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Sediment accumulation rate and carbon burial rate in the Pacific white shrimp (*Litopenaeus vannamei*) ponds, Phetchaburi Province, upper Gulf of Thailand

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Abstract Sediment accumulation rate and carbon burial rate in Pacific white shrimp ponds was reported. The results can be helpful for the sediment quality management during crop to get the high productivity of both marketable species and to make the environment sustainable. The sediment accumulation rate and carbon burial rate were studied at shrimp farm in Phetchaburi Province, upper Gulf of Thailand. The two ponds were sampled every two weeks for one crop. The most sediment quality parameters were appropriated standard criteria. However, at the end of the crop, total nitrogen and organic carbon were higher than other periods ($p<0.05$) and higher than standard criteria. It indicated that the amount of accumulated waste in the ponds increased with enhancing culture periods. The sediment depth had a high level of positive correlation ($p<0.05$) with total nitrogen ($r=0.965$), total phosphorus ($r=0.785$) and organic carbon ($r=0.817$). The results indicated that the nutrient and waste increased along the culture periods and the highest amount during the harvesting period. The averaged data of sediment accumulation rate were 21.50 ± 2.95 cm yr^{-1} and the averaged data of carbon burial rate in the Pacific white shrimp ponds in study area were 51.94 ± 26.55 g C m^{2} yr^{-1}.

Keywords: Pacific white shrimp, Sediment accumulation rate, Carbon burial rate

Introduction

Commercial culture of Pacific white shrimp (*Litopenaeus vannamei*) plays an important role in the national and international economy. Demand has increased continuously for both domestic and foreign markets year on year, resulting in Pacific white shrimp farmers having to shorten the time to culture and increasing production continuously, such as high stocking density, increasing food intake and development of feed formulas. These have a

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continuous impact on the balance of the pond's ecological system, which is often followed by environmental problems in the ponds (Páez-Osuna, 2001).

There are many studies, especially in the agricultural areas. Nutrients enriched water can release carbon dioxide (CO_2–C emission) up to 33.1 g C m^{-2} yr^{-1} (Xing *et al*., 2005). Aquaculture ponds water can generate and emit carbon dioxide that causes the greenhouse effect (greenhouse gas; GHG). The rate of carbon fixation in the sediment in aquaculture pond is called carbon burial rate of sediment. Carbon can store in organic compound accumulated in form of sediment at bottom of pond. The carbon burial rate can be used as the carbon credit to compensate for pond's carbon emission (Boyd *et al*., 2010). It is a pattern of aquaculture that is environmentally friendly.

Nowadays, many countries are interested in environmentally friendly agriculture, while Thailand has more earthen pond aquaculture than other farming patterns. Therefore, this research aimed to examine the sediment accumulation rate and carbon burial rate in the Pacific white shrimp ponds, Phetchaburi Province, upper Gulf of Thailand. In this culture evaluation, basic data of sediment quality all along this study would be helpful for proper sediment quality management during crop helping to create high productivity of both marketable species as well as enhance environment sustainability.

Materials and methods

Study area and pond characteristics

The samples were collected from shrimp farm in Ban Lam District, Phetchaburi Province, upper Gulf of Thailand. Samples were collected in 2 ponds and 1 crop per pond (Table 1), which were in August to November 2019. The most of the ponds were small, covering areas of around 0.16 hectare with 4 aerators in each pond.

Table 1. Characteristics and management of culture ponds and growth performance of Pacific Pacific white shrimp

Culture pattern and growth performance	**Pond No.**	
	1	**2**
Pacific white shrimp (average per crop)		
- Pond size (hectare)	0.16	0.16
- Pond depth (m)	1.5	1.5
- Stocking density (shrimps/ha)	625,000	625,000
- Shrimp weight at beginning crop (g)	200	200
- Total feed (kg/pond/crop)	1,415.00	1,000.00
- Total shrimp product (kg/pond)	536	360
- Feed conversion ratio	2.64	2.78

Sediment sampling and analysis methods

Sediment samples were taken from the ponds between August to November 2019 combining for a total of crop growth. Physical and chemical characteristics of the collected sediment were studied. Sediment samples were collected at sediment deposition points from three sites in each pond; one site at feeding area and other sites at the deep end of the pond. Naturally the sediment would accumulate more at the deepest slope area in the pond, but the feeding area may have some food sediment leftover, so the sampling areas were designed in two areas with three samples obtained from each site.

