CO_2 and CH_4 flux from the water-air interface of three shrimp culture technologies

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Abstract. Shrimp farming in ponds leads to increase in greenhouse gas (GHG) emissions such as CO_2 and CH_4, due to land conversion and culture processes. The purpose of this study was to examine the rate of CO_2, and CH_4 cross water-air interface fluxes during shrimp farming in ponds with three different cultivation technologies (i.e. extensive, semi-intensive and intensive) and the related environmental parameters. The samples of CO_2, CH_4 gas and aquatic environmental parameters were taken from the shrimp pond area in Karawang, West Jawa - Indonesia every 10 days. The research was conducted from day of culture zero (DOC-0) until harvesting time at 3 ponds for each cultivation technology. The results showed variation in CO_2 and CH_4 water-air interface fluxes in three cultivation technologies. The estimated average CO_2 emissions during shrimp farming in extensive, semi-intensive and intensive ponds were 0.19575 g m^{-2} day^{-1}, 0.35019 g m^{-2} day^{-1}, and 0.14965 g m^{-2} day^{-1} respectively, while CH_4 production were 0.00063 g m^{-2} day^{-1}, 0.00024 g m^{-2} day^{-1} and 0.00022 g m^{-2} day^{-1}, respectively. The average Global Warming Potential (GWP) CO_2-e for each cultivation technology is 96.55 g m^{-2} day^{-1}, 80.92 g m^{-2} day^{-1} and 27.75 g m^{-2} day^{-1}, respectively. It is influenced by environmental parameters such as the concentration of CO_2 and CH_4 in air, water temperature, chlorophyll *a*, pH, NO_2^-, NO_3^-, and $PO4^-$.
Key Words: GHG emission, sink carbon, source carbon, shrimp ponds.

Introduction. Climate change triggered by global warming is attributed to the accumulation of greenhouse gases (GHG) in the atmosphere (CO_2, CH_4, and N_2O) (IPCC 2001). For instance, conversion of mangrove ecosystem into shrimp ponds causes 58-82% loss of ecosystem carbon stocks, increasing the average potential emissions to 1,390 Mg CO_2-e ha^{-1} (Kauffman et al 2018). During shrimp culture, there are potential CO_2 emissions of 4.37 kg CO_2 m^{-2} $year^{-1}$ from embankment and 1.60 kg CO_2 m^{-2} $year^{-1}$ from the bottom of intensive ponds (Sidik & Lovelock 2013). Similarly, on the energy use produce 89.48 kg CO_2 day^{-1} during pond preparation phase and 751.87 kg CO_2 day^{-1} during the nearly-harvested phase. Similarly, the potential CH_4 emissions during pond preparation phase is 1.24-64.61 mg kg^{-1} of waste $year^{-1}$ and 0.45-1.08 mg kg^{-1} of waste $year^{-1}$ in the nearly-harvested phase (Dewata 2013).

Improper management of shrimp ponds had an enormous potential to emit CH_4 into the atmosphere (Yang et al 2019a). Both the shrimp farming (*Marsupenaeus japonicus*) that were fed, and polyculture shrimp and sea cucumber (*Apostichopus japonicus*) without fed might facilitate global warming with total GWP values of 33.55 and 47.71 respectively (Chen et al 2016). However, there was no information comparing CO_2 and CH_4 cross-water interface shrimp pond fluxes of three different cultivation technologies. Cross water-air interface fluxes can be used to measure gross GHG flux between water and air with the simple method using floating chamber (Lambert & Fréchette 2005).

The release of carbon elements into the atmosphere may produce greenhouse gas compounds such as CO_2 and CH_4 through biological processes (Setyanto 2008). The microorganisms activity in using organic matter affected the rate of GHG emissions (Dariah et al 2011). Generally, greenhouse gas samples are taken manually for emissions measurement in the morning, afternoon, and evening (Hervani & Wiharjaka 2014). Nevertheless, in tropical shrimp pond an experiment showed that it was needed to be conducted at 8-11 A.M (Rifqi et al 2020).

Climate change due to global warming are considered to affect the aquaculture business, including shrimp farming (Ahmed & Diana 2015). It caused a decrease in survival and growth rate, and ultimately reducing shrimp production in ponds (Ahmed & Diana 2015; Ahmed & Thompson 2019). It is therefore essential to estimate GHG emissions during shrimp culture in ponds for predicting the impact on global warming (Vasanth et al 2016).

Data on the amount of CO_2 and CH_4 cross water-air interface fluxes from the pond during shrimp culture are needed in preparing a plan for developing a sustainable and low carbon emission shrimp pond areas. This research was aimed to estimate the amount of CO_2, and CH_4 cross water-air interface fluxes in shrimp ponds with three different technologies.

