The daily variance of CO$_2$ and CH$_4$ emission from shrimp ponds

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Abstract. Scientist and environmentalist highlight the negative impact of a shrimp farm. The last decade analyzed numerous greenhouse gas emissions and aquaculture activities previously discussed. However, there are limited studies that reveal the emission of CO$_2$ and CH$_4$ related to aquaculture activities. The purpose of this study, therefore, is to examine the daily dynamics of these gases flux across the water-air interface of the shrimp ponds using a 3-day observation method and by examining the environmental factors responsible. This research was carried out in TIR Karawang shrimp farm area, with the gas samples were taken six times daily every 4 hours and analyzed using the gas chromatography. The results of this study show that in 24 hours, the minimum CO$_2$ emission ($-0.15841\pm0.19220$ mg m$^{-2}$ minute$^{-1}$) found at 00.00 – 02.00 local time, and the maximum (0.22544$\pm$0.18361 mg m$^{-2}$ minute$^{-1}$) at 12.00-14.00 local time. Conversely, the minimum CH$_4$ emission ($-0.00024\pm0.00023$ mg m$^{-2}$ minute$^{-1}$) was at 00.00-02.00 local time and the maximum (0.00023$\pm$0.00017 mg m$^{-2}$ minute$^{-1}$) at 12.00-14.00 local time. The dominant environmental factor influencing both gases is temperature. The semi-intensive shrimp farm CO$_2$-e calculated is 0.02707 g C m$^{-2}$ day$^{-1}$, for 2,500 m$^2$ ponds within a 110-day of culture, with 7.44545 kg C emitted.

1. Introduction

Aquaculture should be carried out in an ecosystem approach [1] with a minimum impact on the environment [2]. An aquaculture activity needs to utilize land and water efficiently, to develop technology, and implement cultural or Better Management Practices (BMP) [3]. It also chooses the proper location appropriate with the environmental supporting resource, and implements aquaculture using the right Ecosystem Approach to Aquaculture (EAA) to avoid the environmental danger [2]. In Indonesia and some other countries, the unplanned and irregular shrimp culture led to mangrove destruction of blue carbon storage [4, 5].
Presently, the average blue carbon storage at the mangrove is 858 ton ha$^{-1}$, with an average emission due to being converted into shrimp ponds at 554 ton ha$^{-1}$, thereby producing per kilogram of shrimp with 437 kg emissions [6]. The emission potency of the mangrove conversion into the shrimp pond is 1,390 ton CO$_2$-e ha$^{-1}$ [7]. Besides, it also causes the loss of CO$_2$ absorption ability from the photosynthesis process between 36.52-263.85 ton ha$^{-1}$ year$^{-1}$ [8-11].

During the shrimp culture, the potency of the CO$_2$ emission is 4.37 kg CO$_2$ m$^{-2}$ year$^{-1}$ from the embankment and 1.60 kg CO$_2$ m$^{-2}$ year$^{-1}$ from the bottom of intensive shrimp pond [12]. The emissions from fossil fuel utilized are 89.48 kg CO$_2$ days$^{-1}$ water replacement preparation phase and 751.87 kg CO$_2$ days$^{-1}$ nearly-harvested phase [13]. At the water replacement preparation phase, the potential CH$_4$ gas emission is 1.24-64.61 mg kg$^{-1}$ effluent year$^{-1}$ and 0.45-1.08 mg kg$^{-1}$ effluent year$^{-1}$ at the close of harvest [13]. The carbon element of greenhouse gases such as CO$_2$ and CH$_4$ released into the atmosphere through biological processes [14]. To complete the consideration of the shrimp pond development plan is necessary to calculate the number of blue carbon emissions (CO$_2$ and CH$_4$) from the decomposition of pond organic matter. The factor which influences the greenhouse gas emission rate is identical to the microorganism activity of organic material decomposers [15]. The emission measurement of the gas manually is used in the morning, afternoon, and evening [16].

The climate change formed by global warming is the effect of green-house gas accumulation in the atmosphere, such as CO$_2$ and CH$_4$. The most significant contribution toward is CO$_2$ 48%, while others are in the sequence of ozone 26%, methane 8%, NO$_2$ 6%, and other gases 2% [17]. Even the contribution of CO$_2$ to global warming can reach 60% [18]. Climate change determines the aquaculture effort perpetuity [19]. As previously stated, the impact of climate change toward shrimp cultural activity is the changing of some environmental variables related to the climate [20]. This consists of frequency in improved flood, hurricane, sea-level rise, aridity, sea-level temperature, rainfall, and salinity alteration [19-21]. Its condition causes survival rate degradation, growth, and shrimp production [19].

