Science of the Total Environment 635 (2018) 1025–1035

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Fluxes of carbon dioxide and methane across the water–atmosphere interface of aquaculture shrimp ponds in two subtropical estuaries: The effect of temperature, substrate, salinity and nitrate

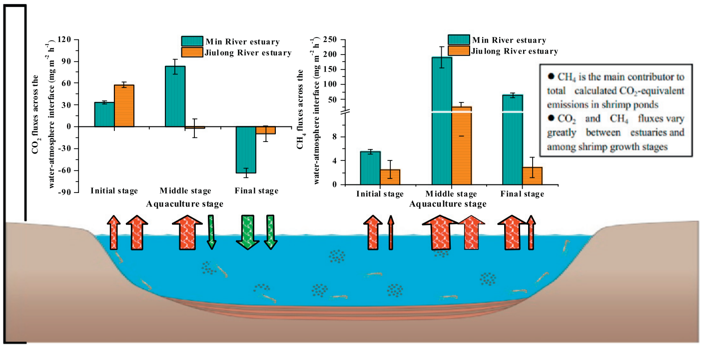
Ping Yang [a,b,c,1], Yifei Zhang [a,b,1], Derrick Y.F. Lai [d,*], Lishan Tan [a,b], Baoshi Jin [a,b], Chuan Tong [a,b,c,**]

[a] School of Geographical Sciences, Fujian Normal University, Fuzhou 350007, PR China
[b] Key Laboratory of Humid Subtropical Eco-geographical Process of Ministry of Education, Fujian Normal University, Fuzhou 350007, PR China
[c] Research Centre of Wetlands in Subtropical Region, Fujian Normal University, Fuzhou 350007, PR China
[d] Department of Geography and Resource Management, The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong, China

HIGHLIGHTS

- Shrimp ponds are CH_4 emission "hotspots" in subtropical estuaries of China.
- CH_4 is the main contributor to total calculated CO_2-equivalent emissions in shrimp ponds.
- CO_2 and CH_4 fluxes vary greatly between estuaries and among shrimp growth stages.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 27 January 2018
Received in revised form 5 April 2018
Accepted 6 April 2018
Available online xxxx

Editor: J Jay Gan

Keywords:
Methane
Carbon dioxide
Greenhouse gas fluxes
Salinity
Global warming potential
Aquaculture pond
Subtropical estuary

ABSTRACT

While aquaculture pond is a dominant land use/cover type and a distinct aquatic ecosystem in the coastal zones of China and southeast Asia, their contributions to the fluxes of greenhouse gases (GHGs) have only been poorly quantified. Fluxes of CO_2 and CH_4 in the shrimp ponds with different salinities were simultaneously measured *in situ* using the floating chamber technique in two different subtropical estuaries, namely, the Min River Estuary (MRE) and Jiulong River Estuary (JRE). The average CO_2 and CH_4 fluxes in the shrimp ponds over the observation periods varied from −2.09 to 3.37 mmol CO_2 m^{-2} h^{-1} and from 0.28 to 16.28 mmol CH_4 m^{-2} h^{-1}, respectively, with higher fluxes being detected during the middle stage of aquaculture. The temporal variation of CO_2 and CH_4 fluxes in both estuaries ponds closely followed the seasonal cycle of temperature. Higher CH_4 emissions were observed in MRE ponds than in JRE ponds because of the lower water salinity and N-NO_3^- concentrations as well as a greater supply of carbon substrates. Our findings suggested that shrimp ponds were CH_4 emission "hotspots" in the subtropical estuaries of China. Based on a new global warming potential model, we conservatively estimated an anuual GHG emission rate of approximately 63.68 Tg CO_2-eq during the culture period from aquaculture ponds across the subtropical estuaries of China. Our results demonstrate the importance of aquaculture ponds as a major GHG source and a contributor to climate warming in the subtropical estuarine regions of China, and call for effective regulation of GHG emissions from these ponds for climate mitigation in future.