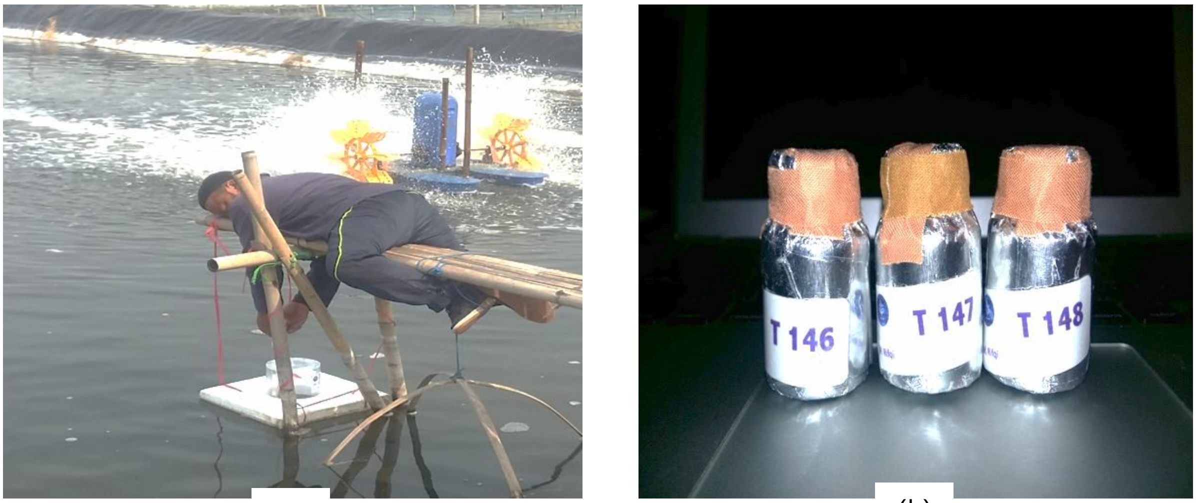
Material and Method

Pond research location. This research was carried out in the first cultivation season of April-July 2019 in Karawang shrimp ponds area, West Jawa - Indonesia. The study was conducted in 9 shrimp ponds with three different cultivation technologies (extensive, semi-intensive and intensive). The examination was conducted at each technology with three replicates. All of the 5000 m^2 extensive ponds are earthen ponds with area 5,000 m^2 (125 m x 40 m). Whereas 2000 to 2,400 m^2 semi-intensive and intensive shrimp ponds are fully plastic lined ponds. Rainfall during April-July is relatively low, ranging between 39 and 126 mm with only 5-9 rainy days (BPS Karawang Regency 2017).

All ponds were stocked with Specific Pathogen Free (SPF) *Litopenaeus vannamei* post larvae from local hatchery. Stocking density of extensive, semi-intensive and intensive shrimp culture technology were 5 shrimps m^{-3}, 70 shrimps m^{-3} and 145 shrimps m^{-3}, respectively. The protocol of semi-intensive and intensive shrimp culture follows the Standard Operational Procedure (SOP) set up by each farm manager. In general, shrimp were routinely fed with commercial pellet 4 to 5 times a day. The feeding rate was based on the weekly growth and ages, and both of the shrimp culture technologies are equipped with paddlewheel aerators. However, in the extensive shrimp culture technology, they were given no additional feed and no paddlewheel aerator applied. In semi-intensive and intensive ponds, water replacement to dispose of pond bottom sludge starts from the shrimp are day of culture (DOC) 30 and is carried out every 3-5 days. In intensive ponds, water replacement is carried out quite often. In case there is adequate visibility, no water replacement is performed in extensive ponds. The water addition is only conducted to replace the volume lost due to evaporation.

Gas sampling and analysis. In the sampling of CO_2 and CH_4 gas, static, closed, and floating cylinder chamber methods were used (Lambert & Fréchette 2005; Tangen et al 2016; Chen et al 2016; Vasanth et al 2016; Yang et al 2017; Yang et al 2018) as shown in Figure 1a. The cylinder chamber has a diameter and height of 20 cm and headspace of 18 cm. The chamber is made of transparent acrylic for easy observation of the temperature on the thermometer. The cap float uses styrofoam, and therefore the chamber floats on the water surface with the bottom 2 cm submerged to avoid gas leakage.

The sampling of CO_2 and CH_4 gas and the related environmental parameters are determined at 10 days interval from the shrimp stocking (DOC 0) to harvesting. This takes 80, 110, and 70 days for traditional, semi-intensive, and intensive shrimp ponds technologies, respectively. The samples were taken from 08.00-11.00 local time (Chen et al 2016; Yang et al 2017; Rifqi et al 2020). The amount of CO_2 and CH_4 cross water-air interface fluxes is determined 3 times at the intervals of 0, 30, and 60 minutes after the chamber is installed (Queiroz et al 2019). The gas from the chamber was collected using a 20 mL syringe through a hose mounted (Setyanto 2000). The syringe is pumped severally before samples are taken to ensure the air is uniform inside the chamber (Chen et al 2016). To deliver the gas to the laboratory, the sample was inserted into a 10 mL vacuum vial covered with rubber and iron ring to maintain high pressure (Bloom et al 2010; Marwanto et al 2019) as shown in Figure 1b.



(a) (b)

Figure 1. (a) The static, closed, and floating cylinder chamber to collect CO_2 and CH_4 gas sample, (b) The gas sample in vacuum vial covered with rubber and iron ring.

