Environmental Pollution 212 (2016) 489–497

Contents lists available at ScienceDirect

Environmental Pollution

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

Carbon dioxide and methane fluxes from feeding and no-feeding mariculture ponds☆

Yan Chen [a, b], Shuanglin Dong [a, b, *], Fang Wang [a, b], Qinfeng Gao [a, b], Xiangli Tian [a, b]

[a] Key Laboratory of Mariculture, Ministry of Education of China, Ocean University of China, Qingdao, 266003, PR China
[b] Function Laboratory for Fisheries and Aquaculture, Qingdao National Laboratory for Marine Science and Technology, Qingdao, PR China

ARTICLE INFO

Article history:
Received 1 November 2015
Received in revised form
20 February 2016
Accepted 20 February 2016
Available online 8 March 2016

Keywords:
Mariculture ponds
Carbon dioxide flux
Methane flux
Global warming potential

ABSTRACT

The CO_2 and CH_4 fluxes at the water–air interface were measured in shrimp (*Marsupenaeus japonicus*) monoculture ponds (S) with feed supply and shrimp-sea cucumber (*Apostichopus japonicus*) polyculture ponds (SS) without feed supply. During farming seasons of the whole year, cumulated CO_2–C fluxes were -5.69 g m^{-2} (S) and 11.23 g m^{-2} (SS), respectively. The cumulated CO_2 emissions from S and SS did not differ significantly. The cumulated CH_4–C emissions from S (0.57 g m^{-2}) were significantly higher than those from SS (0.068 g m^{-2}). S absorbed C from the atmosphere with a mean absorption rate of -5.12 g m^{-2}, whereas SS emitted C to the atmosphere with a mean emission rate of 11.30 g m^{-2}. Over 20-year horizon, the compressive global warming potentials (cGWPs) were 33.55 (S) and 47.71 (SS), respectively, indicating both feeding and no-feeding mariculture ponds could promote global warming.

1. Introduction

Carbon dioxide (CO_2) and methane (CH_4) are key greenhouse gases (GHGs) contributing to global warming. CO_2 concentration in the atmosphere was up to 389 ppm in 2010 corresponding to a 39% increase since the industrial revolution (NOAA, 2010). Methane (CH_4) is second only to CO_2 in volume, but 72 times greater than CO_2 on a mass basis in global warming potential (IPCC, 2007). The increase in CO_2 and CH_4 concentrations in the atmosphere has already incentivized many studies on terrestrial and aquatic ecosystem CO_2 and CH_4 cycles during the past decades (Bange et al., 1994; Kirschke et al., 2013; Ortiz-Llorente and Alvarez-Cobelas, 2012; Raymond et al., 2013; Striegl et al., 2012).

The CO_2 and CH_4 fluxes at the water–air interface vary among aquatic ecosystems. Inland lakes are a potential source of atmospheric CO_2, and Cole et al. (1994) estimated global CO_2 emissions from inland lakes to be 0.14 Pg yr^{-1} (Pg $= 10^{15}$ g). Additionally, inland lakes were found to emit CH_4 at a mean rate of 18.1 mg CH_4 m^{-2} h^{-1}, and the emission rates in eutrophic waters were higher than those of oligotrophic lakes (Juutinen et al., 2009; Ortiz-Llorente and Alvarez-Cobelas, 2012). Bastviken et al. (2004) estimated that inland lakes emit 8–48 Tg CH_4 yr^{-1} (Tg $= 10^{12}$ g) globally. Oceans are considered the dominant player in global carbon cycle, and the carbon storage in oceans is about 3.9×10^{16} kg corresponding to 93% of the total carbon in the global ecosystem. On a multi-millennial timescale, the oceans will be the sink for 80–95% of the anthropogenic CO_2 emissions (Archer et al., 2000). Currently, the oceans take up about 25% of the emissions (Rödenbeck et al., 2013), and coastal areas account for about 50% of the total absorption (Cai et al., 2006). On the other hand, oceans emit an estimated 10.9–17.8 Tg CH_4 annually (Bange et al., 1994; Ortiz-Llorente and Alvarez-Cobelas, 2012). Both estuarine and coastal areas produce more CH_4 as organic matter of continental origin in these places is richer than other marine ecosystems (Naqvi et al., 2010; Ortiz-Llorente and Alvarez-Cobelas, 2012; Zhang et al., 2008). Mariculture ponds play important roles in marine ecosystems. According to statistical data maintained by China Fisheries Yearbook 2015, the combined water surface area of mariculture ponds is estimated to be 2,566,900 ha in China, and the total production through mariculture ponds are 2.30×10^9 kg. However, no detailed studies have been conducted to investigate CO_2 and CH_4 sink/source functions at the water–air interface of mariculture ponds.

