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A comparison of methane and nitrous oxide emissions from inland mixed-fish and crab aquaculture ponds

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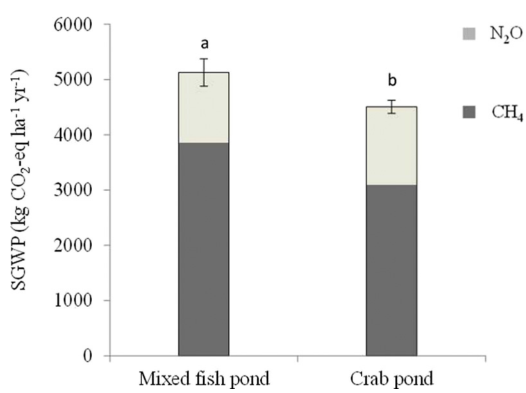
HIGHLIGHTS

- The annual CH_4 emissions were 64.4 kg C ha^{-1} from mixed fish pond and 51.6 kg C ha^{-1} from crab pond.
- The annual N_2O emissions were 2.99 kg N ha^{-1} from mixed fish pond and 3.22 kg N ha^{-1} from crab pond.
- CH_4 emissions in the mixed fish pond were higher and N_2O emissions were lower than the crab pond.
- CH_4 emissions were 14.0% greater in the area with aquatic vegetation than that without aquatic vegetation.

GRAPHICAL ABSTRACT



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ABSTRACT

Inland aquaculture ponds in China collectively cover 2.57 million ha, so emissions of the greenhouse gases methane (CH_4) and nitrous oxide (N_2O) from these ponds may constitute a significant contribution to global warming. During 2016 and 2017, CH_4 and N_2O fluxes and a range of pond-water and sediment properties were measured in replicated ($n = 4$) "mixed-fish" and "crab" aquaculture ponds in southeast China. Annual CH_4 and N_2O emissions were 64.4 kg C ha^{-1} and 2.99 kg N ha^{-1}, respectively, from the "mixed-fish" ponds, and 51.6 kg C ha^{-1} and 3.32 kg N ha^{-1}, respectively, from the "crab" ponds. Emission differences between pond types were significant ($p < 0.05$) for both gases. CH_4 fluxes from the "crab" ponds were significantly increased by the presence of aquatic vegetation, but N_2O fluxes were not affected. Emissions of N_2O were estimated to be 0.54% and 0.71% of the total nitrogen input (in the feed) for the "mixed-fish" and "crab" ponds, respectively. The net economic benefit-scaled sustained-flux global warming potential (NEB-scaled SGWP) of the "crab" ponds was 61.6% higher ($p < 0.05$) than that of the "mixed-fish" pond. Our CH_4 and N_2O emissions results suggest that aquaculture ponds can be

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Crab aquaculture pond
NEB-scaled SGWP

important contributors to regional and national GHG inventories, with aquaculture type an important factor in total GHG impact. Further CH_4 and N_2O flux research is needed at aquaculture ponds across China to better establish the range of potential GHG impacts, and to confirm the importance of the influencing factors identified in this study.

1. Introduction

Methane (CH_4) and nitrous oxide (N_2O) are key radiatively active greenhouse gases (GHGs) in the atmosphere. Over a 100-year time scale, the global warming potential (GWP) of CH_4 and N_2O are 28 and 265 times that of carbon dioxide (CO_2), respectively (IPCC, 2013a). Overall, CH_4 and N_2O contribute 16% and 6%, respectively, to global radiative forcing, and their atmospheric concentrations are rapidly increasing (World Meteorological Organization, 2016).

Aquatic ecosystems are significant sources of atmospheric CH_4 and N_2O. To date, most research on GHG emissions from aquatic ecosystems has focused on natural lakes (Huttunen et al., 2003), rivers (Aufdenkampe et al., 2011; Clough et al., 2011; Yang et al., 2015), ditches (Schrier-Uijl et al., 2011) and reservoirs (Huttunen et al., 2003; Diem et al., 2012). These studies found that variations in GHG emissions were linked to weather, water thermal regimes, nutrient content and other environmental factors (Natchimuthu et al., 2014).

Aquaculture is an important anthropogenic source of GHG emissions which has recently received worldwide attention (Liu et al., 2016). Aquaculture ecosystems receive large amounts of nutrient inputs to accelerate primary production (Serrano-Grijalva et al., 2011; Zhang et al., 2015; Xiao et al., 2017). The organic feeding material used can also have significant effects on microbial processes, which in turn affect carbon (C) and nitrogen (N) biogeochemical processes that emit CH_4 and N_2O (Yang et al., 2015).