Data and information on the emitted CO$_2$ and CH$_4$ require sustainable low blue carbon. Currently, there are no research reports the daily dynamics of CO$_2$ and CH$_4$ emission, considering the ideal sample collection time used to determine its daily emission. This research is a part of our studies concerning arranges the coastal area management for shrimp pond, which is sustainable and low in blue carbon emission.

2. Research methods

2.1. Data collection

This study was carried out in two observational periods, with the environmental parameter observed (dissolved oxygen, saturation, pH, temperature, and salinity) on 9th February 2018 and the dynamic observation of CO$_2$ and CH$_4$ emission conducted for three days, i.e., from 10-12 April 2019. The environmental parameter observation has been conducted in the semi-intensive technological shrimp pond (Block A1 – Ex Area of TIR Karawang). Similarly, the dynamical observation of CO$_2$ and CH$_4$ emission located in semi-intensive technological shrimp pond (Block J2 – Ex Area of TIR Karawang) was operated by the Business Service Office of Cultural Fishery Cultivation (BLUPPB) Karawang – Directorate General of Aquaculture, Ministry of Marine Affairs and Fisheries. Samples were taken with 12 times frequencies at 08.30, 10.30, 12.30, 14.30, 16.30, 18.30, 20.30, 22.30, 00.30, 02.30 04.30 and 06.30 local time respectively to determine the daily dynamic environmental parameter. Also, the CO$_2$ and CH$_4$ emission were obtained by taking the sample 6 times in a day at 04.00-06.00, 08.00-10.00, 12.00-14.00, 16.00-18.00, 20.00-22.00 and 24.00-02.00 local time respectively and in 3 (three) partitions.

The gas samples of CO$_2$ and CH$_4$ were obtained using closed and afloat cylinder gas collector chamber with a diameter and height of 20 cm each [25], the headspace of 18 cm and the bottom surface layer of 2 cm. It made from transparent acrylic to ease the temperature observation in thermometer placed in the chamber. During the observation, the chamber is clamped by Styrofoam or
stopper to make it afloat on the water surface. Approximately 2 cm of the bottom edge is inserted in the water surface to avoid gas leakage. Each sampling is conducted three times by measuring the concentration at intervals of 0, 30, and 60 minutes after the chamber has been installed to calculate the gas flux across the water-air interface of CO$_2$ and CH$_4$. The gas sample is extracted from inside using a 20 ml syringe through the installed pipe on the top of chamber [22]. During transmission, it was inputted into a vacuum vial bottle with rubber cover and iron ring in the volume of 10 ml [23]. This was conducted to create high pressured gas in the vial bottle [24]. Gas analyzed with gas chromatography at the Agriculture Environmental Research Office (Balingtan) was used to complete the thermal conductivity detector (TCD) in order to measure the concentration of CO$_2$, and flame ionization detector (FID) in order to measure the CH$_4$ concentration [23].

2.2. Data analysis

The emission calculation of CO$_2$ and CH$_4$ follow this equation [8, 25]:

$$E = \frac{Bm \times \frac{dc}{dt} \times V}{V_m \times A \times T}$$

Where

E = CO$_2$ and CH$_4$ emission (mg m$^{-1}$ day$^{-1}$)
V = chamber volume (m$^3$)
A = chamber bottom wide (m$^2$)
T = an air temperature average in chamber (°C)
$dc/dt$ = gas concentration alteration rate of CO$_2$ and CH$_4$
Bm = gas molecule weight of CO$_2$ and CH$_4$
V$_m$ = gas volume at STO condition (standard temperature and pressure) is 22.41 liters.

Ratio of $dc/dt$ obtained from the slope of the regression equation of between 3 times concentrations that measured from chamber [25]. CO$_2$-e emission from the shrimp pond was calculated by the addition of CO$_2$ with 23 times of CH$_4$ [14]. Furthermore, the ideal time interval is determined by looking at the daily mean [24]. Kruskal-Wallis test used to assess difference of CO$_2$ and CH$_4$ emission between 3 days observation [26-28].

3. Results and discussion

3.1. Dissolved oxygen (DO), pH, temperature, and salinity fluctuation in the shrimp pond

The emission of CO$_2$ and CH$_4$ from the waters was influenced by the aquatic organism activity and several parameters directly or indirectly. In this research, DO is a measured water quality parameter, with the solvent oxygen saturation, pH, temperature, and salinity, as shown in Figure 1.