The samples were analyzed by gas chromatography (GC) at the Agricultural Environment Research Institute in Pati – Province Central Jawa. The GC is equipped with a thermal conductivity detector (TCD) to measure CO_2 concentrations and flame ionization detectors (FID) for determining CH_4 concentrations (Figure 2).

Figure 2. The gas chromatography (GC) of the Agricultural Environment Research Institute in Pati – Province Central Jawa.

Calculation of CO_2 and CH_4 emissions follow the equation below (IAEA 1992; Lambert & Frechette 2005; Sa'ad et al 2007):

$$E = \frac{Bm}{Vm} \, x \, \frac{dc}{dt} \, x \, \frac{V}{A} \, x \, \frac{273.2}{T + 273.2}$$

where: E = emission CO_2 or CH_4 (mg m^{-2} $minute^{-1}$);
V = chamber volume (m^3);
A = wide of chamber base (m^2);
T = average of air temperature in the chamber (^oC);
dc/dt = rate of change of CO_2 and CH_4 gas concentrations;
Bm = CO_2 and CH_4 gas molecular weights;
Vm = the volume of gas at STP is 22.41 liters.

The dc/dt ratio is obtained from the slope of the regression equation in the change of gas sampling concentration (Chen et al 2016; IAEA 1992; Lambert & Frechette 2005).

Global warming potential*.* Global warming potential (GWP) is a method of comparing the strength of radiation from different gases such as CO_2 and CH_4. It primarily helps to determine whether a gas has warms or cools the climate (Neubauer & Megonigal 2015). The GWP unit used is CO_2-e, where the CO_2 GWP value = 1, while the GWP CH_4 = 72 (IPCC 2007). Therefore, the GWP value of shrimp ponds was calculated from the sum of CO_2 add 72 times CH_4 emissions.

Statistical analysis*.* The difference between CO_2 and CH_4 water-air interface fluxes between the three cultivation technologies is determined using one-way ANOVA and independent-sample t-test at p = 0.05 (Yang et al 2017). The estimation of the total interface fluxes during the shrimp culture in ponds is carried out using the Single Exponential Smoothing (SES) method. In general, SES refines data by removing irregular components (Risteski et al 2004; Gardner & Diaz-Saiz 2008; Raharja et al 2010). However, it is challenging to determine the best parameter value with a small error using the exponential smoothing method. The package forecasts for R software find the best parameter values in historical data (Chapman & Feit 2019).

The influence of aquatic environmental factors on CO_2 and CH_4 interface fluxes on each of the technologies is determined through Partial Least Square Regression (PLS). The analysis was conducted with R-studio software with the tidyverse package, pls and mdatools (de Jong 1993; Tobias 1995; Indriati 1997; Chong & Jun 2005; Rajalahti et al 2009; Chapman & Feit 2019; Mevik & Wehrens 2019).

Results

Shrimp aquaculture environmental parameters in ponds*.* The dynamics of environmental parameters during shrimp culture in the ponds with three cultivation technologies are shown in Figure 3. The figure shows a drastic increase in CO_2 concentration in gas sampling at DOC 30 to 70 days (mid-May to June). This is attributed to the burning of straw after the harvest period within the research site. The high concentration of CO_2 in the air on traditional ponds is also influenced by the burning activity for land clearing around the pond. The pattern is almost the same as fluctuations in CH_4 concentration in air, but with lower values. The average air temperature is higher than the water warmth in traditional, semi-intensive, and intensive ponds.

The lowest and the highest average dissolved oxygen content is found in traditional and intensive shrimp ponds, respectively. The high dissolved oxygen content in intensive and semi-intensive ponds is attributed to the use of paddlewheel to increase diffusion process.

The highest and lowest average of chlorophyll *a* content was in intensive and traditional shrimp ponds, respectively. Additionally, pH and NO_2^- fluctuations during shrimp culture were found in traditional, semi-intensive, and intensive ponds. Relatively large fluctuations were at the beginning of the culture period, especially in semi-intensive ponds.

