Sedimentary waste nutrients, water quality and production profiles of intensive *Penaeus vannamei* culture reared in low salinities

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Abstract. The availability of seawater for farming is limited to certain locations, therefore, *Penaeus vannamei* is often cultured in places with low-salinity media. The objective of this study was to evaluate sedimentary waste nutrients, water quality and production profiles of *P. vannamei* reared in low salinity ponds. Data were obtained for different rearing periods (age) of *P. vannamei*: 32, 46, 92, and 108 days. Each age group was sourced from two ponds, as sampling points. The results showed that 1 kg of sediment waste (wet weight) released by the rearing of the 4 age groups of *P. vannamei* contained 63.68-175.01 g of organic carbon, 13.33-19.4 g of nitrogen and 2.7-4.3 g of phosphorus. The concentrations of organic carbon and nitrogen in sediment and orthophosphate in the water column in a pond of *P. vannamei* reared for 46 days were significantly higher compared to other age groups ($P<0.05$). The overall wastes produced by 1 ha of pond during the production cycle of *P. vannamei* were estimated: (1) at their 32 days of rearing, there were found 2.63 to 3.52 t of solid sediment material, of which: 0.321-0.430 t were organic carbon, 0.039 to 0.052 t were nitrogen and 0.008 to 0.01 t were phosphorus; (2) at 108 days of rearing (ready-to-harvest), there were found 157.58 to 189.29 t of solid sediment material, of which: 10.03 to 12.05 t were organic carbon, 2.38 to 2.85 t were nitrogen and 0.6 to 0.81 t were phosphorus. The ready-to-harvest *P. vannamei* had an average body weight of 20.38±3.16 g, an estimated survival rate of 66.67-69.57%, feed conversion ratio of 1.45-1.55 and a biomass content of 13.96-14.71 mt ha^{-1}. *P. vannamei* reared intensively in ponds with low water salinity tend to have a higher food conversion ratio.

Key Words: feed nutrients accumulation, solid sediment material, total nitrogen, total phosphorus.

Introduction. The pacific white shrimp, *Penaeus vannamei*, is commonly farmed in ponds where water salinity ranges from 15 to 25 g L^{-1} (Bray et al 1994; Gao et al 2016), which is similar to the salinity for the post larval *P. vannamei* production in the hatchery (SNI-7311 2009). The availability of seawater with high salinity is limited to certain shrimp farming locations, especially those that are far from the coastline, such as in Mexico (Araneda et al 2008), India (Kutty 2005) and western parts of Indonesia, like Lamongan and Subang. Therefore, *P. vannamei* culture is carried out in places with low salinity levels.

P. vannamei can act as a hypo-osmoregulator or a hyper-osmoregulator when the salinity of the medium is below or above the isotonic point, respectively, therefore shrimp can be cultivated at low salinity levels. Although shrimp have a good osmoregulation ability in conditions of continuous salinity variations, it results in increased energy expenditure for homeostasis, low growth rates and high feed conversion ratio values (Laramore et al 2001; Brune et al 2003; Li et al 2007). A high feed conversion ratio is an indicator of the low assimilation of feeds energy, causing a release of larger amounts of feed energy and potentially polluting organic waste into the aquatic environment (Wu et al 2014). Besides, the nutrients are not entirely utilized. The uneaten feed nutrition is accumulated and associated with bacteria as organic sedimentary waste at the bottom of the pond. In intensive *P. vannamei* culture, the accumulated sediment waste is removed from the pond periodically, using the siphon or gravity method. The chemical compounds at the bottom of the ponds, from the sediment waste rich in nutrients, can poison shrimps and increase pathogens density.

Several studies reported the effects on the amount of released sediment, the nutrient concentrations and the water quality characteristics, and the shrimp production performance when reared in high salinity ponds (Avnimelech & Ritro 2003; Jackson et al 2003; Suwoyo et al 2015). However, the information on white shrimp reared in low-salinity ponds is limited. Previous studies focused on survival and production performance were conducted on a laboratory scale (Atwood et al 2003; McNevin et al 2004; Sowers & Tomasso 2006). The objective of this study was to evaluate the dynamics of nutrients in the sedimentary waste, the water quality and the production performance of *P. vannamei* intensively cultivated in low salinity ponds.

Material and Method

Research location. The research was conducted at the *P. vannamei* farms in Langensari, Subang Regency, West Java, Indonesia. Four pond groups were constituted, based on the *P. vannamei* rearing period (the dependent variable of the study) in the pond, namely: 32, 46th, 92 and 108 days. For each group there are 2 culture ponds, both used as sampling points. The research was conducted from March to May 2019.

