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The contribution of phytoplankton in the carbon adsorption and stock during shrimp culture in brackishwater ponds

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Abstract. *Widigdo B, Rifqi M, Mashar A, Nazar F, Wardiatno Y. 2020. The contribution of phytoplankton in the carbon adsorption and stock during shrimp culture in brackishwater ponds. Biodiversitas 21: 5170-5177.* In environmental point of view, it is important to determine the potential of adsorption and stock of blue carbon during shrimp farming in ponds with three cultivation technologies namely: extensive/traditional, semi-intensive, and intensive. The aquatic primary productivity approach is used to measure the potential of carbon adsorption in shrimp ponds, while the carbon conversion of chlorophyll-a content is used to measure its stock. The primary productivity and chlorophyll-a content were measured using three ponds for each cultivation technology every ten days from stocking (DOC 0) until the harvest period. The sampling location is in the BLUPPB shrimp pond area of Karawang, West Java - Indonesia. The study concluded that the adsorption and stock of blue carbon varied during shrimp farming in ponds. The primary productivity and chlorophyll-a content of the three cultivation technologies were the significant difference as the results of ANOVA Single Factor. Carbon adsorption average during extensive/traditional, semi-intensive, and intensive shrimp farming in ponds was 1.912832 g C m^{-3} day^{-1}, 7.097145 g C m^{-3} day^{-1} and 8.250195 g C m^{-3} day^{-1}, respectively. While, the average carbon stock during shrimp farming in extensive/traditional, semi-intensive, and intensive ponds were 0.64896 g m^{-3}, 14.97473 g m^{-3}, and 25.11102 g m^{-3}, respectively.

Keywords: Carbon chlorophyll-a ratio, carbon sink, primary productivity

INTRODUCTION

The Indonesian mangroves that convert into shrimp ponds have happened since the 1800s (Ilman et al. 2016), which caused blue carbon emission. The emission is due to the loss of approximately 79.2 - 242.2 tons C ha^{-1} carbon stocks (Hilmi et al. 2017), carbon burial deficiency of 1.15 - 2.70 tons ha^{-1} $year^{-1}$ (Bianchi et al. 2013; Siikamäki et al. 2013), loss of CO_2 sequestration capacity from 36.52 - 263.85 tons ha^{-1} $year^{-1}$ (Chen et al. 2016; Rahman et al. 2017) and the release of 262 - 1,084 tons ha^{-1} carbon stored in the substrate of the mangrove (Siikamäki et al. 2013; Kauffman et al. 2014; Liu et al. 2014). The conversion of mangroves into shrimp ponds resulted in the loss of 58% - 82% carbon stock in its ecosystems with an average potential emission of 1,390 Mg CO_2-e ha^{-1} (Kauffman et al. 2018).

The potential emission of CO_2 during shrimp farming was 0.02436 g C m^{-2} day^{-1} or 0.08037 ton C ha^{-1} $year^{-1}$ from the surface of the pond water (Rifqi et al. 2020), 4.37 kg CO_2 per m^2 $year^{-1}$ from embankments, and 1.60 kg CO_2 per m^2 $year^{-1}$ from the substruction of intensive shrimp ponds (Sidik and Lovelock, 2013). Furthermore, 89.48 kg CO_2 day^{-1} - 751.87 kg CO_2 day^{-1} fossil fuels were derived, and the potential emission of CH_4 was from 0.45 - 64.61 mg kg^{-1} waste $year^{-1}$ during the shrimp culture period (Dewata 2013).