The maintenance of mariculture pond ecosystems depends on artificial management such as stocking, feeding, harvesting, water exchange, etc. Some mariculture ponds are maintained through

☆ Both the feeding and no-feeding mariculture ponds promote global warming at the water–air interface.

* Corresponding author. Key Laboratory of Mariculture, Ministry of Education of China, Ocean University of China, Qingdao, 266003, PR China.
E-mail address: dongsl@ouc.edu.cn (S. Dong).

http://dx.doi.org/10.1016/j.envpol.2016.02.039
0269-7491/

daily feed supply to produce aquatic animals. Such ponds retain a large quantity of organic carbon from residual feed and feces. Only a small portion of the nutrient input into mariculture ponds is converted into shrimp production and the feed utilization efficiency is about 4.0–27.4%. Most of the organic carbon input remains in aquaculture systems or is discharged to adjacent water bodies (Liu et al., 2002; Su et al., 2009). However, some mariculture ponds, such as sea cucumber farming ponds, are maintained without feed supply. Sea cucumber (*Apostichopus japonicus*) is one of the dominant mariculture species in northern China, and total production reached over 214,180,000 kg in 2014 (China Fisheries Yearbook, 2015). Sea cucumbers *A. japonicus* are deposit feeders, ingesting sediment to gain nutrients from organic matter, bacteria and protozoa. It has been proved that the nutrient loading on the bottom is relieved through sea cucumber culture (Zheng et al., 2009).

Feed supply will influence the CO_2 and CH_4 fluxes of aquaculture ponds at the water–air interface. Some studies have shown that CO_2 emissions decrease when primary production is high, or that CO_2 sequestration is enhanced with increases in primary production (Takahashi et al., 2002; Xing et al., 2005). However, the decomposition of organic carbon from residual feed, faeces and phytoplankton can also accelerate CO_2 emissions (Burford et al., 2003; Cai et al., 2006; Chen et al., 2015). Many studies have suggested that the decomposition of allochthonous organic carbon can stimulate CH_4 production (Datta et al., 2013; Huttunen et al., 2003; Li et al., 2012; Repo et al., 2007). In addition, the mineralization of allochthonous organic carbon can lead to phytoplankton blooms and the newly produced autochthonous organic matter is able to supply more substrates for methanogenesis (Jayakumar et al., 2001; Repo et al., 2007; Yvon-Durocher et al., 2011). Therefore, the feeding and no-feeding mariculture ponds may have different impact on CO_2 and CH_4 fluxes at the water–air interface.

In the present study, annual CO_2 and CH_4 fluxes at the water–air interface were measured in three shrimp monoculture ponds (S) with feed supply and three shrimp and sea cucumber polyculture ponds (SS) without feed supply to quantify the effects of feeding on CO_2 and CH_4 fluxes.

2. Methods

2.1. Experimental ponds

The study was carried out at a mariculture base at Qingdao (36°18′N, 120°00′E), Shandong Province, China, which represents a typical temperate monsoonal climate of mean annual temperature of about 12.3 °C. The mean annual precipitation is 662.1 mm. There is much more precipitation in summer than in other seasons. The study was conducted in 3 shrimp *Marsupenaeus japonicus* monoculture ponds (S, 160.0 m length × 59.7 ± 5.1 m width × 2.5 ± 0.1 m depth) (means ± S.D., n = 3) and 3 sea cucumber *A. japonicus*-shrimp polyculture ponds (SS, 160.0 m length × 70.3 ± 7.8 m width × 3.0 ± 0.1 m depth) (means ± S.D., n = 3) from 30 March, 2014 to 26 March, 2015. Ponds used in this study were selected randomly. There are two crop farming seasons of the shrimp *M. japonicus* in S ponds: Spring (from 30 March to 20 July) and Autumn (from 3 August to 22 November). The fresh clam *Potamocorbula laevis* and trash fish were given daily to S as feed. The seawater in the ponds was routinely exchanged though water in-outlet during spring tides. Juvenile sea cucumbers were stocked on 7 April in SS and the culture time lasted for 1 year. No supplemental feed was provided to SS during the study period and other managements including water exchange, stocking and harvesting the shrimp *M. japonicus* etc. were consistent with S. The information of stocking densities of shrimp *M. japonicus* and sea cucumber *A. japonicus* are listed in Table 1.