Pond operational system. The pond areas used in this research were located ±3.75 km from the coastline, and they were adjacent to a rice field. The seawater was obtained from the Kaliasem and Kaliblanakan rivers confluence. Both rivers have a very low salinity, which is 5 ppt. High salinity only occurs when the tide is at the peak. Low salinity water was collected in plots and subsequently distributed to the rearing ponds using pipelines. Moreover, the *P. vannamei* were reared intensively in semi-closed systems such that water loss due to the siphons was limited and replaced by underground freshwater at 5 ppt, to maintain the salinity fluctuations between 3 and 8 ppt and the water level at 112 cm. In addition, the sediments accumulated at the bottom of the pond were layered with low-density polyethylene (LDPE) plastic and were siphoned through the drainage channel at four days interval using a 1,000 L minutes^{-1} water pump, during 0.5-1.33 hr. The first siphoning process was, however, conducted after 28 days of culture. The post larva (PL) PL_{-12} *P. vannamei* fries were obtained from a hatchery in Anyer, West Java. Each of the plots was stocked at a density of 118 shrimp m^{-2}. The *P. vannamei* nutrition consisted of pellet feed with a protein content of 34.89%. The frequency of feeding varied according to the age of *P. vannamei*: 2 times a day (at 07:00 AM and 07:00 PM) between 1 and 17 days and 4 times a day (at 07:00 AM, 11:00 AM, 03:00 PM and 07:00 PM) at more than 17 days.

Sedimentation rate. Sediment waste released from *P. vannamei* ponds was generated by unconsumed feed, metabolic waste as feces, dead microorganisms and soil particles brought by the water supply. The total sediments released by the ponds in one production cycle were estimated using the suspended method, while the volume of sludge waste was calculated using the modified formulas of Nastain & Suroso (2005):

$$Vsludge = Q \ x \ \Sigma t$$

Where:
V_{sludge} - total volume of pond sludge waste during the siphoning (L);
Q - flow generated by the water pump (1,000 L h^{-1});
t - siphoning duration (h).

Subsequently, the sediment load was calculated using the formula:

$$Vsediment = Cs \ x \ Q \ x \ \Sigma t$$

Where:
$V_{sediment}$ - total solid material of sediment volume (t ha^{-1});

Cs - a ratio of solid material sediment load to sludge waste (%);
t - siphoning duration (h).

The minimum and maximum volumes of sediment wastes were recorded based on the shortest and longest siphoning durations, respectively.

Nutrient sediment analysis. Sediments were collected using a mixed-method, suggested by Jackson et al (2003). In this experiment, 2 ponds with the same rearing period were selected as sampling points, with 5 sediment samples collected from each pond, at different points. Sediment samples from pond 1 and 2, corresponding to the same shrimp age, were combined. The CNP analysis of sediments for each rearing period of shrimp was repeated 3 times (triplicated). Furthermore, the separation of sediment CNP values of the mixed samples (for the same shrimp age) was converted based on shrimp biomass at the pond locations 1 and 2, so that there were 6 replications of the sediment CNP data for each rearing period of shrimps. Analyzes of organic carbon, nitrogen, and phosphorus were carried out at the Aquaculture Environment Laboratory, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University. Moreover, the organic carbon was analyzed referring to Walkley & Black's method, the nitrogen through the Kjeldahl method and the phosphorus using the ammonium molybdate spectrophotometry method.

Water quality analysis. The evaluated water quality parameters included: NH_3-N, NO_2^--N, NO_3^--N, TOM and PO_4^{3-}-P. The water samples analysis at each pond was carried out 3 times, so that each age category of shrimp contained 6 data replications. The DO levels in each pond were measured at the water surface and bottom in 6 different points, 4 located at the corners of the pond and 2 located on the pond's length median, so that each rearing period category of the shrimp has 12 replications. The TAN, nitrite, nitrate, TOM, and phosphate content were analyzed at the Aquaculture Environment Laboratory, Department of Aquaculture, Bogor Agricultural University, referring to APHA 2012.

The production profile of P. vannamei. The productivity of *P. vannamei* was evaluated by calculating the average body weight (ABW), the amount of feed provided, the survival rates, the biomass and the feed conversion ratio (FCR). The daily amounts of feed were used to calculate the total amount of feed. Feed pellets were spread continuously in each pond at a rate of about 5-7% daily from the total shrimp biomass. Moreover, the quantity of daily feed and the feed rate were used to estimate the shrimp biomass, while the number of living shrimp was calculated based on the ratio of total biomass to ABW. The average body weight (ABW) of *P. vannamei* was calculated by the given formula (Zonneveld et al 1991):

$$ABW = \frac{Shrimp\ sampling\ weight\ (kg)}{number\ of\ shrimp\ (individual)}$$

The biomass was calculated by the formula suggested by Adiwidjaya et al (2005):

$$Biomass = \frac{Quantity\ of\ daily\ feeding\ at\ sampling\ (kg)}{Feeding\ rate}$$

The population was calculated by the formula (Adiwidjaya et al 2005):

$$Population = \frac{Biomass\ (kg)}{ABW\ (g)}\ x\ 1000$$

The survival was calculated by the formula recommended by Zonneveld et al (1991):

$$SR = \frac{Final\ population}{Initial\ population}\ x\ 100$$

The feed conversion ratio was calculated by the formula (Zonneveld et al 1991):

$$FCR = \frac{Total\ feed\ given\ (kg)}{Biomass\ of\ P. vannamei\ (kg)}$$

Statistical analysis. Data on concentration of nutrient sediment (carbon, nitrogen, fosfor), number of bacteria in sediment, water quality (DO, TOM, TAN, nitrite, nitrateand orthophosphate), and the bodyweight of *P. vannamei* were analyzed using one-way ANOVA with Duncan tests at the significance level of $p<0.05$. Data on total sediment (Vsed.), total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP) and productivity of *P. vannamei* were analyzed descriptively.