Nevertheless, shrimp farming adsorbs CO_2 through the photosynthetic activities of phytoplankton and production of the carbon as aquatic organism biomass. Microalgae adsorbs CO_2 and stores carbon in form of biomass (Bhakta et al. 2015). The presence of phytoplankton in aquaculture production systems contribute to carbon cycle and aquatic food chain (Wetzel 2001; Lee et al. 2014; Ma et al. 2014; Xiao et al. 2015; Mercado-santana et al. 2017), because of their photosynthetic activities (Mitra and Zaman 2015) and assimilates or adsorbs CO_2 (Geider and Osborne 1992; Baker 2004). Furthermore, in aquatic ecosystems, phytoplankton or microalgae are the major contributors to primary productivity (Nontji 1984; Iriarte and Purdie 1994; Chen et al. 2017; Reeder 2017; Vallina et al. 2017) while the rest are plants and macroalgae (Silva et al. 2009). The determination of primary productivity is an approach used to calculate carbon adsorption. Blue carbon stock is stored in form of phytoplankton and aquatic animal biomasses in the coastal aquatic ecosystem (Mitra and Zaman 2015).

However, some experts question the existence of phytoplankton biomass as one of the blue carbon stocks, because of its relatively short life span and inability to form their own organic-rich sediments. Phytoplankton biomass is a rich carbon source and it significantly contributes to the detritus habitat, therefore it tends to act as a carbon donor (Hill et al. 2015). Microalgae as a CO_2 biology adsorbent is reported by Singh and Ahluwalia (2013) as a promising technology because of its superiority over other aquatic plants. Reduction of blue carbon emissions as one of the greenhouse gases tends to ultimately support the sustainability of aquaculture businesses (Ahmed et al. 2017). This study to determine blue carbon adsorption and stock during shrimp culture in the ponds.

MATERIALS AND METHODS

Study area

The research was carried out in nine shrimp ponds located at the BLUPPB Karawang, West Java, Indonesia on April - July 2019. Among those nine ponds, three of them are located in Block F4 sizing of 5,000 m^2 and of earthen. The second three ponds located in Block J2 having size of 2,000 m^2 and covered with high-density polyethylene (HDPE), while the last three ponds located in Block F3 having size of 2,400 m^2 and covered with mulch plastic. The first three ponds (Block F4) were used as an extensive/traditional shrimp culture, the second (Block J2) and the third (Block F3) were used as semi-intensive and intensive shrimp culture, respectively. All ponds received water supplied from the same irrigation unit. Coastal water which was mixed with groundwater to meet proper salinity supplied to the ponds.

The SPF shrimp post larvae stocked to all ponds supplied of locals hatchery at density of 5 PL m^{-2}, 70 PL m^{-2}, and 145 PL m^{-2} for extensive/traditional, semi-intensive and intensive shrimp culture, respectively. The protocol of shrimp culture followed Standard Operation Procedure (SOP) as determined by the technician. The shrimp cultured in extensive way received their feed from natural sources. While the shrimp in the semi-intensive and intensive ponds were fed 4-5 times a day. Weekly growth and ages used to predict the feeding rate. No paddlewheel aerator supports extensive/traditional ponds. While in the semi-intensive ponds was equipped with three units electrical paddlewheel aerator and intensive pond was equipped with eight units of electrical paddlewheel aerator. The new water was added to the shrimp ponds during the first 30 days of culture in the semi-intensive and intensive to replace water that lost by evapotranspiration, onward every 3-5 days of 3-5 % water exchange to keep water on proper quality. At the water exchange, the bottom mud is removed to reduce the organic matter in the pond. Conversely, no water exchange in extensive/traditional pond. The new water is added only carried out to replace volume loss.

Primary productivity (PP) and carbon adsorption

Measurement of primary productivity was carried out every ten days in the three ponds for each shrimp culture technology. The oxygen method was widely used to determine primary productivity (Yang et al. 2002). It was measured by referring to the APA standard method part 10000 at 10200 J (APA 2012), which is similar to the oxygen method using dark and light bottles (Wetzel 2001; Alianto et al. 2008). Oxygen content in the sample bottles was measured using DO meters (Krismono et al. 2017; Mardhiya et al. 2017). The primary productivity was calculated using the Umaly and Cuvin (1988) formula:

$$\text{PP (mg C m}^{-3}\text{ hours}^{-1}) = \frac{(0_2LB) - (O_2DB)(1{,}000)}{(PQ)(t)}\ x\ 0.375$$

Where: O_2 = dissolved oxygen (mg l^{-1}); LB = light bottle; DB = dark bottle; PQ = photosynthetic quotient (1.2); t = incubation duration (hours); 1.000 = conversion of liters to m^3; 0.375 = the conversion coefficient of oxygen to carbon (12/32).