---

* Corresponding author.
** Corresponding author at: School of Geographical Sciences, Fujian Normal University, Fuzhou 350007, PR China.
E-mail addresses: dyflai@cuhk.edu.hk, (D.Y.F. Lai), tongch@fjnu.edu.cn. (C. Tong).
[1] Ping Yang and Yifei Zhang contributed equally to this work.

https://doi.org/10.1016/j.scitotenv.2018.04.102
0048-9697/© 2018 Elsevier B.V. All rights reserved.

1. Introduction

Carbon dioxide (CO_2) and methane (CH_4) are two potent greenhouse gases (GHGs). Together, they contribute to approximately 80% of the overall radiative forcing of the atmosphere due to anthropogenic influence (Myhre et al., 2013). There is, however, uncertainty regarding the contribution of different sources to the global atmospheric budgets of these two gases (Walter et al., 2007; Musenze et al., 2014). Aquatic ecosystems are known to be important sources of both CO_2 and CH_4, and inland water (e.g., lakes, reservoirs, and rivers) in particular has been regarded as a strong source of atmospheric CH_4 (Schrier-Uijl et al., 2011; Bastviken et al., 2011; Raymond et al., 2013; Musenze et al., 2014; Tonetta et al., 2017). Recent estimates suggest that inland aquatic ecosystems could emit 1.4 Pg of C (CO_2-eq) year^{-1} in the form of CO_2 (Tranvik et al., 2009) and 0.65 Pg of C (CO_2-eq) year^{-1} in the form of CH_4 (Bastviken et al., 2011), which is equivalent to approximately 80% of the terrestrial carbon sink (Raymond et al., 2013; Tangen et al., 2016). However, these estimates are highly uncertain because the existing datasets have largely ignored the contribution of CO_2 and CH_4 emissions from shallow water ponds (Long et al., 2016), in particular, those created for aquaculture purposes.

Aquaculture ponds form an important component of the Earth's surface water ecosystems. They are widely distributed around the world, from the temperate to tropical regions. Based on the statistical data maintained by the Food and Agriculture Organization of the United Nations, the total global surface area of freshwater and brackish aquaculture ponds is estimated to be 110,832 km^2 (Verdegem and Bosma, 2009; Yang et al., 2018). These aquaculture ponds are generally maintained through daily feed supply to culture aquatic animals (Chen et al., 2015, 2016). However, only a small portion of the feed input is actually converted into fish biomass, with the feed utilization efficiency being as low as ~4.0%–27.4% (Molnar et al., 2013; Chen et al., 2015). Most of the added feeds end up accumulating within the aquaculture systems (Chen et al., 2015; Yang et al., 2017a) or are being discharged into adjacent bodies of water (Herbeck et al., 2013; Molnar et al., 2013; Chen et al., 2015). The organic residues (e.g. uneaten feeds, feces, and phytoplankton) generated during aquaculture production might provide an abundant supply of labile carbon and nitrogen to microbes that can stimulate microbial decomposition and subsequently GHG emissions (Yang et al., 2018). Some recent studies have suggested that aquaculture ponds might play a potentially significant role in GHG emissions (Boyd et al., 2010; Hu et al., 2012; Yang et al., 2015; Chen et al., 2016). To date, some efforts have been made on characterizing GHG fluxes in aquaculture ponds, especially in China (e.g., Hu et al., 2014; Yang et al., 2015; Chen et al., 2015, 2016; Hu et al., 2016; Wu et al., 2018). However, the number of field records of GHG emissions from aquaculture ponds remains small as compared to that from other aquatic systems (e.g., lakes and reservoirs). More importantly, the majority of existing studies of aquaculture pond GHG fluxes focused on an individual study area only, without making any cross-comparisons between study areas using the same methodology simultaneously. Previous studies have suggested that the spatiotemporal variation of GHG fluxes might introduce additional uncertainties in evaluating the contribution of aquatic systems to the atmospheric GHG budgets (Zhao et al., 2013; Musenze et al., 2014; Natchimuthu et al., 2016, 2017). Therefore, detailed field studies covering both the spatial and temporal dimensions are critical to better understand the variability, and improve the large-scale assessment of GHG emissions from aquaculture ponds.