Sediment depth was collected using a transparent PVC pipe, 5cm in diameter and 50cm in length then took notes. Sediment samples of bulk density and sediment moisture were collected by 5cm in diameter and 3cm in high of cylindrical metal container. All samples were stored at 4 ℃ for analysis in the laboratory, then it was drying completely in hot air oven at 105 ℃.

Soil texture and soil pH were collected a transparent PVC pipe as the same of the sediment depth's equipment. A disposable 4cm wooden dowel was used to extract the sediment out of the pipe. All samples were stored at 4 ℃ for analysis in the laboratory. After drying completely in hot air oven at 60 ℃, then the samples were grinded by mortar and pestle, separated size of sediments in 1.800 mesh sieves. Total nitrogen, total phosphorus and organic carbon were collected by core sampler, with five centimeters depth of sediment samples in the ponds. All samples were stored at 4 ℃ for analysis in the laboratory. After drying completely in hot air oven at 60 ℃, then the samples were grinded by mortar and pestle, separate size of sediments in 0.425 mesh sieves.

The analysis of the sediment qualities in each parameter showed in Table 2.

Sediment accumulation rate and carbon burial rate

The calculations of sediment accumulation rate and carbon burial rate adapted from Boyd *et al.* (2010) and Adhikari *et al.* (2012).

$$\text{Sediment accumulation rate } (cm \cdot yr^{-1}) = \frac{\text{Average total sediment depth } (cm)}{\text{Age of rearing (yr)}}$$

$$\text{Carbon burial rate } (g\,C \cdot m^{-2} \cdot yr^{-1}) = \text{Sediment accumulation rate } (cm \cdot yr^{-1}) \times \text{drybulk density of sediment} (\text{g} \cdot \text{cm}^{-3}) \times \text{percentage of organic carbon} \times 10^{4}$$

Where the sediment accumulation rate (cm $\cdot$yr $^{-1}$) in this study did not represent the sediment accumulation rate per pond area, but this method meant the sediment accumulation rate at the deposition point in pond which was already mentioned in the sediment sampling and analysis method above.

Table 2. Sediment analysis methods

Sediment parameters	Analytical venue		Analytical method
	Field	Laboratory	
1. Sediment depth	X		Steeby *et al*. (2004)
2. Bulk density		X	Clod method (Blake and Hartge, 1986)
3. Sediment moisture		X	Black (1965)
4. Soil texture		X	Hydrometer (Weber, 1977)
5. Soil pH		X	1:1 mixture (Thunjai *et al*., 2001)
6. Total nitrogen		X	Kjeldahl method (Bremner and Mulvaney, 1982)
7. Total phosphorus		X	Use $HClO_4$, spectrophotometer (Olsen and Sommers, 1982)
8. Organic carbon		X	Walkley-Black (Nelson and Sommers, 1982)

Statistical analysis

Sediment-quality data were analyzed using descriptive statistics. Furthermore, One-way ANOVA analysis was used to compare the differences between various all factors without soil texture, if the data were normally distributed, it would be analysed by parametric statistic. On the other hand, if the data were not normally distributed, it would be analysed by non parametric statistic. But, the soil texture, percentage of sand, silt and clay were compared at the beginning of the crop as well as during harvesting by using T-test analysis at a 95-percent-confidence level.

A correlation of coefficiency analysis was used to indicate a relationship between sediment quality factors in Pacific white shrimp ponds at a 95-percent-confidence level.