The adsorption of carbon in shrimp ponds is suspected to determine primary productivity. According to Singh and Ahluwalia (2013), it is the production of atmospheric and aquatic CO_2 by organic macromolecules, particularly during photosynthesis. The number of oxygen molecules produced was not the same as the assimilated carbon dioxide. Furthermore, photosynthetic quotient (PQ) is expressed as the rate of oxygen evolution to the amount of carbon dioxide assimilated during photosynthesis (Geider and Osborne 1992).

Chlorophyll-a content and carbon stock

Water sampling for the determination of chlorophyll-a content was carried out every ten days in the three ponds for each shrimp culture technology. Conversely, phytoplankton biomass is stated in relation to the chlorophyll-a pigment content (Kaswadji et al. 1993). The pigment content was calculated using the spectrophotometer technique (Parsons et al. 1992) which is referred to as the APA standard method part 10000 at 10200 H. The amount of chlorophyll is calculated using the APA (2012) equation:

$$Ca\left(\frac{mg}{m^3}\right) = \frac{11\ x\ 2.43\ x\ [(A664_b - A750_b) - (A665_a - A750_a)]\ x\ V_1}{V_2\ x\ L}$$

Where: Ca = the amount of chlorophyll-*a* (mg m^{-3}); V_1 = extract volume (mL); V_2 = sample volume L); L = cuvette length or width (cm); $A750_b$ = absorbance at 750 ηm wavelength before acidification; $A750_a$ = absorbance at 750 ηm wavelength after acidification; $A664_b$ = absorbance at 664 ηm wavelength before acidification; $A665_a$ = absorbance at 665 ηm wavelength after acidification.

The chlorophyll content in phytoplankton and other biomass parameters were determined using a conversion approach (Nontji 1984). The conversion factor used in this study was 1: 75 (Gieskes and Kraay 1989).

Statistical analysis

The difference in primary productivity and chlorophyll-a content of the three cultivation technologies was determined by ANOVA single factor (Yang et al. 2017) and Tukey's HSD (honestly significant difference) for post hoc test. The estimated average value of carbon adsorption and stock in the shrimp ponds was calculated using the single exponential smoothing (SES) method. SES is a method of modifying data by removing the irregular components in it (Risteski et al. 2004; Gardner and Diaz-Saiz 2008; Raharja et al. 2010). The difficult aspect of this method is in discovering the ideal parameter/value used to obtain the least possible error. Package forecasts in R software is used to identify the perfect parameter/values in historical data (Chapman and Feit 2019).

RESULTS AND DISCUSSION

Primary productivity and carbon adsorption

Dynamic of primary productivity (PP) during shrimp farming in the three ponds are shown in Figure 1, with a general increase in PP from the stocking start (DOC 0) to harvest period.

The primary productivity in the intensive shrimp ponds at the beginning of cultivation (DOC 0) was 204.86 mg C m^{-3} $hours^{-1}$ which later increased to 780.38 mg C m^{-3} $hours^{-1}$ during the harvest period (DOC 70). On the contrary, the PP in the semi-intensive shrimp ponds at the beginning of cultivation (DOC 0) was 75.61 mg C m^{-3} $hours^{-1}$ which further increased to 594.27 mg C m^{-3} $hours^{-1}$ during the harvest period (DOC 110). Lower PP values ranging from 35.19 mg C m^{-3} $hours^{-1}$ to 209.03 mg C m^{-3} $hours^{-1}$ was discovered in the extensive/traditional shrimp ponds.