Figure 1 shows the fluctuation of some water quality parameters for 24 hours. These fluctuations occurred on the parameters of temperature, DO, saturation, and pH. However, the salinity parameter did not change during the observational time, with a consistent value of 16 ppm. The dissolved oxygen (DO), and its saturation in water quality is fully attended in the process of shrimp culture aside other main parameters. Its range during the observation was 4.52 mg l$^{-1}$ at 22.30 local time to 5.91 mg l$^{-1}$ at 16.30 local time, with the mean value of 5.18 mg l$^{-1}$. DO degradation commenced after a time of 16.30 and reaches the lowest point at 22.30 local time. This occurrence was possible because the supply was only obtained from diffusion, and the photosynthesis occurred during the lighting by the sun. Furthermore, it slowly increased to 04.30 local time, after lighting by the sun; therefore, DO increase caustically to 16.30 local time. Its improvement from 22.30 to 04.30 local time is possible due to the degradation of aquatic organism activities and owing to the ability of the low temperature to decrease oxygen consumption, thereby spooling its diffusion rate. Saturation shows the solvent oxygen number percentage (DO) that was utilized by the organism for respiration. Its fluctuation is similar to the DO pattern in which the lowest saturation is 65.11% at 22.30 local time, and the highest is 85.44% at 16.30 local time. Temperature is the most influenced factor towards the aquatic organism activity,
during observation, its range was 27.26 °C at 22.30 to 29.11 °C at 16.30 local time, with a mean of 28.10 °C. Then, the observed shrimp pond waters pH was 7.30 to 7.73, with a mean of 7.50.

![Figure 1](image)

Figure 1. Daily variance of DO, saturation, pH, temperature, and salinity.

3.2. Emission fluctuation of CO₂ and CH₄ in the shrimp pond
The emission gauge of CO₂ from the shrimp pond water surface is between -0.15841 mg C m⁻² minute⁻¹ at 00.00-02.00 local time to 0.22544 mg C m⁻² minute⁻¹ at 12.00-14.00 local time. Furthermore, that of CH₄ emission gauge is between -0.00024 mg C m⁻² minute⁻¹ at 00.00-02.00 local time to 0.00023 mg C m⁻² minute⁻¹ at 12.00-14.00 local time. The emission daily dynamical of CO₂ and CH₄ at the shrimp pond waters during the shrimp cultivation is shown in Figure 2.

Figure 2 shows the CO₂ emission at the shrimp pond waters during the shrimp cultivation is higher than the CH₄ emission. After the time at 06.00 local time, CO₂ emission increase from -0.06582 mg C m⁻² minute⁻¹ become 0.01691 mg C m⁻² minute⁻¹ at 08.00-10.00 local time, and it rises continually to achieve the highest point at 12.00-14.00 local time (0.22544 mg C m⁻² minute⁻¹). After 14.00 local time, it decreases till the lowest point at 00.00-02.00 is -0.15841 mg C m⁻² minute⁻¹. The CO₂ emission from the water increases with the rise in temperature and pH [13] due to improved aquatic organism activity at higher temperature [29, 30], including the decomposition of organic matter [16, 31]. Different from CO₂ emissions from the soil are more affected by soil moisture due to day and night and distance from the canal [24]. Figures 1 and 2 show the strong correlation between the CO₂ emissions and the pointed temperature using the same daily dynamical pattern.
Furthermore, the CH$_4$ emission shows almost the same pattern as CO$_2$ emission but with the lower emission level begin to rise after the time at 06.00 local time from -0.00004 mg C m$^{-2}$ minute$^{-1}$ becomes 0.00008 mg C m$^{-2}$ minute$^{-1}$ at 08.00-10.00 and rises continually to the highest point at 12.00-14.00 local time (0.00023 mg C m$^{-2}$ minute$^{-1}$). After 14.00 local time, CH$_4$ emission decreases to achieve the lowest point at 00.00-02.00 local time of -0.00024 mg C m$^{-2}$ minute$^{-1}$. Therefore, as CH$_4$ increases, there is a rise in temperature. The temperature degradation commences after the time at 20.30 local time, and it increases back during sunset. While, mangrove substrate that incurred the aquaculture waste impact has a higher CH$_4$ emission above the nature mangrove substrate, which incurred the domestic activity impact or household [32]. The high CH$_4$ emissions need to get attention in efforts to reduce GHG emissions from agriculture activities, this is also a note on paddy fields [14]. Because CH$_4$ gas has a residence time of up to 12 years and reflects heat 23 times more effectively than CO$_2$ [14].