China has the world's largest mariculture industry (FAO, 2016), with a total mariculture pond area and total aquaculture production of 2.57 × 10^4 km^2 and 2.30 × 10^9 kg, respectively, as of 2015 (Chen et al., 2016). Aquaculture is the most important method of shrimp production in the mariculture ponds of China that are widely distributed in the subtropical estuaries along the coastal zone (Yang et al., 2017b). These mariculture ponds are highly heterogeneous over time and space owing to variations in topography, environmental factors, and astronomical tidal levels, which may in turn lead to large uncertainties in the estimation of GHG production and emission rates. Yet, the variability of GHG fluxes from aquaculture ponds across different subtropical estuaries remains poorly documented. To improve our understanding of the variability of water-atmosphere exchange of CO_2 and CH_4 in shrimp ponds as well as the reliability of flux upscaling from pond to regional scales, we examined the magnitude and controls of CO_2 and CH_4 production and flux rates in the shrimp ponds of two different estuaries in the Fujian Province in southeast China in this study.

2. Materials and methods

2.1. Study area description

The two estuaries investigated in this study were Min River (26°00′–26°03′N, 119°34′–119°41′E) and Jiulong River (24°22′–24°30′N, 117°49′–117°56′E) that were both located in the Fujian Province in Southeast China (Fig. 1). The catchment areas of the Min and Jiulong Rivers cover 60,092 and 14,741 km^2, respectively, with annual discharges of 58.6 × 10^9 and 12.4 × 10^9 m^3 y^{-1}, respectively (Zhou et al., 2016). The climate in the Min River Estuary (MRE) is warm and wet, with a mean annual temperature of 19.6 °C and a mean annual precipitation of 1350 mm (Tong et al., 2010). The Jiulong River Estuary (JRE) is located in the subtropical oceanic climate zone, with a mean annual temperature of 21.0 °C and average annual precipitation of 1371 mm (Wang et al., 2016). The tides at the two sites are typically semidiurnal, with an average tidal range of approximately 4.5 m and 4.0 m in MRE and JRE, respectively. The average salinity of tidal water in MRE and JRE is 4.2 ± 2.5 ppt and 19.0 ± 5.7 ppt, respectively.

2.2. Shrimp pond system and management

Shrimp pond is one of the dominant landscape features in the two estuaries. Most of these ponds were converted by complete removal of the marsh vegetation. Aquaculture production in the majority of these ponds takes place between June and November, with only one single crop of shrimps being produced on an annual basis (Yang et al., 2017a). Prior to shrimp production, these ponds were filled with salt water from the adjacent estuary using a submerged pump. There was no water exchange during the culture period. The shrimps were fed with commercial aquatic feed pellets containing 42% protein (Yuehai™, Guangzhou, China) twice per day at 07:00 AM and 16:00 PM (local standard time), respectively, by direct application from a small boat. In each pond, three to five 1500 W paddlewheel aerators were activated four times a day between 07:00–09:00, 12:00–14:00, 18:00–20:00, and 00:00–03:00 (local standard time) to improve oxygen supply. The water depth in these shrimp ponds ranged between 1.1 and 1.8 m over the culture period. Further details about the shrimp pond system and the associated management practices can be found in our previous paper (Yang et al., 2017a).

To assess the variations of CO_2 and CH_4 production and fluxes between the two estuaries and among the three shrimp growth stages, we collected water, sediment, and gas samples from three replicate commercial shrimp ponds in the Shanyutan Wetland (26°01′49″N, 119°37′39″E) in MRE and the Humao Island (24°26′10″N, 117°53′36″E) in JRE (Fig. 1), respectively. Basic information about the selected shrimp ponds in the two estuaries are given in Table S1. Based on the management practices (e.g. feeding rate, water depth, etc.), water salinity, and shrimp weight, we divided the shrimp grow-out cycle into three different stages (Table S2), similar to the classification scheme adopted by Páez-Osuna et al. (1997), for further investigation.

2.3. Gas sampling and flux estimation

Taking into account the three different culture phases (i.e. early, middle, and late) of the shrimp grow-out cycle as well as the logistical