The primary productivity of the three cultivation technologies was a significant difference as the results of ANOVA Single Factor (p-value $0.000112 < \alpha\ 0.01$). Inverse transformation was carried out to ascertain that the data is distributed normally. Kolmogorov Smirnov Test was used to conduct the data normality test. The post hoc results obtained by using Tukey's HSD test shows the actual difference between extensive/traditional and semi-intensive technology, and that between extensive/traditional and intensive technology. However, there was no significant difference between semi-intensive and intensive technology.

The carbon adsorption day^{-1} from three cultivation technologies is presented in Figure 2.

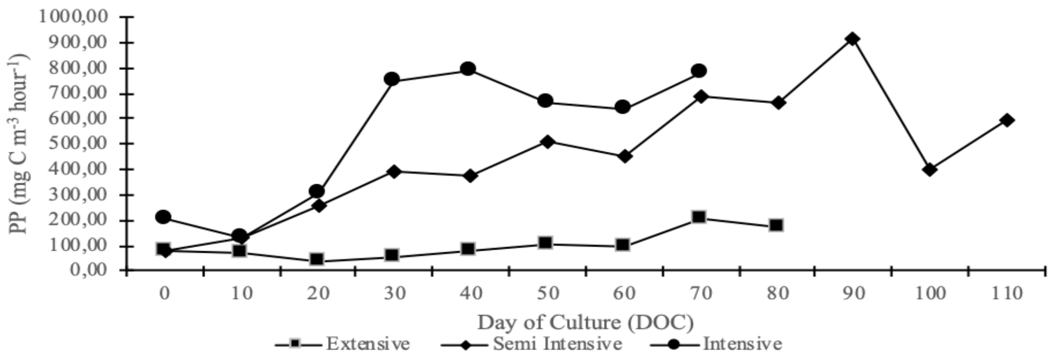


Figure 1. Primary productivity during shrimp farming in ponds with three different culture technologies in Karawang, West Java, Indonesia

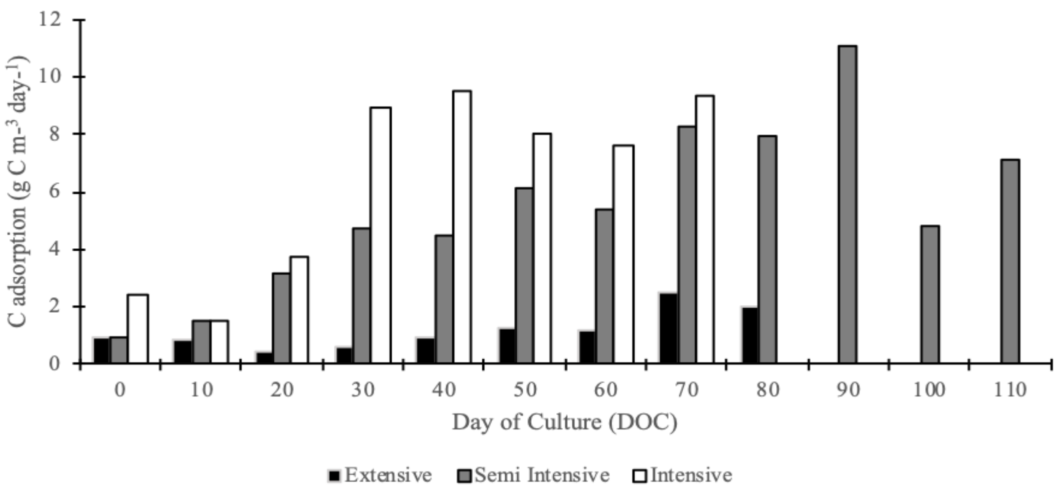


Figure 2. Daily carbon adsorption during shrimp farming in ponds with three different culture technologies in Karawang, West Java, Indonesia