Current knowledge of GHG fluxes from aquaculture ponds is limited. The most recent Intergovernmental Panel on Climate Change (IPCC) report provides methodological guidance on CH_4 emissions, but no field measured data of direct emissions. Methodologies are available to calculate emission factors and estimate N_2O emissions from aquaculture ponds (IPCC, 2006). The model results based on indirect calculations suggest that global N_2O-N emissions from aquaculture will increase from 9.30×10^{10} g to 3.83×10^{11} g by 2030, which will account for 5.72% of global anthropogenic N_2O emissions if the world aquaculture industry continues to grow at the present annual growth rate of 7.1% (Muralidhar et al., 2017). These modeling results must be validated and calibrated with field N_2O flux measurements. There are few published measurements of direct CH_4 and N_2O fluxes from aquaculture ponds (Hu, 2015; Liu et al., 2016), with most focusing on CH_4 and N_2O emissions from the conversion of rice paddies to inland aquaculture ponds. Environmental factors that potentially affect GHG production should also be evaluated, including temperature (T), pH, dissolved oxygen (DO), and C substrate availability (Xing et al., 2005; Yang et al., 2015; Liu et al., 2016).

Aquaculture is the fastest-growing food-production sector in China due to the increasing population and a rapidly expanding consumer demand for fish (Williams et al., 2010). Collectively, aquaculture ponds in China cover 2.57 million ha, about 10% of the total cropping area (Cao et al., 2011). The Taihu Lake region (Yangtze Delta Plain) is one of the most intensive regions of aquaculture, particularly for fish and crab production (Cao et al., 2007).

The objectives of this study were to (1) quantify and compare CH_4 and N_2O emissions from inland "mixed-fish" and "crab" aquaculture ponds in the Taihu Lake region, and (2) to determine the properties driving temporal variation in CH_4 and N_2O fluxes. This data will be used to more accurately quantify the GHG budget and GWP of the Chinese aquaculture industry.

2. Materials and methods

2.1. Experiment site

Field experiments were carried out during 2016–2017 in "mixed-fish" and "crab" aquaculture ponds at the Changshu Agro-Ecological Experimental Station (31°32′93″N, 120°41′88″E) of the Chinese Academy of Sciences in Jiangsu province. The two sets of ponds were approximately 200 m apart. The soil under the pond-water is an Anthrosol (FAO World Reference Base) developed from lacustrine sediments, and has a silty clay texture. Physicochemical properties of the sediment are detailed in Table 1.

2.2. Field experiments in the "mixed-fish" and "crab" ponds

Four "mixed-fish" aquaculture ponds (50 × 140 m) and four "crab" aquaculture ponds (50 × 100 m) were set up as experimental replicates. The "mixed-fish" and "crab" ponds were 2.0 m and 1.4 m deep, respectively. On 22 March 2016, the "mixed-fish" ponds were fry-stocked with 250 kg ha^{-1} of black carp (*Mylopharyngodon piceus*), 650 kg ha^{-1} of grass carp (*Ctenopharyngodon idella*), and 270 kg ha^{-1} of chub (*Hypophthalmichthys molitrix*). Each "crab" pond was split into 'with aquatic vegetation' or 'without aquatic vegetation'. On 14 March 2016, *Elodea nuttallii* was planted across 60% of the bottom sediment area of each pond to provide food and a molting shelter for the crabs. On 28 March 2016, young crab fry (*Eriocheir sinensis*) were stocked at 100 kg ha^{-1}. Sudan grass (*Sorghum sudanense*), snail compound feed, and pellet feed were used as feed in the "mixed-fish" pond, while corn, hairtail, and compound feeds were used for feed in the "crab" ponds. The total annual N input was 550 kg N ha^{-1} in the "mixed-fish" ponds and 469 kg N ha^{-1} in the "crab" ponds. These stocking rates and feed inputs were in line with local commercial "mixed-fish" and "crab" farming practices. Details of aquaculture operations and N inputs are given in Table 2.

2.3. Measurement of CH_4 and N_2O fluxes

Gas emissions from the water-atmosphere interface were collected with floating static chambers (Liu et al., 2016), consisting of a floating bottom collar and a PVC open-bottomed chamber (50 cm × 50 cm × 50 cm). During the pond drainage period, emissions from the sediment-atmosphere interface were collected with enclosed static chambers (Ma et al., 2013). The enclosed static chamber was 0.5 m high, covered an area of 0.25 m^2, and was placed on a PVC frame inserted into the sediment.

Gas fluxes were measured three or four times per month in both pond types (water-atmosphere interface: March 2016–December 2016; sediment-atmosphere interface: January 2017–March 2017). All samples were collected between 09:00 and 11:00 am. During sampling, gas samples were transferred from the chambers into airtight 500 mL gas sampling bags at 10 min intervals for 40 min after chamber closure. The airtight gas sampling bags were pre-evacuated to approximately 0 Pa. The CH_4 and N_2O concentrations were analyzed using a gas chromatograph (Agilent 7890) equipped with a flame ionization detector (FID) and an electron capture detector (ECD). The CH_4 and N_2O fluxes