



# *Spartina alterniflora* invasions impact CH<sub>4</sub> and N<sub>2</sub>O fluxes from a salt marsh in eastern China



Shenglai Yin<sup>a,b</sup>, Shuqing An<sup>a,b</sup>, Qi Deng<sup>c</sup>, Jinghan Zhang<sup>b</sup>, Haiting Ji<sup>a</sup>, Xiaoli Cheng<sup>c,\*</sup>

<sup>a</sup> School of Life Science and Institute of Wetland Ecology, Nanjing University, Nanjing 210093, PR China

<sup>b</sup> Nanjing University Ecology Research Institute of Changshu (NJUecoRICH), Changshu, 215500 Jiangsu, PR China

<sup>c</sup> Key Laboratory of Aquatic Botany and Watershed Ecology, Wuhan Botanical Garden, Chinese Academy of Sciences, Wuhan 430074, PR China

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## ABSTRACT

*Spartina alterniflora*, an invasive species originating from North America, has spread widely along the eastern coast of China. However, the impacts of *S. alterniflora* invasions on CH<sub>4</sub> and N<sub>2</sub>O fluxes from salt marshes in eastern China are not fully understood. We conducted a field experiment in three treatments (transparent, opaque, and clipping) to compare the CH<sub>4</sub> and N<sub>2</sub>O fluxes from *S. alterniflora* community with native C<sub>3</sub> plant *Suaeda salsa* and *Phragmites australis* communities and the mudflat in a coastal wetland of eastern China over one year. CH<sub>4</sub> flux from the *S. alterniflora* community was higher than the *S. salsa* community and mudflat but lower than the *P. australis* community. The opaque treatment did not significantly alter CH<sub>4</sub> flux, except for the *S. salsa* community. Clipping significantly decreased CH<sub>4</sub> flux from the *S. alterniflora* and *P. australis* communities but increased CH<sub>4</sub> flux from the *S. salsa* community. In contrast, N<sub>2</sub>O fluxes in the *S. alterniflora* and *P. australis* communities were lower than for the *S. salsa* community and mudflat. The opaque treatment did not significantly change N<sub>2</sub>O fluxes across communities. Clipping significantly increased mean N<sub>2</sub>O fluxes from the *S. alterniflora* and *P. australis* communities but did not significantly change N<sub>2</sub>O flux in the *S. salsa* community. CH<sub>4</sub> flux was positively related to the aboveground biomass and negatively related to density, whereas N<sub>2</sub>O flux was negatively related to aboveground biomass and positively related to density. Meanwhile, CH<sub>4</sub> flux was strongly dependent on temperature, soil moisture and water depth ( $P < 0.05$ ), while N<sub>2</sub>O fluxes under the transparent and opaque chambers were significantly related to water depth ( $P < 0.05$ ), but N<sub>2</sub>O flux under the clipping treatment was not significantly related to environmental factors ( $P > 0.05$ ). Overall, CH<sub>4</sub> and N<sub>2</sub>O fluxes from this coastal wetland were 17.38 g m<sup>-2</sup> and -36.64 mg m<sup>-2</sup>, respectively, indicating that *S. alterniflora* invasions in this salt marsh in eastern China could play a negligible role in emitting CH<sub>4</sub> and a significant role in absorbing N<sub>2</sub>O when compared with other studies worldwide.

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## 1. Introduction

Methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O), important trace gases, play critical roles in regulating the greenhouse gas effect in the atmosphere. Although atmospheric CH<sub>4</sub> and N<sub>2</sub>O concentrations are far lower than CO<sub>2</sub> concentrations, the global warming potential of CH<sub>4</sub> and N<sub>2</sub>O are 25 and 298 times greater, respectively, than that of CO<sub>2</sub> (Rodhe, 1990). It has been shown that atmospheric CH<sub>4</sub> and N<sub>2</sub>O concentrations have increased from 715 to 1803 ppb and from 270 to 324 ppb, respectively, since the Industrial Revolution as a result of the warming of the earth's surface and other climate changes (IPCC, 2013). Wetlands are the world's

largest CH<sub>4</sub> sources due to the wet and submerged soils (IPCC, 2013; Song et al., 2009), which make a considerable contribution to global warming at local, regional and global scales (Song et al., 2003; Roehm, 2005). The exotic species invaded in wetland not only greatly change CH<sub>4</sub> fluxes but also potentially affect N<sub>2</sub>O fluxes (Cheng et al., 2007). However, CH<sub>4</sub> and N<sub>2</sub>O fluxes in wetlands are complex interactions of production, transportation and consumption, which are regulated by multiple factors, such as vegetation, microbial activities, temperature, inundation and soil properties (Conrad 1999; Kutzbach et al., 2004; Minkkinen and Laine, 2006; Dou et al., 2013). Thus, to better understand the role of plant invasions of wetland in global warming, more field studies of synthetic evaluation of CH<sub>4</sub> and N<sub>2</sub>O fluxes is necessary.