Figure 2 shows the various changes in carbon adsorption in the ponds. There was an increase from the beginning of stocking (DOC 0) to the end of cultivation (harvest) in the three shrimp cultivation technologies. The highest average of carbon adsorption was detected in the intensive ponds with a value of 2.46 g C m^{-3} day^{-1} obtained at stocking (DOC 0) which increased to 9.37 g C m^{-3} day^{-1} at the harvest period (DOC 70). In the semi-intensive ponds was obtained 0.91 g C m^{-3} day^{-1} at the beginning of the cultivation (DOC 0) and increased to 7.13 g C m^{-3} day^{-1} at the harvest period (DOC 110). And in the extensive/traditional pond ranging from 0.42 g C m^{-3} day^{-1} (DOC 0) and it later increased to 2.51 g C m^{-3} day^{-1} at the harvest period (DOC 80).

Carbon adsorption during shrimp farming in the ponds was determined daily by estimating its average using simple exponential smoothing (SES) as shown in Table 1 and Figure 3. The results from the SES analysis, shows that the average carbon adsorption in intensive, semi-intensive, and extensive/traditional ponds were 8.250195 g C m^{-3} day^{-1}, 7.097145 g C m^{-3} day^{-1} and 1.912832 g C m^{-3} day^{-1}, respectively.

Chlorophyll-a and carbon stock

Variation of chlorophyll-a content in the three cultivation technologies is shown in Figure 4. Relatively large changes are detected in semi-intensive and intensive ponds from stocking (DOC 0) to harvest period. The chlorophyll-*a* content of intensive and semi-intensive cultivation technology is higher than the extensive/traditional ponds. The contents of the intensive shrimp ponds at the beginning of cultivation (DOC 0) was 153.97 mg m^{-3}, which increased to 356.89 mg m^{-3} during the harvest period (DOC 70). The contents in the semi-intensive shrimp ponds at the beginning of cultivation (DOC 0) were 7.83 mg m^{-3} however, it later increased to 143.74 mg m^{-3} at the harvest period (DOC 110). The chlorophyll-a content in extensive/traditional shrimp ponds was low, ranging from 2.14 mg $^{-3}$ to 8.0 mg m^{-3}.

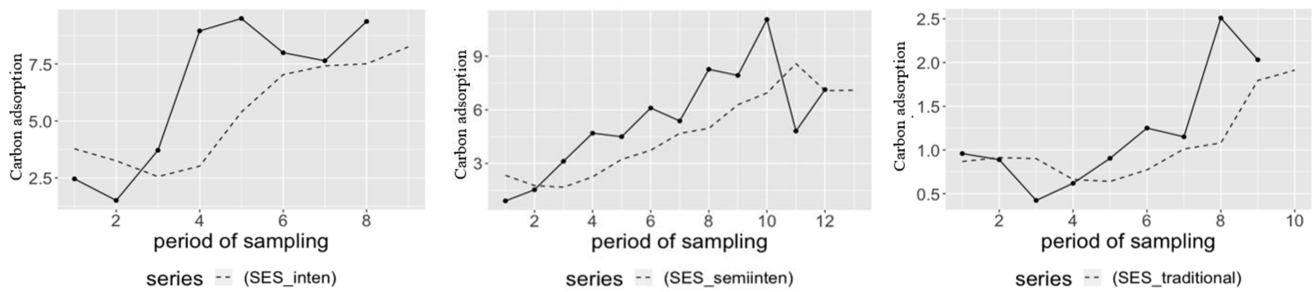
There was a significant difference between the chlorophyll-a content of the three cultivation technologies (extensive/traditional, semi-intensive, and intensive) as the results of the single factor ANOVA test (p-value 0.0000000 < α 0.01). Logarithmic transformation was carried out in order to ensure the data is distributed normally. Data normality test was conducted by using the Kolmogorov Smirnov. The post hoc results obtained using Tukey’s HSD test shows that a significant change occurred in the three cultivation technologies. Figure 5 shows the carbon stock in the three different technology of shrimp ponds.