Results

Sediment-Quality factors in study areas

Sediment Quality data in culture period was analyzed (Table 3 and 4). In the results of the Sediment Quality in the ponds, it was found that the most of the sedment quality parameters were within the appropriate standard criteria. However, during harvesting period, organic carbon and total nitrogen was higher than standard criteria. It indicated that the amount of waste accumulated in the ponds increased with increasing culture periods. While comparing the sediment qualities during the culture periods, it was indicated that the sediment quality of the most parameters had a statistically significant difference ($p<0.05$), details of sediment qualities were shown in Table 3 and 4.

Table 3. Average and standard deviation of Sediment-quality factors in each culture period (Pond No.1)

Sediment quality parameters	Culture period				Standard
	Beginning crop	1st month	2nd month	Harvesting period	
Sediment depth (cm)	3.00 ±0.00[a]	4.00 ±0.00[b]	5.00 ±0.00[c]	9.33 ±0.58[d]	< 20
Bulk density (g/cm^3)	1.06 ±0.04[d]	0.85 ±0.03[c]	0.46 ±0.03[b]	0.35 ±0.03[a]	< 0.30
Sediment moisture (%)	0.88 ±0.12[a]	3.47 ±0.04[b]	9.83 ±0.06[c]	13.66 ±0.14[d]	26.00 - >100.00
Sand (%)	47.77 ±0.37[a]	-	-	47.92 ±1.00[a]	-
Silt (%)	21.21 ±3.25[a]	-	-	9.31 ±1.53[a]	-
Clay (%)	31.01 ±3.35[a]	-	-	42.77 ±0.58[a]	> 20
pH	8.22 ±0.03[c]	8.19 ±0.02[c]	8.12 ±0.02[b]	8.05 ±0.01[a]	7.50-8.50
Total nitrogen (%TN)	0.13 ±0.01[a]	0.17 ±0.01[b]	0.21 ±0.03[c]	0.38 ±0.02[d]	0.10 – 0.25
Total phosphorus (%TP)	0.06 ±0.02[a]	0.07 ±0.01[ab]	0.08 ±0.01[ab]	0.09 ±0.01[b]	< 1.00
Organic carbon (%C)	1.87 ±0.02[a]	2.94 ±0.06[b]	3.06 ±0.02[b]	3.98 ±0.37[c]	1.00-2.50

Remak: Standard values were based on Avnimelech *et al*. (2001); Boyd (1995); Boyd *et al*. (2002); Boyd (2008); Egna and Boyd, (1997).
The different characters in the row refer to statistically significant difference at 95 % confidence interval ($P<0.05$).

Relationship between Sediment Quality factors in Pacific white shrimp ponds

Analysis of the correlation coefficiency between sediment quality parameters in the part of nutrient and waste showed that the total nitrogen had a high level of positive correlation with statistical significance ($p<0.05$) with sediment depth ($r=0.965$), sediment moisture ($r=0.930$) and total phosphorus ($r=0.847$). Moreover, total phosphorus was also highly positive related ($p<0.05$) with percentage of clay ($r=0.891$) and organic carbon ($r=0.847$). Organic carbon was highly positive related ($p<0.05$) with sediment depth ($r=0.817$).

Considering the results of the sediment quality analysis in the ponds, it was found that sediment quality parameters in the part of nutrient and waste in the ponds indicated that the nutrient and waste increased along the culture period and the highest amount being during the harvesting period. The details of the relationship between sediment quality factors in Pacific white shrimp ponds were shown in Table 5.

Table 4. Average and standard deviation of Sediment-quality factors in each culture period (Pond No.2)