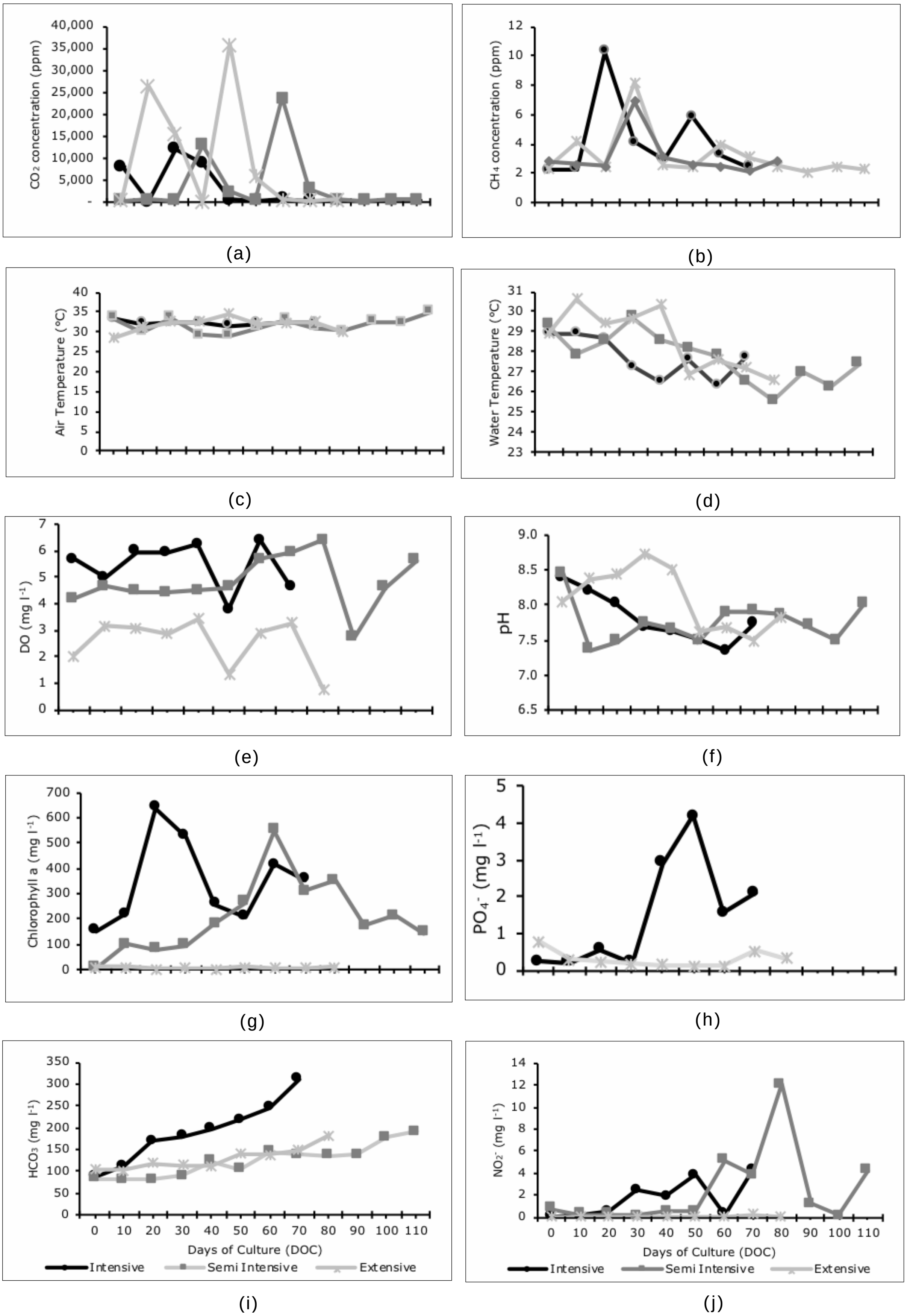


Figure 3. The average of (a) air CO_2 concentration, (b) air CH_4 concentration, (c) air temperature, (d) water temperature, (e) DO, (f) pH, (g) chlorophyll a (h) PO_4^- and (i) HCO_3 and (j) NO_2^- during shrimp culture in ponds with different cultivation technologies.

The average HCO_3 in 3 shrimp farming technologies tended to increase until the end of the culture period, though the highest average was in the intensive ponds. PO_4^- fluctuations during shrimp culture are found both in traditional and intensive ponds. Nevertheless, relatively large fluctuations were evident in intensive ponds.

CO_2 water-air interface fluxes. The activity of aquatic organisms in shrimp ponds is influenced by water environmental parameters, which causes fluctuations in CO_2 water-air interface fluxes. The dynamics during shrimp farming in 3 different cultivation technologies is shown in Figure 4.