Figure 5 shows the changes increased steadily from the beginning of stocking to the end of cultivation (harvest), except for extensive/traditional ponds. Carbon stock in the semi-intensive pond was 5.87 tons C ha^{-1} at the beginning of cultivation (DOC 0) which was later increased to 107.80 tons C ha^{-1}1 at the harvest period (DOC 110). Average carbon content of 115.48 tons C ha^{-1} at stocking (DOC 0) was found in intensive ponds and this increase to 267.67 tons C ha^{-1} at the harvest period (DOC 70). Conversely, carbon stock in extensive/traditional ponds was 8.28 tons C ha^{-1} at the beginning of cultivation and later decrease to 7.51 tons C ha^{-1} at the harvest period (DOC 80).

Estimated average of carbon stock in the shrimp pond was determined using simple exponential smoothing (SES) as shown in Table 2 and Figure 6.

Table 1. The estimated average of carbon adsorption in the shrimp pond using single exponential smoothing method

Cultivation technology	Estimated average (g C m^{-3} day^{-1})	80% confidence rate		95% confidence rate	
		Lo	Hi	Lo	Hi
Extensive/Traditional	1.912832	1.123965	2.701699	0.7063636	3.1193
Semi-intensive	7.097145	3.891806	10.30248	2.195002	11.99929
Intensive	8.250195	4.112752	12.38764	1.922522	14.57787



A B C

Figure 3. Graph of estimating a model of carbon adsorption in the cultivation technology of (A) intensive, (B) semi-intensive, and (C) extensive/traditional shrimp ponds

Total carbon adsorption and stock during shrimp culture

Based on the estimated average value, the total carbon absorption and stock determined during shrimp farming in extensive/traditional, semi-intensive, and intensive ponds, are shown in Table 3. According to the results from the SES analysis, the daily estimated average of carbon stock in intensive, semi-intensive, and extensive/traditional shrimp ponds was 25.11102 g m^{-3}, 14.97473 g m^{-3}, and 0.64896 g m^{-3}, respectively.

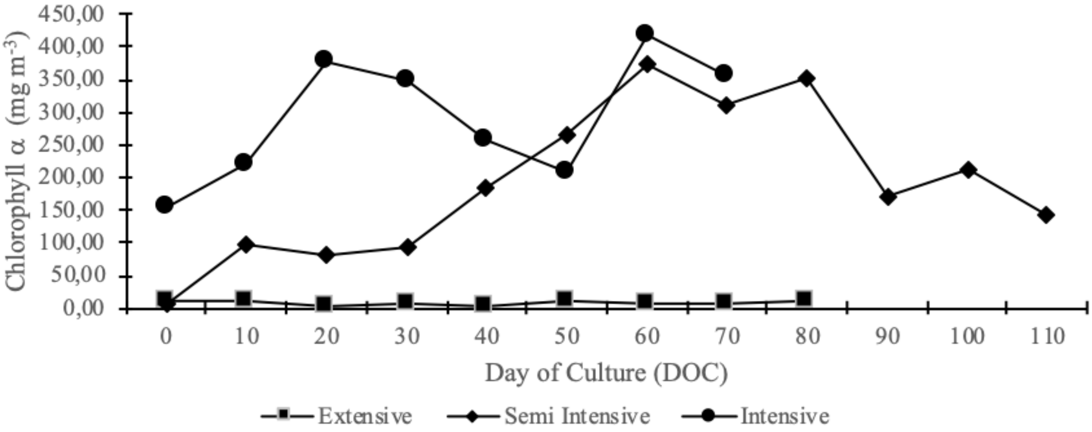


Figure 4. Chlorophyll-a content during shrimp farming in ponds with three different culture technologies in Karawang, West Java, Indonesia

