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Seasonal and spatial dynamics of greenhouse gas emissions under various vegetation covers in a coastal saline wetland in southeast China

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ABSTRACT

Coastal saline wetlands are recognized as prominent sources of greenhouse gas emissions. However, insufficient attention has been paid to the effect of coastal wetlands in mitigating global warming caused by greenhouse gases in China. This study aims to investigate how vegetation and soil parameters affect greenhouse gas emissions in a coastal saline wetland. Fluxes of CO_2, CH_4, and N_2O were measured simultaneously in situ using the closed static chamber technique in four different coastal tidal flats, namely, mud flat, *Spartina alterniflora* flat, *Suaeda glauca* flat, and grass flat. The measurements were obtained from September 2012 to August 2013 in the Yancheng coastal wetland, southeast China. The average fluxes across all seasons and flats varied from 10.7 to 2297.6 mg $CO_2\,m^{-2}\,h^{-1}$ (ecosystem respiration), from −0.368 to 4.959 mg $CH_4\,m^{-2}\,h^{-1}$, and from 1.5 to 65.7 μg $N_2O\,m^{-2}\,h^{-1}$. Higher CO_2 and CH_4 fluxes were observed during the summer and autumn seasons. However, the seasonal change of the N_2O fluxes was complicated. For the *S. alterniflora* and grass flats, the highest emissions were observed during summer. For the mud and *S. glauca* flats, the emissions peaked during winter. The spatial variations of the three greenhouse gas fluxes in the coastal saline wetland primarily depended on vegetation type. The greenhouse gas fluxes from the three tidal flats with vegetation covers (*S. alterniflora*, *S. glauca*, and grass flats) were higher than those from the mud flat. Higher CO_2 emissions were observed in the *S. alterniflora* flat than those in the other flats because of the higher carbon sequestration rate, together with higher net primary production and aboveground biomass. However, CH_4 and N_2O emissions were highest in the grass flat, followed by the *S. alterniflora* flat. The effects of tidal flats on the CH_4 and N_2O emissions differed according to the season. The *S. alterniflora* invasion increased the CO_2 emission while slightly lowering the CH_4 fluxes, compared with that of native plant communities dominated by *Phragmites*. Results also suggested that *S. alterniflora* had the highest global warming potential among the tidal flats in the coastal saline wetland.

1. Introduction

Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are key radiatively active greenhouse gases (GHG) that contribute greatly to global warming (IPCC, 2013; IPCC, 2013b). The global warming potential (GWP) of CH_4 for a 100-year horizon is approximately 28 times larger than that of CO_2, while that of N_2O is approximately 265 times larger (IPCC, 2013). Natural wetlands account for a small proportion of the land surface of the earth, but much of the carbon in the world is stored in the soil, sediments, and detritus of these waterlogged areas (Whiting and Chanton, 2001; Kayranli et al., 2010).

Wetlands are important in governing the atmospheric concentrations of CO_2, CH_4, and N_2O (Bartlett and Harriss, 1993; Van der Nat and Middelburg, 2000; Song et al., 2009). To date, numerous efforts have been focused on GHG fluxes from natural wetlands worldwide (Whiting and Chanton, 2001; Whalen, 2005; Laanbroek, 2010; Page and Dalal, 2011b), including tropical wetlands (Couwenberg et al., 2010; Beringer et al., 2013; Inubushi et al., 2003), temperate peatlands (Olson et al., 2013; Juszczak and Augustin, 2013), boreal wetlands (Joiner et al., 1999), and subarctic wetlands (Joabsson and Christensen, 2001; Ström and Christensen, 2007). Although coastal saline wetlands have been recognized as major contributors to atmospheric GHG emissions (Hirota et al.,

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2007; Tong et al., 2010), these areas are not well-documented because of the difficulty in conducting fieldwork in these harsh environments (Magenheimer et al., 1996; Morse et al., 2012). Thus, the effects of GHG on global warming remain ambiguous because of large temporal and spatial variations, as well as lack of GHG flux data for specific wetlands. In China, numerous studies on GHG emissions from natural wetlands have been conducted in the Sanjiang Plain (Song et al., 2009), Yellow River estuary (Sun et al., 2013a,b,b), Yangtze River estuary (Cheng et al., 2007, 2010), Min River estuary (Tong et al., 2013), Qinghai-Tibetan Plateau (Hirota et al., 2004), Zoige Alpine Wetland (Chen et al., 2009), and mangrove swamps (Chen et al., 2010), and are summarized by Ding and Cai (2007) and Tian et al. (2011a,b); Tian et al. (2011a,b). However, similar research is lacking on the GHG emissions along the south Yellow Sea especially in the Yancheng coastal saline wetland. The temporal and spatial variations in the CO_2, CH_4, and N_2O fluxes differed greatly in various wetlands. For example, Sun et al. (2013a,b); Sun et al. (2013a,b) reported that in the Yellow River, the coastal *S. salsa* marsh acted as an N_2O source and a CH_4 sink at inter-seasonal scales. Cheng et al. (2010) showed that in the Yangtze River estuary, the seasonal variations of CH_4 from *Spartina alterniflora* and *Scirpus mariqueter* followed similar patterns. Further research stated that the invasion of *S. alterniflora* significantly increased the CH_4 (Cheng et al., 2007, 2010; Zhang et al., 2010) and N_2O emissions (Zhang et al., 2013a), compared with the native *Phragmites*, *S. mariqueter,* and *S. salsa*. However, no significant difference was observed among the tidal flats in the coastal saline wetlands (Chen et al., 2010,b; Sun et al., 2013a,b). The temporal variations of the CH_4 emissions are related to temperature, soil moisture, and salinity, whereas the spatial variations are mainly influenced by vegetation composition (Sun et al., 2013b). The following three mechanisms control N_2O production (Tian et al., 2011b; Beringer et al., 2013): (1) oxidation of ammonium to nitrite (nitrification), (2) reduction of nitrite to nitrate (denitrification), and (3) microbial assimilatory nitrate reduction. A flux is closely regulated by oxygen availability, tidal influence, and nitrogen substrate availability (Chen et al., 2010) in coastal wetlands. Although N_2O fluxes are not correlated with any environmental variables (Hirota et al., 2007; Juszczak and Augustin, 2013), high N_2O values are observed after the application of fertilizers to the soil (Couwenberg et al., 2010; Couwenberg et al., 2010a). Hirota et al. (2007) found that the spatial–temporal variations of the three GHG fluxes were primarily attributed to the water level fluctuation in the sandy shore; however, in the salt marsh, the spatial–temporal variations of three GHG fluxes resulted from the aboveground biomass and soil temperature. Koelbener et al. (2010) investigated and compared the CH_4 emissions under different vascular plant species from peat cores. However, a limited number of comparative studies have been conducted on the effects of different plant species on GHG fluxes in coastal tidal flats.