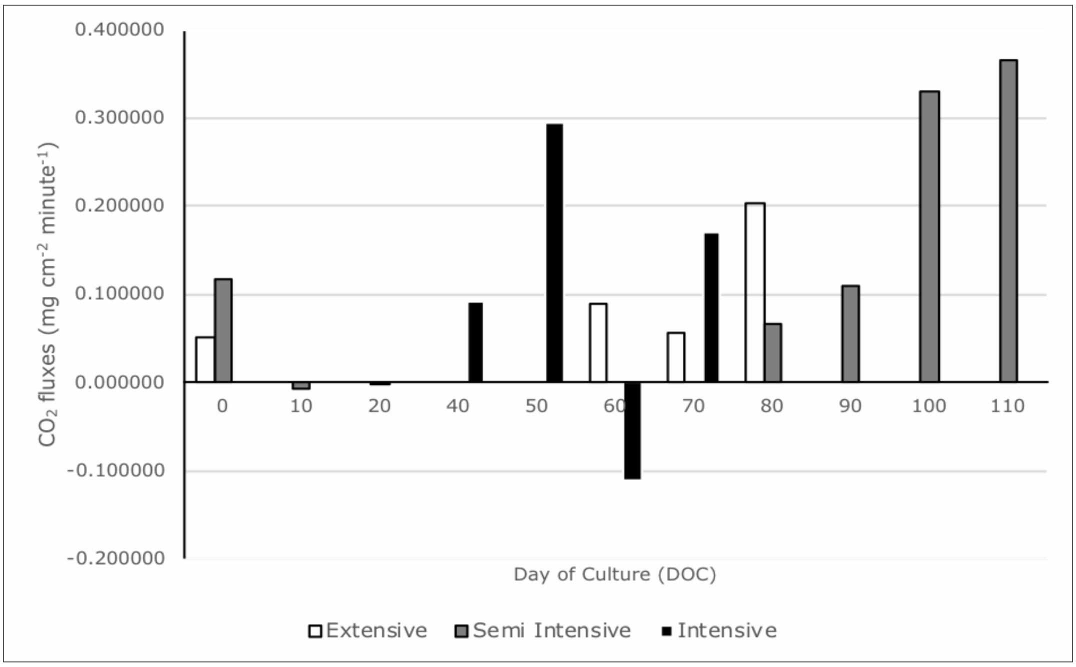


Figure 4. The dynamics of CO_2 water-air interface water fluxes in 3 shrimp farming technologies in a pond.

Figure 4 shows there are fluctuations in the amount of CO_2 water-air interface fluxes from extensive, semi-intensive, and intensive technology shrimp culture. Shrimp cultivation with traditional technology is a net source since the CO_2 water-air interface fluxes for 80 days of culture are positive (emissions). The 110 days of shrimp culture with semi-intensive and 70 days for intensive technology fluctuate as source (positive flux) or turns into the sink (negative flux). Generally, the negative flux indicates that the absorption of CO_2 by phytoplankton photosynthetic activity in the pond is more significant than its production, while the positive value shows the CO_2 absorbed is less than its yield. These two technologies seek to maintain the ideal conditions of population density and phytoplankton composition for high natural productivity.

Based on the average CO_2 water-air interface fluxes of the three cultivation technologies, a source with the emissions of extensive, semi-intensive and intensive shrimp culture technologies include 0.100400 ± 0.157053 mg m^{-2} minute^{-1}, 0.139930 ± 0.35259 mg m^{-2} minute^{-1}, and 0.111632 ± 0.15440 mg m^{-2} minute^{-1}, respectively. Although there were variations in the mean values of CO_2 water-air interface fluxes, one-way ANOVA test shows there were no significant differences in the three cultivation technologies ($p = 0.419$). Independent samples, of t-test, empirically are not enough to prove a significant difference between CO_2 water-air interface and extensive pond intensive fluxes ($p = 0.224$), extensive and semi-intensive ($p = 0.127$), and semi-intensive and intensive ponds ($p = 0.851$). Therefore, there are similarities in the various variables of the groups compared.

CH_4 water-air interface fluxes. The fluctuations in the CH_4 water-air interface fluxes from traditional, semi-intensive, and intensive shrimp ponds are shown in Figure 5 below.

The three shrimp culture technologies can be the source (emission) or sink (absorption) of CH_4 gas. CH_4 water-air interface fluxes are quite high during DOC 10 to 40 days, especially in the traditional/extensive ponds. In these ponds, high fluctuations in the interface were evident due to the absence of water replacement and bottom sludge removal. Based on the average CH_4 water-air interface fluxes during shrimp culture, the three culture technologies as source with the emissions of each traditional or extensive, semi-intensive and intensive technology are 0.000877 + 0.00142 mg m^{-2} $minute^{-1}$, 0.000131 + 0.00047 mg m^{-2} $minute^{-1}$, and 0.000119 + 0.00106 mg m^{-2} $minute^{-1}$, respectively.