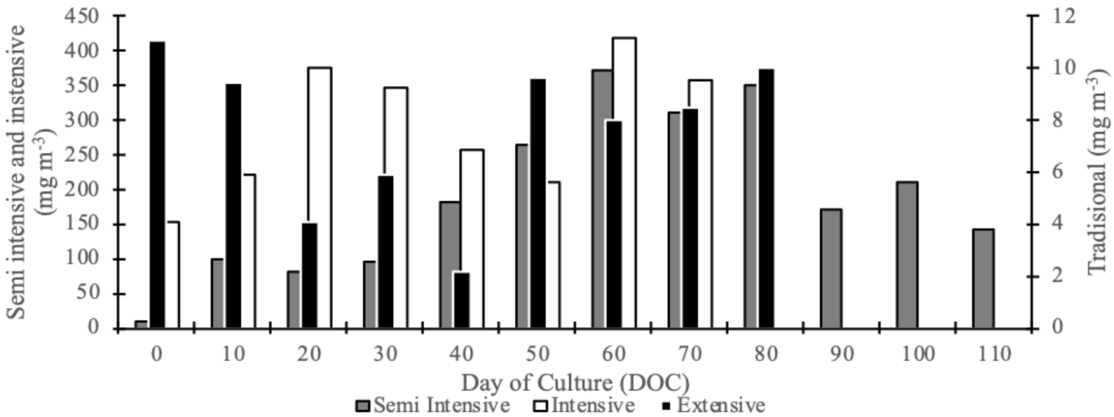
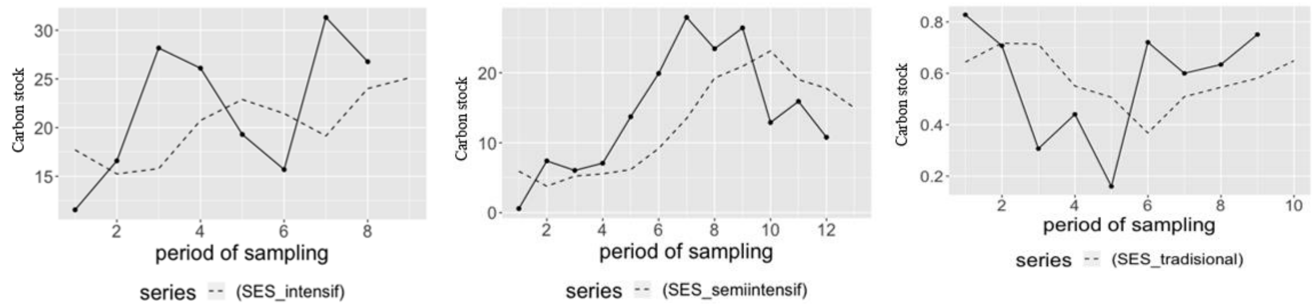


Figure 5. Carbon stock during shrimp farming in ponds with three different culture technologies in Karawang, West Java, Indonesia

Table 2. The estimated average carbon stock in the shrimp pond using single exponential smoothing method

Cultivation technology	Estimated average ($g\ m^{-3}$)	80% confidence rate		95% confidence rate	
		Lo	Hi	Lo	Hi
Extensive/ traditional	0.64896	0.306193	0.991727	0.12474	1.17318
Semi-intensive	14.97473	4.760039	25.18942	-0.64729	30.59676
Intensive	25.11102	14.34295	35.87908	8.64268	41.57935



A B C

Figure 6. Graph of estimating a model of carbon stock in shrimp cultivation technology at (A) intensive (B) semi-intensive and (C) extensive/traditional shrimp ponds