Sediment quality parameters	**Culture period**				**Standard**
	Beginning crop	**1st month**	**2nd month**	**Harvesting period**	
Sediment depth (cm)	3.00±0.00[a]	4.33±0.58[b]	5.33±0.00[c]	9.00±0.00[d]	< 20
Bulk density (g/cm^3)	0.99±0.04[c]	0.51±0.04[b]	0.36±0.03[a]	0.32±0.02[a]	< 0.30
Sediment moisture (%)	1.27±0.20[a]	9.60±0.07[b]	15.32±0.21[c]	17.40±0.18[d]	26.00 - >100.00
Sand (%)	46.65±0.51[a]	-	-	44.35±0.37[a]	-
Silt (%)	29.24±0.83[a]	-	-	19.55±0.51[a]	-
Clay (%)	24.11±0.58[a]	-	-	36.11±0.58[a]	> 20
pH	8.20±0.01[d]	8.16±0.02[c]	8.08±0.01[b]	8.01±0.02[a]	7.50-8.50
Total nitrogen (%TN)	0.08±0.02[a]	0.20±0.01[b]	0.30±0.01[c]	0.43±0.02[d]	0.10 – 0.25
Total phosphorus (%TP)	0.03±0.02[a]	0.06±0.01[b]	0.07±0.01[bc]	0.08±0.00[c]	< 1.00
Organic carbon (%C)	0.16±0.01[a]	1.46±0.02[b]	2.15±0.09[c]	4.87±0.12[d]	1.00-2.50

Remak: Standard values were based on Avnimelech *et al.* (2001); Boyd (1995); Boyd *et al.* (2002); Boyd (2008); Egna and Boyd, (1997)
The different characters in the row refer to statistically significant difference at 95 % confidence interval ($P<0.05$).

Sediment accumulation rate

Sediment accumulation rate differed significantly between ponds. Mean sediment accumulation rate of the pond No.1 (19.00±1.73 cm yr^{-1}) was significantly lower ($P<0.05$) than the pond No.2 (24.00±0.00 cm yr^{-1}). If the pond was low pond age and high sediment depth caused the pond's the sediment accumulation would been high, according to the sediment data in Table 6. Also, the average data of sediment accumulation rate in the Pacific white shrimp ponds in these study areas were 21.50±2.95 cm yr^{-1} (Figure 1).

Table 5. Relationship between sediment quality factors in Pacific white shrimp ponds

Sediment quality parameters	Sediment depth (cm)	Bulk density (g/cm^3)	Sediment moisture (%)	Clay (%)	pH	Total nitrogen (%TN)	Total phosphorus (%TP)	Organic carbon (%C)
Sediment depth (cm)	-	-0.922* (p=0.000)	0.904* (p=0.000)	0.903* (p=0.000)	-0.929* (p=0.000)	0.965* (p=0.000)	0.785* (p=0.000)	0.817* (p=0.000)
Bulk density (g/cm^3)	-0.922* (p=0.000)	-	-0.960* (p=0.000)	0.629* (p=0.029)	0.931* (p=0.000)	-0.933* (p=0.000)	-0.647* (p=0.001)	-0.715* (p=0.000)
Sediment moisture (%)	0.904* (p=0.000)	-0.960* (p=0.000)	-	0.562 (p=0.057)	-0.916* (p=0.000)	0.930* (p=0.000)	0.651* (p=0.001)	0.705* (p=0.000)
Clay (%)	0.903* (p=0.000)	0.629* (p=0.029)	0.562 (p=0.057)	-	-0.651* (p=0.022)	0.779* (p=0.003)	0.891* (p=0.000)	0.768* (p=0.004)
pH	-0.929* (p=0.000)	0.931* (p=0.000)	-0.916* (p=0.000)	-0.651* (p=0.022)	-	-0.929* (p=0.000)	-0.612* (p=0.001)	-0.746* (p=0.000)
Total nitrogen (%N)	0.965* (p=0.000)	-0.933* (p=0.000)	0.930* (p=0.000)	0.779* (p=0.003)	-0.929* (p=0.000)	-	0.847* (p=0.000)	0.793* (p=0.000)
Total phosphorus (%P)	0.785* (p=0.000)	-0.647* (p=0.001)	0.651* (p=0.001)	0.891* (p=0.000)	-0.612* (p=0.001)	0.847* (p=0.000)	-	0.847* (p=0.000)
Organic carbon (%C)	0.817* (p=0.000)	-0.715* (p=0.000)	0.705* (p=0.000)	0.768* (p=0.004)	-0.746* (p=0.000)	0.793* (p=0.000)	0.847* (p=0.000)	-

remark: * is a statistical significant different ($p<0.05$).