Vegetation is one of the most important factors affecting CH<sub>4</sub> and N<sub>2</sub>O fluxes in wetlands. Vegetation has been reported to influence gas fluxes by affecting soil redox potentials (Van der Nat et al., 1998;

\* Corresponding author. Tel.: +86 27 87510881; fax: +86 27 87510251.  
E-mail address: [xlcheng@fudan.edu.cn](mailto:xlcheng@fudan.edu.cn) (X. Cheng).

Han et al., 2005), acting as transportation pathways (Verville et al., 1998; Jorgensen et al., 2012; Tong et al., 2012) and exuding substrate for bacteria (Cheng et al., 2007). Meanwhile, vegetation could affect the  $N_2O$  flux by competing nitrogen with nitrifiers and denitrifiers (Cheng et al., 2007; Maljanen et al., 2007), as well as suppressing  $N_2O$  production by photosynthesis (Yu et al., 2012). In addition to vegetation, temperature also influences  $CH_4$  and  $N_2O$  fluxes in wetlands (Bartlett et al., 1992; Van der Nat and Middelburg, 2000; Tong et al., 2012). For instance, previous studies have demonstrated that temperature can affect bacterial activities (Van der Nat and Middelburg, 2000), the diffusion efficiency of trace gas in soil (Heincke and Kaupenjohann, 1999; Jorgensen et al., 2012) and litter decomposition rate (Liu et al., 2014), and hence, determine  $CH_4$  and  $N_2O$  gas production and/or consumption. Water depth on the soil's surface also directly influences gas fluxes by acting as a flux barrier (Bartlett and Harriss, 1993; Cheng et al., 2007) and indirectly influences gas fluxes by altering the soil's aerobic and anaerobic environment (Cheng et al., 2007) and vegetation composition (Kutzbach et al., 2004). Therefore, alterations in important factors, for example, plant species invasions, can change the vegetation composition and environmental properties, which can potentially alter gas fluxes in wetland ecosystems (Cheng et al., 2007).

*Spartina alterniflora*, a smooth cordgrass species from North America, was introduced into China in the 1970s for coastal protection (Qin and Zhong, 1992). This exotic species has great advantages in competing with native species such as *Phragmites australis*, *Suaeda salsa*, *Cyperus malaccensis* and *Scirpus mariquetet* (Chen et al., 2007; Li et al., 2009; Zhang and Ding, 2011; Tong et al., 2012). As a successful colonizer in China, *S. alterniflora* has greatly affected the structure and function of native ecosystems (Windham and Ehrenfeld, 2003; Wang et al., 2006; Qing et al., 2012). For example, some studies have reported that *S. alterniflora* significantly increases the soil carbon content in a wetland, which probably alleviates the wetland's contribution to the global warming effect (Cheng et al., 2006; Liu et al., 2007; Wan et al., 2009; Yang et al., 2013). In this study, we build on previous findings to hypothesize whether an *S. alterniflora* invasion would alter the contribution of China's saltmarshes to greenhouse gas fluxes, and whether greenhouse gas fluxes would be related to plant traits and environmental factors. To test this hypothesis, we conducted a field experiment for three treatments (transparent chambers, opaque chambers, and a clipping treatment) to study the effects of *S. alterniflora* on  $CH_4$  and  $N_2O$  fluxes by comparing fluxes from areas of *S. alterniflora* with native  $C_3$  plants and *S. salsa* and *P. australis* communities in the mudflat in a coastal wetland of eastern China over one year. We specifically focused on (1) how an *S. alterniflora* invasion would impact  $CH_4$  and  $N_2O$  fluxes from the salt marsh and (2) how the associated plant traits (e.g., biomass and density) and environmental factors (e.g., temperature, soil moisture and water depth) would regulate  $CH_4$  and  $N_2O$  fluxes following this invasion.