2.2. Gas samples collection and analysis

Gas sampling was taken at roughly 1-week or 2-week intervals at a fixed time (9:00–11:00 AM). CO_2 and CH_4 at the air–water interface were collected with the floating static chambers. Three replicate chambers were placed on each pond. The floating chambers (50 cm in height and 30 cm in diameter) were made from Plexiglas, and covered by aluminum foil to avoid high temperature in summer resulting from direct sunlight (Chen et al., 2015). A small vertical vent stopped by silicon septum on the top was used for sampling, and a 4.5v dry battery driven fan was equipped inside the chamber to mix air but not to disturb the water–air interface. Prior to sampling, the syringe was pumped several times to mix the air inside the chamber. Four samples were drawn from the chamber via 100 mL Tygon syringes at 0, 10, 20, and 30 min after deployment. These air samples were driven into evacuated sample bags, and transported to laboratory in a cool box.

Gas samples were analyzed as soon as possible with the GC–2010 plus Gas Chromatograph (Shimadzu) connected with a MGS–4 gas sampler and MTN–1 methanizer. The gas samples were injected into the MGS–4 gas sampler and CH_4 concentrations in gas samples were determined with a FID detector at 100 °C after being separated from column SS–2 m × 2 mm at 40 °C packed with TDX (60–80 mesh). The separated CO_2 was converted into CH_4 in the MTN–1 methanizer by Nickel catalyst at 375 °C and then was determined with a FID detector at 100 °C. The carrier gas (N_2) flow rate was 20 mL min^{-1}, and flame gases (H_2 and compressed air) were set at 18 and 30 mL min^{-1} respectively. Standard gases were measured every four gas samples in order to determine the sample concentrations and check the errors. The CO_2 and CH_4 fluxes were calculated from the linear changes in time inside the chamber.

2.3. Global warming potential (GWP)

Global Warming Potential (GWP) is used as a method for comparing the potential climate impact of emissions of different greenhouse gases (IPCC, 2007). The GWP is the time-integrated radiative forcing due to a pulse emission of a given gas, over some given time period relative to a pulse emission of CO_2. Emission targets are set in terms of equivalent emissions of CO_2, where the CO_2 equivalence of emissions of other greenhouse gases e.g. methane is determined using the GWP with a time horizon (Shine et al., 2005). We applied the value of GWP over 20 years, and the corresponding values are 1 for CO_2 and 72 for CH_4 (IPCC, 2007).

2.4. Water samples collection and analysis

At the same time, 9 water samples (samples of surface, middle and bottom water layers in 3 different sites) were taken from each pond with a horizontal sampler. Water temperature and pH was measured with an acidometer (PHS–3C; Shanghai REX Instruments, Shanghai, China) *in situ* when the samples were collected. The samples were stored in clean plastic bottles (2 L) and transported to the laboratory immediately. TN (Total nitrogen) of the water was analyzed using the potassium peroxydisulfate oxidation method developed by Grasshoff et al. (2009), and TP (Total phosphorus) was analyzed according to Murphy and Riley (1962). Chl *a* (Chlorophyll *a*) was extracted with acetone (90%) in darkness for 24 h after filtration of water samples through GF/F glass microfiber filters and analyzed according to the method of National standardization management council (2007). Water samples for DOC (Dissolved organic carbon) were analyzed by multi–2100s TOC analyzer (Analytikjena) after being filtered through pre-combusted (450 °C, 2 h) Whatman GF/F-filters. The quantity of feed supplied to S was noted daily. The survival and