Many studies have demonstrated that plants can influence CH_4 emissions from wetlands mainly by controlling the production, consumption, and transport of CH_4 to the atmosphere (Van der Nat and Middelburg, 2000; Whalen, 2005; Koelbener et al., 2010b). Additionally, the photosynthetic rate and fixed carbon in underground structures seem to influence both vegetative CH_4 transport and substrate quality (Joabsson and Christensen, 2001). Furthermore, higher rates of ecosystem respiration, as well as CH_4 and N_2O emissions are observed in the presence of vascular plants (Ström and Christensen, 2007; Van der Nat and Middelburg, 2000), especially for invasive vegetation, such as *Phragmites* (Mozdzer and Megonigal, 2013) and *S. aterniflora* (Cheng et al., 2007, 2010; Zhang et al., 2010). In addition, soil temperature can change the decomposition rate of the organic matter in the soil by regulating soil respiration and microbial activities (Cheng et al., 2010). However, the correlations between air temperature and CH_4 and N_2O emissions remain unclear (Dijkstra et al., 2012; Juszczak and Augustin, 2013). Megonigal and Schlesinger (2002) found that temperate wetlands showed minimal seasonal variability caused by a restricted air temperature range. However, the CH_4 emission was positively correlated with the soil temperature (Cheng et al., 2010). Furthermore, the physicochemical properties of wetland soil could affect GHG fluxes (Danevčič et al., 2010; Sun et al., 2013). For example, Chen et al. (2010) showed that CO_2 and N_2O fluxes were positively correlated with the soil organic carbon (SOC) and total nitrogen (TN) in mangrove soils. However, insufficient research has been conducted on the relationship between the seasonal and spatial variations of GHG fluxes, and the environmental controlling factors in the Yancheng coastal saline wetland.

The Yancheng coastal saline wetland is located along the middle region of the Jiangsu coastline in southeast China. The wetland is a silty, muddy, tidal flat, and the first and largest coastal wetland nature reserve in China (Liu et al., 2007). No human interference on vegetation succession has been observed within the core area. Thus, this area is the ideal site for investigating the GHG fluxes from the natural wetlands in China. The invasion of *S. alterniflora* in this area has significantly changed the SOC and TN distributions in the coastal tidal flats (Gao et al., 2007). Different tidal flats have different plant communities, soil characteristics, hydrologic conditions, environmental factors, and astronomic tidal fluctuations (Sun et al., 2013a), which may affect the dynamics of the GHG emissions. Thus, observing the seasonal and spatial variations of the GHG emissions is necessary to fill the research gap and estimate the global-warming potential (GWP) of natural coastal saline wetlands.

In this study, the CO_2, CH_4, and N_2O fluxes are investigated simultaneously in the Yancheng coastal saline wetland from September 2012 to August 2013, using the closed static dark chamber method. This study aims to (1) quantify and compare the CO_2, CH_4, and N_2O emissions in different tidal flats within the core region; (2) determine if distinct temporal variations occur in the CO_2, CH_4, and N_2O fluxes; and (3) assess the effects of plant traits and environmental factors (air temperature, soil moisture, SOC, TN, and mean grain size) on GHG emissions.

2. Materials and methods

2.1. Study area

The field experiment was conducted in the intertidal zone within the core region of the Yancheng National Nature Reserve for Wetlands and Rare Birds (32° 48′47″ N–34° 29′28″ N, 119° 53′ 45″ E–121° 18′12″ E) in Jiangsu Province, China (Fig. 1). The nature reserve covers an area of 2.47×10^5 ha, with a core area of 0.23×10^5 ha. The study area is between a sub-tropical and a warm-temperate transitional zone, and has a typical warm, humid, oceanic, monsoon climate. The annual average temperature is 11.4–13.8 °C, the frost-free period lasts 209–218 days, and the average annual precipitation ranges from 1000 to 1,080 mm, with 40–50% of precipitation occurring between June and August (Liu et al., 2007).

Four tidal flats that developed from the sea to the inland were investigated, namely, the mud flat (MF), *S. alterniflora* flat (SAF), *S. glauca* flat (SGF), and grass flat (GF) (Fig. 1). The area and proportion of the MF, SAF, SGF, and GF were 2985.285 hm^2 (26.1%); 3999.236 hm^2 (34.96%); 1437.572 hm^2 (12.57%); and 3017.433 hm^2 (26.38%), respectively (Zhang et al., 2013b). The plant community distribution of the Yancheng coastal wetlands has a typical landward succession sere, and the dominant species from the coast to the inland are *S. alterniflora*, *S. glauca*, *Aeluropus littoralis*, *Imperata cylindrica*, and *Phragmites australis* (Liu et al., 2007).