Table 3. The total carbon adsorption and stock during shrimp farming in ponds

Cultivation technology	Estimated average	Pond volume (m^3)	Duration of culture (days)	Total
Extensive/ traditional	Ad = 1.91283 g C m^{-3} day^{-1} Sc = 0.64896 g m^{-3}	10.000	110	Ad = 0.7139 ton C Sc = 0.0071 ton
Semi intensive	Ad = 7.09715 g C m^{-3} day^{-1} Sc = 14.97473 g m^{-3}	10.000	110	Ad = 7.8069 ton C Sc = 0.1560 ton
Intensive	Ad = 8.25020 g C m^{-3} day^{-1} Sc = 25.11102 g m^{-3}	10.000	110	Ad = 9.0752 ton C Sc = 0.2663 ton

Note: Ad: Carbon adsorption; Sc: Carbon stock

Discussion

The environmental factors that influence the absorption of CO_2 are light intensity, temperature, and the concentration of CO_2 and pH (Bhakta et al. 2015). According to Moreira and Pires (2016), CO_2 adsorption occurs through two processes, such as pump solubility and biological sequestration. Microalgae is a productive biological system that produces biomass and absorbs carbon (Sayre 2010). It is effective for capturing and adsorbing atmospheric CO_2 (Sayre 2010; Moreira and Pires 2016). The existence of algae in the aquatic ecosystem serves as a controller of CO_2 released into the air, because it rapidly converts CO_2 into organic material through photosynthesis unlike terrestrial plants (Jeong et al. 2003). The efficiency of microalgae to convert CO_2 during photosynthesis ranges from 10-29% while terrestrial plants are from 1-2%, however, some types of microalgae are able to increase their biomass within 3.5 hours (Chisti 2007). The fastest-growing microalgae are *Chlorella pyrenoidosa* with 1.17 optical density per five days (Jeong et al. 2003). It is a phototrophic microorganism with simple nutritional requirements and also acts as a primary producer (Singh and Ahluwalia 2013).

Several methods are used to determine phytoplankton biomass, such as cell counting, cell volume measurement, ATP, DNA, and chlorophyll a content (Nontji 1984; Steigenberger et al. 2004). All photosynthetic cells contain one or several chlorophyll pigments, such as green, brown, red, or violet (Wetzel 2001; Kirk 2011). Chlorophyll a concentration is the main indicator used to estimate primary productivity and an important variable in photosynthetic process (Lee et al. 2014; Xiao et al. 2015; Chen et al. 2017). Algae have an efficient photosynthetic mechanism and high biomass production (Moreira and Pires 2016). Microalgae develop rapidly with high biomass productivity. Microalga is a bio-mitigating organism (Moreira and Pires 2016). Numerous studies including Gieskes and Kraay (1989) stated that the ratio of carbon to chlorophyll is 1:75 and 1: 125 in the different parts of the Banda Sea, Indonesia.

The high carbon content of phytoplankton in the aquatic ecosystem compared to primary productivity indicates the level of CO_2 adsorption and the water volume unit at a certain time (Gieskes and Kraay 1989). The high carbon content in intensive and semi-intensive ponds is possible due to the availability of sufficient nutrients that support the growth of phytoplankton, this is in accordance with the research conducted by de Jonge (1980).

The adsorption of carbon during shrimp farming in extensive/traditional, semi-intensive, and intensive ponds was 0.7139 tons C ha^{-1}, 7,8069 tons C ha^{-1}, and 9,0752 tons C ha^{-1}, respectively. That ability of carbon adsorption is lower than the mangrove ecosystem, it was 36.52 - 263.85 tons C ha^{-1} (Chen et al. 2016; Rahman et al. 2017). Carbon stock in the extensive/traditional, semi-intensive, and intensive ponds was 0.0071 tons ha^{-1}, 0.1560 tons ha^{-1}, and 0.2663 tons ha^{-1}, respectively. That carbon stock is still much lower than the mangrove ecosystem carbon stock, it was 79.2 - 242.2 tons ha^{-1} (Hilmi et al. 2017).

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