3.3. CO$_2$ and CH$_4$ emission from shrimp pond

Based on the daily fluctuation data, the daily or yearly emission of CO$_2$ and CH$_4$ in the shrimp pond waters during its cultivation at the certain large was calculated. The result of greenhouse gas emission measurement must be under or overestimate, credible, and cheaper [16]. Its sample is taken at the certain time to represent one-day emission, therefore, to the sample is meant to be multiplied with the day of culture (DOC) to show its emission during the shrimp cultivation. The greenhouse gas extracted the sample at 08.00 local time [33, 34]. However, it is also conducted in the afternoon [33].

The variation of CO$_2$ and CH$_4$ emissions during this observation is shown by the standard deviation values as shown in Figure 2 and Table 1. CO$_2$ and CH$_4$ emissions during 3 days of observation did not differ statistically according to the Kruskal-Wallis test where the H is smaller than the H$_{table}$ respectively 1.31 < 4.60 and 1.72 < 4.60 reference to Table O $n_1$= 3; $n_2$= 3; $n_3$= 3; $\alpha$ = 0.05. The CO$_2$ gauge emission is between -0.15841 mg C m$^{-2}$ minute$^{-1}$ at 00.00-02.00 local time to 0.22544 mg C m$^{-2}$ minute$^{-1}$ at 12.00-14.00 local time, while CH$_4$ is between -0.00024 mg C m$^{-2}$ minute$^{-1}$ at 00.00-02.00 local time to 0.00023 mg C m$^{-2}$ minute$^{-1}$ at 12.00-14.00 local time. The emission observational mean result of both gases at the shrimp pond waters in Ex area of TIR Karawang sequentially is 0.00955 mg C m$^{-2}$ minute$^{-1}$ and 0.00005 mg C m$^{-2}$ minute$^{-1}$. The observational value combination closest to its
mean is the gas sample extracted from CO\textsubscript{2} and CH\textsubscript{4} at 08.00-10.00 local time; therefore, the underestimation is avoided. These time intervals are different from the sample taking at the paddy field at 15.00-16.00 local time [16] the palm-trees farm in Jambi at 15.00-18.00 local time [24] and at 11.00 to measure the CH\textsubscript{4} in the paddy field [35].

**Table 1.** The emission means of CO\textsubscript{2} and CH\textsubscript{4} per observation time interval.

| Time          | Emission CO\textsubscript{2} (mg C m\textsuperscript{-2} minute\textsuperscript{-1}) | Emission CH\textsubscript{4} (mg C m\textsuperscript{-2} minute\textsuperscript{-1}) |
|---------------|---------------------------------|---------------------------------|
| 04.00 - 06.00 | -0.06582 ± 0.16350               | 0.00004 ± 0.00037               |
| 08.00 - 10.00 | 0.01691 ± 0.12645                | 0.00008 ± 0.00006               |
| 12.00 - 14.00 | 0.22544 ± 0.18361                | 0.00023 ± 0.00017               |
| 16.00 - 18.00 | 0.19076 ± 0.26081                | 0.00005 ± 0.00004               |
| 20.00 - 22.00 | -0.15160 ± 0.30906               | 0.00015 ± 0.00014               |
| 24.00 - 02.00 | -0.15841 ± 0.19220               | -0.00024 ± 0.00023              |
| Mean          | 0.00955 ± 0.20594                | 0.00005 ± 0.00017               |

The yearly emission gauge of CO\textsubscript{2} in the shrimp pond waters of 1 ha during the semi-intensive shrimp cultivation is 0.08037 ton C, and CH\textsubscript{4} emission is 0.00039 ton C, while the CO\textsubscript{2}-e is 0.08935 ton C. Emission of CO\textsubscript{2} from feeding and no-feeding mariculture are -0.0569 ton ha\textsuperscript{-1} year\textsuperscript{-1} and 0.1123 ton ha\textsuperscript{-1} year\textsuperscript{-1}, respectively, and CH\textsubscript{4} emission from feeding and no-feeding mariculture are 0.0057 ton ha\textsuperscript{-1} year\textsuperscript{-1} and 0.0068 ton ha\textsuperscript{-1} year\textsuperscript{-1}, respectively [36]. That means CO\textsubscript{2} and CO\textsubscript{2}-e emission from feeding mariculture lower than emission from semi-intensive shrimp cultivation. On the other hand, CO\textsubscript{2} emission is 4.37 kg CO\textsubscript{2} m\textsuperscript{-2} year\textsuperscript{-1} from the embankment and 1.60 kg CO\textsubscript{2} m\textsuperscript{-2} year\textsuperscript{-1} from the bottom of intensive shrimp pond [12], its much higher than CO\textsubscript{2} emission from shrimp pond water column (only 0.009 kg CO\textsubscript{2} m\textsuperscript{-2} year\textsuperscript{-1}). The emission of CO\textsubscript{2} and CH\textsubscript{4} occurred when the pH is lower [23].