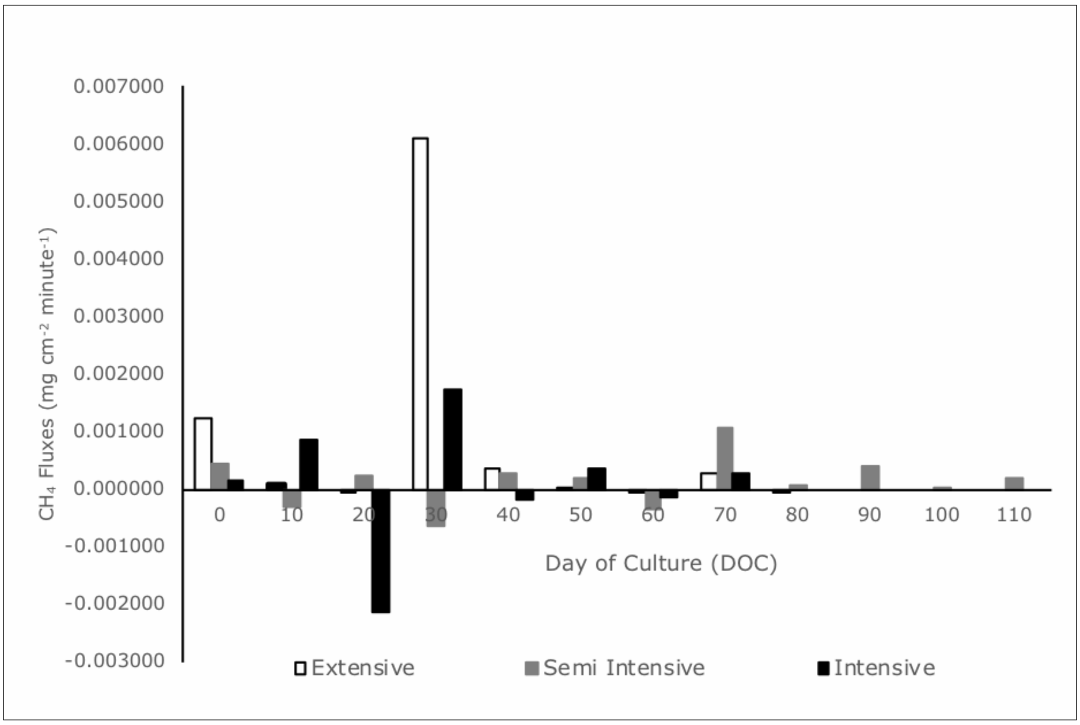


Figure 5. The dynamics of CH_4 water-air interface water fluxes in 3 shrimp farming technologies in a pond.

Although there was variation in the mean values of the fluxes in each cultivation technology, statistically, through the one-way ANOVA test, there were no significant differences in the variables ($p = 0.352$). Also, the independent-sample t-test did not show significant difference between CO_2 water-air interface and extensive pond intensive fluxes ($p = 0.383$), extensive and semi-intensive ($p = 0.057$), semi-intensive and intensive ponds ($p = 0.170$). Therefore, there are similarities between the variables and the groups compared.

Discussion

CO_2 and CH_4 emissions and Global Warming Potential of shrimp farming in ponds. CO_2 water-air interface fluxes during shrimp culture in extensive ponds ranged from 0.052178 to 0.202611 mg m^{-2} $minute^{-1}$ with an average of 0.100400±0.157053 mg m^{-2} $minute^{-1}$. In semi-intensive ponds, the range was -0.008120 to 0.365513 mg m^{-2} $minute^{-1}$ with an average of 0.139930±0.35259 mg m^{-2} $minute^{-1}$. The values in the intensive ponds ranged from -0.111393 0.295950 mg m^{-2} with an average of 0.111632±0.15440 mg m^{-2}, each per minute. The high variation of CO_2 flux was also found in the Soares & Henry-Silva (2019) research.

The results of this research indicate that the CO_2 emissions of shrimp ponds in three shrimp culture technologies are much lower compared to Otero et al (2017) on natural mangrove emissions, which is 11.2+19.17 tons of CO_2 ha^{-1} $year^{-1}$ or 2.13 mg m^{-2} $minutes^{-1}$. Moreover, the emissions in shrimp ponds are also lower compared to what rice field produces and ranged from 1.49 to 1.71 mg m^{-2} $minute^{-1}$ (Hervani & Wiharjaka 2014). Emissions of semi-intensive ponds during shrimp culture were higher than the daily fluctuations and ranges from -0.15841 to 0.22544 mg m^{-2} $minute^{-1}$ (Rifqi et al 2020).

The CH_4 water-air interface fluxes during shrimp culture in extensive ponds ranged from -0.000070 to 0.006097 mg m^{-2} $minute^{-1}$ with an average of 0.000877±0.00142 mg m^{-2} $minute^{-1}$. In semi-intensive ponds the flux ranged from -0.000658 to 0.001078 mg m^{-2} $minute^{-1}$ with an average of 0.000131±0.00047 mg m^{-2} $minute^{-1}$. In intensive ponds it ranged from -0.002122 to 0.001747 mg m^{-2} $minute^{-1}$ with an average of 0.000119±0.00106 mg m^{-2} $minute^{-1}$. The high amplitude of CH_4 flux variation was also evident in the Soares & Henry-Silva (2019) study.

The CH_4 emissions from shrimp ponds in three shrimp farming technologies are much lower compared to rice field emissions which ranged from 0.05 to 0.06 mg m^{-2} $minute^{-1}$ (Hervani & Wiharjaka 2014). The CH_4 emissions are also higher than the daily fluctuations that ranged from -0.00024 to 0.00023 mg m^{-2} $minute^{-1}$ (Rifqi et al 2020). In terms of density and , CH_4 emissions of ponds with low density and without the addition of fertilizer are higher than in high density with fertilizer (Soares & Henry-Silva 2019). According to Chen et al (2016), the CH_4 emission of shrimp farming fed was 0.57 g m^{-2} while the polyculture of shrimp and sea cucumber wihout feeding was 0.068 g m^{-2}. These emissions are higher than the values in this study, probably due to the temperature difference. The average temperature at the Chen et al (2016) research site is 12.3°C, a significantly lower value than the average in the pond water at this research site (28.32°C). Anaerobic carbon mineralization was also considered to be the primary control of CH_4 production (Segers 1998). The higher temperature increases the rates of electron acceptor reduction. However, the low concentrations of electron acceptors encourage the formation of CH_4 (Segers 1998).