## 2. Materials and method

### 2.1. Site description

This study was conducted in the Yancheng National Natural Reserve (119°29' to 121°16'E, 32°20' to 34°37'N), the location of one of the largest and most important coastal salt marshes in China (Zhou et al., 2009). The study area is located in the belt between subtropical and warm-temperate zones, with a mean temperature of approximately 18.7 °C, a mean annual rainfall of approximately, 1000–1080 mm, a mean tidal range of approximately, 2.5–4.0 m, a mean radiation of approximately 502.42 KJ cm<sup>-2</sup> and a mean seawater salinity of 2.95–3.22% (Ren, 1986; Zhu et al., 2004; Zhou et al., 2009). *S. alterniflora* was introduced into this nature reserve in the 1970s for the purpose of ecological engineering (Qin and

Zhong, 1992). In the following three decades, *S. alterniflora* spread widely along the eastern coast of China and became an invasive species, which seriously influenced local biogeochemical cycles (Cheng et al., 2006, 2007; Tong et al., 2011). *P. australis* is native  $C_3$  plant, which grows in the inner-land side of the nature reserve and locates 7.4 km away to the sea. *S. salsa* is a native halophyte, which grows between *S. alterniflora* and *P. australis*. The vegetation continuity from land to seaward is *P. australis*, *S. salsa*, *S. alterniflora* community, and mudflat (Yang et al., 2013). The three plant species slightly overlapped in their distribution in the salt marsh.

### 2.2. Field sample collection

In April 2011, three transects (5000 m × 20 m), each including mudflat, *S. alterniflora*, *S. salsa* and *P. australis* communities, were laid out in the nature reserve for this study. Within each transect, we randomly selected four sites in the mudflat, *S. alterniflora*, *S. salsa* and *P. australis* communities. A static chamber technique was used to measure trace gas fluxes. Nine static chamber bases were randomly and permanently inserted into the selected sites, except for the mudflat, where only three chamber bases were inserted monthly. Care was taken to minimize disturbances to the soil surface and plants, especially inside the chambers, during insertion. Areas of 50 × 50 cm (height varied depending on the plants) were covered by static chambers. Three transparent chambers made of Plexiglas were used to measure gas fluxes from photosynthesis; another three transparent chambers were used with the clipping treatment to measure fluxes from the soil surface. The clipping treatment was performed at the very beginning of the experiment, and the new materials in each base were cut weekly and removed. Finally, the last three chambers, which were opaque, were made of polyvinyl chloride and were used to measure gas fluxes from respiration. During sampling, the chambers were placed on their bases, and airtight closures were ensured by water-filled sealing. Air inside the chamber was circulated with a battery-driven fan during the sampling process to ensure that gas samples were well-mixed (Cheng et al., 2010). Generally, four samples from each chamber were taken using a 100 ml syringe at 0, 15, 30 and 45 min after water sealing. Samples were injected into 100 ml pre-evacuated gas bags for laboratory analysis. Air temperatures inside the chambers were recorded simultaneously for each measurement. Sampling started in April 2011 and ended in March 2012 (11 times in total), except for soil respiration sampling in the *S. salsa* community, which started in July 2011 and ended in March 2012 (8 times in total). Additionally, we examined the air temperature (AT) by digital thermometer, soil temperature (ST) by mercurial thermometer, water depth (WD) on the soil surface by steel ruler, soil moisture (SM) from 0 to 5 cm by the oven-dried method and photosynthetically active radiation (PAR) by illuminometer with three replicates at each sampling site. Soil samples of 0–15 cm were also randomly selected in each sampling site, with three replicates on May 5, August 25, December 23, and March 28 for total carbon (TC), total nitrogen (TN) and soil organic carbon (SOC) measurements. The aboveground plants were collected at the end of the growing season in 2012, and the stem density and plant height were recorded simultaneously.

### 2.3. Laboratory analysis

Soil samples were stored in a freezer and sent to the Nanjing Soil Research Institute of CAS for analysis of TN and TC content by a Vario MAX elemental analyzer and SOC content by titration method. Aboveground plants were dried at 85 °C to a constant weight for aboveground biomass. Gas concentrations were analyzed at Key Laboratory of Ecosystem Network Observation and Modeling, CAS, Beijing, by gas chromatography (GC 7890A,

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