis* and *Scirpus* spp. (Huang and Zhang, 2007; Li et al., 2009). Therefore, how to examine the changes in spatiotemporal patterns of GPP during the community change is essential for tracing the further carbon budget in the impacted salt marshes.

Numerous studies have estimated ecosystem GPP using photosynthesis measurements, biomass inventories and eddy covariance (EC) techniques (Baldocchi et al., 2001; Beer et al., 2010). In recent decades, remote sensing observations have aided in the upscaling of field-based measurements of GPP, based on a variety of land surface parameterizations for modeling photosynthetic activities (Kanniah et al., 2011, 2013; Peng and Gitelson, 2012). As an example, the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor provides information for estimating GPP at 0.5–1 km resolution and 8-day intervals (Xiao et al., 2005). Other studies have used Landsat data which have higher resolution (30 m) for spatial scaling of carbon fluxes with the assistance of EC measurements (Chen et al., 2009, 2010). Nevertheless, the difficulty in estimating model parameters has led to a focus on coupling process-based models with remote sensing datasets for accurate broad-scale estimations of primary production (Sitch et al., 2003; Beer et al., 2010; Becker-Reshef et al., 2011; Hu et al., 2014).

Based on the previous work (Ge et al., 2013, 2014, 2015a), the spatiotemporal dynamics of salt marsh vegetation and the photosynthetic parameters of native C_3 and exotic C_4 plants were quantified in the Yangtze Estuary. Consequently, the main objective of the current study is to investigate the spatiotemporal patterns of GPP in the salt marshes undergoing rapid community change, mainly resulted from plant invasion. First at all, the performance of a process-based vegetation model with species-specific parameterization was validated against the GPP from EC measurements and MODIS-based estimation in two plots of salt marsh mixtures of exotic and native species. Thereafter, the spatial and temporal variability of GPP corresponding with the changing vegetation community in the salt marshes in the Yangtze Estuary was estimated by coupling the high-resolution remote sensing information (Landsat data) to the vegetation model.

2. Materials and methods

2.1. Study site

The study area lies on the two largest salt marshes in the Chongming Dongtan wetland (31°25′–31°38′ N, 121°50′–122°05′ E) and Jiuduansha wetland (31°03′–31°17′ N, 121°46′–122°15′ E) of the Yangtze Estuary (Fig. 1). *P. australis* and *Scirpus* spp. (C_3 plants) are the dominant native species in the salt marsh (Ge et al., 2008). The exotic species *S. alterniflora* was first introduced to the coastal wetlands in the Yangtze Estuary in the 1990s. Over the past twenty years, this exotic species has gradually invaded large areas of unvegetated mudflats and has also begun to invade areas formerly covered by native vegetation (Zhou and Xie, 2012). From 1998 to 2012, the area of *S. alterniflora* increased by approximately 1500 ha and 2100 ha in the Chongming Dongtan wetland and Jiuduansha