The gauge of CO\textsubscript{2}, CH\textsubscript{4}, and CO\textsubscript{2}-e emission from the shrimp pond waters during the shrimp cultivation is lower than the intermittent irrigation and inundated paddy field, the turf drainage sewers and the turf surface [16, 23, 37, 38] as shown Table 2.

**Table 2.** The shrimp pond comparison of CO\textsubscript{2}, CH\textsubscript{4} and CO\textsubscript{2}-e emission with the paddy field, drainage sewers and the turf land surface.

| No. | Item  | Emission from the shrimp pond | Emission from paddy field | Emission in the turf drainage sewers | Emission in the turf surface |
|-----|-------|-------------------------------|---------------------------|--------------------------------------|-----------------------------|
| 1.  | CO\textsubscript{2} | 0.08037                        | 9.01\textsuperscript{**)  | 10.59\textsuperscript{****)               | 5.11 - 9.13\textsuperscript{***)     |
| 2.  | CH\textsubscript{4}  | 0.00039                        | 0.31\textsuperscript{**)  | 0.24\textsuperscript{**)                      | 0.01 - 0.14\textsuperscript{***)         |
| 3.  | CO\textsubscript{2}-e | 0.08935                        | 16.04\textsuperscript{**)  | 13.32\textsuperscript{**)                      | 10.72 - 89.21\textsuperscript{**)             | 6.96 - 29.19\textsuperscript{**)             |

Unit: ton ha\textsuperscript{-1} year\textsuperscript{-1}

Notes:
\textsuperscript{***)} = processed by [16]
\textsuperscript{****) = processed by [23]
\textsuperscript{***) = processed by [37]
\textsuperscript{****) = source [38]

The high accumulation of organic matter in shrimp pond caused by uneaten feed and excretion of shrimp [39], if the organic material is anaerobically decomposed it will produce unstable compounds, especially ammonia (NH\textsubscript{3}), methane (CH\textsubscript{4}), and hydrogen sulfide (H\textsubscript{2}S) [40]. Most of the animal waste is a potential source of CH\textsubscript{4} emission [25]. The stagnant condition is an ideal condition for the
methanogen bacteria in conducting the metabolism activity to produce the gas \( \text{CH}_4 \). Therefore, it also gets bigger emission [16]. Methanotrophs bacteria are able to synthesize \( \text{CH}_4 \) into \( \text{CO}_2 \) through its metabolism [14]. Striving for aerobic decomposition can also reduce \( \text{CH}_4 \) emissions because the result of decomposition formed under aerobic conditions is \( \text{CO}_2 \) [14]. This condition shows many variations of \( \text{CH}_4 \) production and its consumption potential [37].

4. Conclusion and recommendation

The gauge emission of \( \text{CO}_2 \) and \( \text{CH}_4 \) in shrimp pond waters during the shrimp cultivation fluctuate according to time due to the influence of the temperature parameter fluctuation, pH, and DO. \( \text{CO}_2 \) emissions in pond waters during shrimp culture are higher than \( \text{CH}_4 \) emissions. \( \text{CO}_2 \) emission during this process is 0.02436 g C m\(^{-2}\) day\(^{-1}\) or 0.08037 ton C ha\(^{-1}\) year\(^{-1}\) and \( \text{CH}_4 \) emission is 0.00012 g C m\(^{-2}\) day\(^{-1}\) or 0.00039 ton C ha\(^{-1}\) year\(^{-1}\). In summary, the \( \text{CO}_2 \)-e emission in the pond waters during the shrimp cultivation is 0.02707 g C m\(^{-2}\) day\(^{-1}\) or 0.08935 ton C ha\(^{-1}\) year\(^{-1}\). Furthermore, using a size of 2,500 m\(^2\) and 110 days of culture, \( \text{CO}_2 \)-e emitted till the harvest was 7.44545 kg C.

Generally, the shrimp culture in the pond was conducted in 70-120 days, during which the environmental parameter changed, and the production facilities input such as feed and fish medicine was the potency used to make daily emission changing during the shrimp culture in the pond. Therefore, further research needs to observe the emission dynamic of \( \text{CO}_2 \) and \( \text{CH}_4 \) during the shrimp culture in the pond and that can reduce greenhouse gas emissions.

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