CH_4 production and consumption are both biological processes, and therefore it is vital to understand its emissions (Segers 1998). In general, the CH_4 emissions relates to microbial activity in the anaerobic zone by methanogenic bacteria (Le Mer & Roger 2001). According to King (1994), the 1 class of microorganisms, specifically methanotrophs, consumes CH_4 in wetlands. With high dissolved oxygen content, the process of decomposition of organic matter occurs aerobically. Therefore, the potential for the formation of CH_4 is relatively lower (Yang et al 2019b).

The results of the analysis of observations of CO_2 and CH_4 emissions using single exponential smoothing had the estimated total value of CO_2 and CH_4 water-air interface fluxes during the shrimp culture period on the pond as shown in Table 1.

Table 1

The estimated total value of CO_2 and CH_4 emissions using single exponential smoothing

Cultivation technology	*Estimated average ($mg\ m^{-2}\ minutes^{-1}$)*	*80% Confidence rate*		*95% Confidence rate*	
		Lo	*Hi*	*Lo*	*Hi*
Traditional/extensive	CO_2 = 0.13594	0.04362	0.22825	-0.00524	0.27712
	CH_4 = 0.00044	-0.00267	0.00354	0.00431	0.00518
Semi intensive	CO_2 = 0.24319	0.00691	0.47946	-0.11815	0.60453
	CH_4 = 0.00017	-0.00052	0.00088	-0.00089	0.00125
Intensive	CO_2 = 0.10392	-0.13181	0.33965	-0.25660	0.46443
	CH_4 = 0.00015	-0.00173	0.00204	-0.00273	0.00304

Based on the estimated values, the projected total CO_2 and CH_4 emissions during shrimp culture at the research site are shown in Table 2.

Table 2

Total CO_2 and CH_4 emissions during shrimp cultivation in ponds

Cultivation technology	*Average emissions ($g\ m^{-2}\ day^{-1}$)*	*Pond size (m^2)*	*Duration of culture (days)*	*Emissions total*	*GWP*
Traditional/ extensive	CO_2 = 0.19575 CH_4 = 0.00063	5.000	80	CO_2 = 78.30 kg CH_4 = 253.44 g	96.55
Semi intensive	CO_2 = 0.35019 CH_4 = 0.00024	2.000	110	CO_2 = 77.04 kg CH_4 = 53.86 g	80.92
Intensive	CO_2 = 0.14965 CH_4 = 0.00022	2.400	70	CO_2 = 25.14 kg CH_4 = 36.29 g	27.75

CO_2 and CH_4 emissions in the semi-intensive ponds are much higher than the average observations of Rifqi et al (2020), namely 0.01375 g m^{-2} day^{-1} and 0.00007 g m^{-2} day^{-1}, respectively. It is also different from CO_2 emissions from Chen et al (2016) of shrimp farming (*M. japonicus*) fed with pellets, namely -5.69 g m^{-2} $year^{-1}$ or -0.015589 g m^{-2} day^{-1}. The shrimp and sea cucumber (*A. japonicus*) polyculture cultivation without feeding was 11.23 g m^{-2} $year^{-1}$ or 0.030767 g m^{-2} day^{-1}. The CO_2 and CH_4 emissions in *L. vannamei* shrimp ponds were 0.200700 g m^{-2} day^{-1} and 0.000899 g m^{-2} day^{-1}, respectively, compared to CO_2 and CH_4 of *P. monodon* shrimp ponds of 0.088400 g m^{-2} and 0.000110 g m^{-2} day^{-1} (Vasanth et al 2016).

The effect of environmental parameters on CO_2 water-air interface fluxes. The concentration of dissolved gases depends on their solubility, salinity, and water temperature (Mitra & Zaman 2015). For instance, increased salinity causes a decrease in the amount of gas dissolved since most water immobility molecules are salt ions (Segers 1998). GHG released into the air depends partly on the physical structure of the water, which is influenced by factors such as temperature, oxygen content, microbial population, and metabolic pathways (Laurion et al 2010).

PLS regression uses iteration techniques to estimate the coefficient values of the influence of environmental parameter variables on CO_2 water-air interface fluxes. The analysis shows that there are no environmental variables that significantly influence it in traditional or extensive and semi intensive pond fluxes. The amount of diversity of all independent variables used on CO_2 cross water-air interface of traditional and semi intensive pond fluxes are 99.99039 and 99.35470, respectively.

From the results of the analysis, variables with significant effects on the interface fluxes on intensive ponds include CO_2 concentration in the air, water temperature, chlorophyll *a*, NO_2^-, and PO_4^- with coefficient values of 0.130103, 0.118325, 0.119039, 0.123512, and 0.125774 with p-values of 0.023135, 0.014677, 0.001092, 0.002138, and 0.052498, respectively. Each had p-values smaller than alpha (5%), except PO_4, which was less than 10%. Other variables are not significant at an alpha level of 5% and 10%. The magnitude of the diversity of all independent variables used on CO_2 emissions is 99.86372%.