Table 6. Mean ± SD (minimum-maximum values) of sediment accumulation rate in Pacific white shrimp ponds

Ponds	Pond age (yr)	Sediment depth (cm)	Sediment accumulation rate (cm yr^{-1})
Pond No.1	0.33	6.33±0.58 (6.00-7.00)	19.00±1.73^{a} (18.00-21.00)
Pond No.2	0.25	6.00±0.00 (6.00-6.00)	24.00±0.00^{b} (24.00-24.00)
Average of all ponds	0.29	6.17±0.41 (6.00-7.00)	21.50±2.95 (19.00-24.00)

Remark: The different characters in the row refer to statistically significant difference at 95 % confidence interval ($P<0.05$).

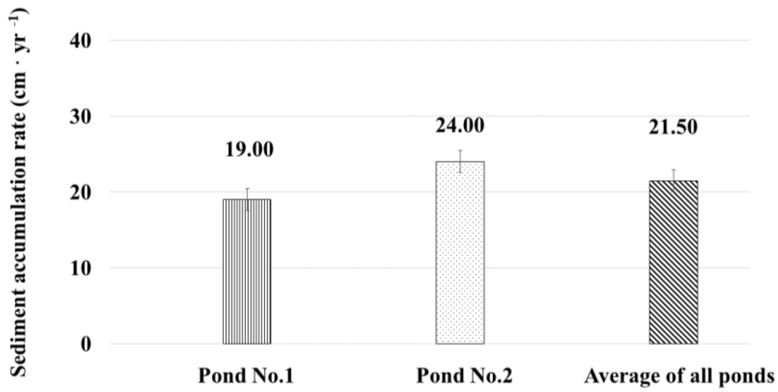

Figure 1. Sediment accumulation rate for each Pacific white shrimp ponds

Carbon burial rate

The carbon burial rate had no statistically significant difference (p>0.05) between ponds (p>0.05) in Table 7. Mean carbon burial rate of the pond No.1 and No.2 were 28.15 (±4.37) and 75.72 (±6.77g) C ·m^{-2} ·yr^{-1} respectively. The average data of carbon burial rate in the Pacific white shrimp ponds in these study areas were 51.94 (±26.55g) C ·m^{2} ·yr^{-1} (Figure 2). The carbon burial rate of sediment in the ponds related with pond age, sediment depth, dry bulk density of sediment and percentage of organic carbon. In this study, the percentage of dry bulk density of sediment were not significantly difference (p>0.05) in each pond. However sediment accumulation rate and organic carbon of pond No.2 were higher than pond No.1. As the result, carbon burial rate of the pond No.2 was higher than the pond No.1, but not significantly difference (p>0.05).

Table 7. Mean ± SD (minimum-maximum values) of carbon burial rate in Pacific white shrimp ponds

Ponds	Dry bulk density of sediment (g ·cm^{3})	organic carbon (%)	Carbon burial rate (g C ·m^{2} ·yr^{-1})
Pond No.1	0.71 ±0.07 [a]	2.11 ±0.38 [a]	28.15 ±4.37 [a]
	(0.64-0.77)	(1.73-2.48)	(23.28-31.71)
Pond No.2	0.67 ±0.05 [a]	4.71 ±0.12 [b]	75.72 ±6.77 [a]
	(0.62-0.72)	(4.58-4.82)	(70.23-83.29)
Average of all ponds	0.69 ±0.06	3.41 ±1.44	51.94 ±26.55
	(0.62-0.77)	(1.73-4.82)	(23.28-83.29)

Remark: The different characters in the column refer to statistically significant difference at 95 % confidence interval (P<0.05).