The regression coefficient shows that an increase in 1 unit of CO_2 concentration in the air raises the value of the fluxes by 0.130103. Also, an increase in 1 unit of water temperature, chlorophyll *a* NO_2^-, and PO_4 boosts the values by 0.118325, -0.119039, 0.123512, and 0.125774, respectively. The $N\text{-}NO_x^-$ and $P\text{-}PO_4^{3-}$ concentrations are associated with phytoplankton biomass (chlorophyll *a* concentration) (Yang et al 2019c). In contrast, Yang et al (2018) which stated that chlorophyll *a*and $N\text{-}NO_3^-$ had no significant effect on CO_2 emissions. An increase in water temperature causes an increase in the mobility of gas molecules, leading to escapes (Segers 1998). High natural productivity has enormous CO_2 absorption potential (Soares & Henry-Silva 2019). Microalgae are the main contributors to primary production in water through photosynthesis process (Iriarte & Purdie 1994).

The effect of environmental parameters on CH_4 water-air interface fluxes. PLS regression uses iteration techniques to estimate the coefficient values of the influence of environmental parameter variables on the CH_4 water-air interface fluxes. From the results of the analysis, concentrations of CH_4 in the air with a coefficient value of 0.62423 and a p-value of 0.000432 smaller than alpha (5%) have a significant effect on the traditional/extensive ponds. Similarly, CO_2 concentration in the air has a significant effect on alpha (10%) with a p-value of 0.051033, and a coefficient value of -0.40661. The other variables are not significant at an alpha level of 5% and 10%. The magnitude of the diversity of all the independent variables used towards CH_4 emissions is 99.99975%. The regression coefficient shows that an increase of 1 unit of CO_2 concentration in the air might reduce the value of CH_4 water-air interface fluxes by 0.40661. Also, an increase of 1 unit of CH_4 concentration in the air increases the fluxes by 0.62423

Furthermore, pH with a coefficient value of 0.454455 and a p-value of 0.057264 smaller than alpha (10%) had a significant effect on CH_4 water-air interface fluxes in semi-intensive ponds. Additionally, the NO_3^- variable had a significant effect on alpha (10 %) with a p-value of 0.094874 and a coefficient value of 0.576345. Nevertheless, the other variables are not significant at an alpha level of 5% and 10%. The magnitude of the diversity of all independent variables used was 99.80813%. The regression coefficient shows an increase in 1 unit of pH boosts the value of the fluxes by 0.454455. Similarly, an increase of 1 unit of NO_3^- increases the fluxes by 0.576345.

Moreover, there are no environmental variables that significantly influence the CH_4 water-air interface fluxes in intensive ponds. The magnitude of the diversity of all independent variables used in this regard is 99.99502. This is different from Yang et al (2018), and Yang et al (2019b), which stated that CH_4 cross water-air interface fluxes during shrimp farming are influenced by water temperature, chlorophyll *a*, total organic carbon (TOC) and dissolved oxygen concentration.

Conclusions. Potential average CO_2 emissions from three shrimp farming technologies in extensive, semi-intensive and intensive ponds were 0.19575 g m^{-2}, 0.35019 g m^{-2} and 0.14965 g m^{-2} day^{-1}, respectively. The potential average CH_4 emissions from 3 shrimp farming technologies include 0.00063 g m^{-2} day^{-1}, 0.00024 g m^{-2} day^{-1} and 0.00022 g m^{-2} day^{-1}, respectively. Besides, the potential global warming (CO_2-eq) of 3 shrimp culture technology in extensive, semi-intensive, and intensive ponds are 96.55 g m^{-2}, 80.92 g m^{-2}, and 27.75 g m^{-2}, per day. CO_2 and CH_4 emissions from 80 days of traditional technology shrimp farming on a 5,000 m^2 pond were 78.30 kg and 253.44 g. The CO_2 and CH_4 emissions from 110 days of semi-intensive technology shrimp farming on a 2,000 m^2 pond are 77.04 kg and 53.86 g. Finally, CO_2 and CH_4 emissions from 70 days of intensive technology shrimp farming in 2,400 m^2 ponds are 25.14 kg and 36.29 g.

Water environmental factors that influence the CO_2 water-air interface fluxes include the concentration of CO_2 in the air, water temperature, chlorophyll *a*, NO_2^-, and PO_4-, respectively, having coefficients of 0.130103, 0.118325, -0.11904, 0.123512, and 0.125774. Additionally, the variables that influence the CH_4 water-air interface fluxes include the CH_4 and CO_2 concentrations in the air, pH, and NO_3^-, respectively, with coefficients of 0.62423, -0.40661, 0.454455 and 0.576345. To minimize CO_2 and CH_4 emissions during shrimp culture, it is necessary to pay attention to these factors, as well as to the control and efficiency in the use of production inputs, including the management of pond wastewater. For the effectiveness of emissions control, further research is needed to determine the production and consumption of these gases. Extensive pond studies need to be facilitated with measurements of CH_4 emissions from aquatic macro plants.

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