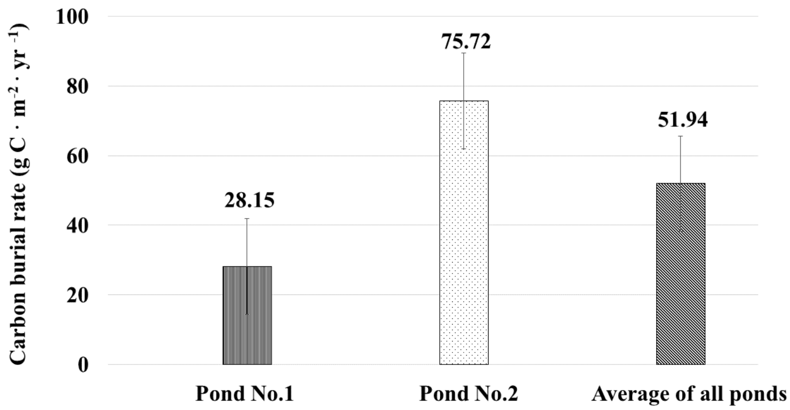

Figure 2. Carbon burial rate for each Pacific white shrimp ponds

Discussion

This study found that the accumulation of nutrients and waste in the Pacific white shrimp culture pond's sediment increased continuously during the culture period; Especially the amount of organic carbon in the pond No.1 which had increased to exceed the standard criteria since the beginning of the culture. Overall, nutrients and wastes accumulation in the sediment increased to exceed standard criteria at the end of the culture period. Consistent with Chen *et al.* (2020) studied in commercial shrimp farming in China, total nitrogen and total phosphorus were the primary nutrients in shrimp cultures abundant in the sediment surface. Most of the nutrients and wastes in the commercial shrimp ponds are nutrients in the nitrogen group, mainly from aquatic animal's excretion and food scraps that are not in aquatic animals feeding habits (Naylor and Burke, 2005). Wu *et al.* (2014) evaluated the nitrogen loading in commercial shrimp ponds in China and found that the inorganic nitrogen loading content in shrimp ponds ranged from -0.06-1.17kg N ha^{-1} yr^{-1} and released nitrogen group nutrients to the environment about 3.58-14.38kg N ha^{-1} yr^{-1}. When considering the relationship between nutrients and sediment quality factors, it was found that the primary nutrients had a high level of positive correlation with statistical significance ($p<0.05$) with sediment depth. Total nitrogen had a high positive correlation with total phosphorus (r=0.847) and sediment moisture (r=0.930). Moreover, total phosphorus was also highly positive related with organic carbon (r=0.847) and percentage of clay (r=0.891). The results indicated that the nutrient and waste increased along the culture period and the highest amount being during the harvesting period. Consistent with Pawar *et al.* (2002) reported the fish cage culture had the correlation between feed input and nutrient accumulation in sediment, the feed input was related to the accumulation of acid volatile sulfide sulfur (AVS-S) content and redox conditions of the sediment. It was indicated that feed input directly affects the accumulation of nutrients and wastes in commercial aquaculture systems sediment. The accumulation of nutrients and wastes in the aquaculture pond sediments often results in anaerobic processes, that accumulation of toxins that are harmful to aquatic animals. In particular, methane and hydrogen sulfide (H_2S) are toxic gases that have an acute effect on aquatic life. The redox potential of sediment in aquaculture ponds with the most nutrient accumulation may be lower than -200 mV (Eh) (Pawar *et al*., 2001; Tsutsumi *et al*., 1991).

The average data of sediment accumulation rate in the Pacific white shrimp ponds in these study areas were 21.50±2.95 cm yr^{-1} and average data of carbon burial rate was 51.94±26.55 g C m^{2} yr^{-1}. Xing *et al*. (2005) reported that nutrients enriched water could release carbon dioxide (CO_2–C emission) up to 33.1g C m^{2} yr^{-1}. Boyd *et al*. (2010) reported that the sediment in the aquaculture pond area was able to produce high carbon fixation or carbon burial rate of sediment, consistent with this study. Moreover, the carbon burial rate can be used as the carbon credit to compensate for pond's carbon emission and it is the basis for the management of soil, sediment and ponds to be environmentally friendly.

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