Results and Discussion

Sediment waste nutrient of P. vannamei. The profiles of organic carbon and nitrogen in sediments in the parcels corresponding to the 46 days of shrimp rearingwere significantly higher compared to the parcels corresponding to the three other shrimp rearing periods ($P<0.05$) (Figure 1). But, the phosphorus in the sediment corresponding to 108 days of rearing was significantly higher compared to the three other rearing periods ($P<0.05$).

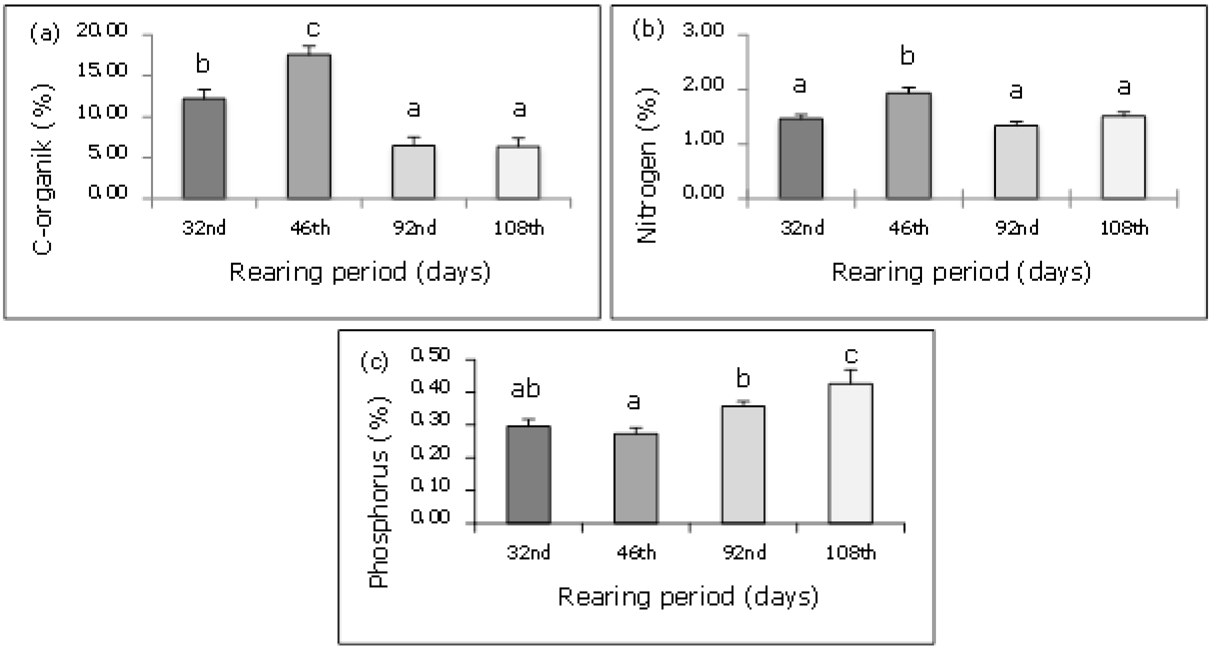

Figure 1. Concentration of nutrient in *Penaeus vannamei* sediment waste: 32; 46, 92 and 108 days of rearing. (a) Organic carbon, (b) Nitrogen, (c) Phosphorus. *Different letter notations show different responses (Duncan test, $p<0.05$). Error bars are standard deviations (SD).

Water quality. A high total ammonia nitrogen was observed in shrimp reared for 32 days, but it significantly decreased both at 108 and 92 days of rearing ($P<0.05$). A slight increase was observed again at 108 days of rearing, but the total nitrogen was still inferior to the value for 32 days of rearing (Figure 2a). Moreover, the highly significant NO_2^--N concentration found in the pond plot of the 108 days rearing period was 0.084±0.007 mg L^{-1}, compared to the three other shrimp rearing periods ($P<0.05$). The lowest nitrite value was obtained for 92 days of rearing, but was not significantly different compared to 32 and 46 days of rearing ($P>0.05$) (Figure 2b). The optimal nitrite content for *P. vannamei* shrimp growth was ≤1.0 mg L^{-1} (Martin et al 1998; Venkatesan et al 2001). The nitrate concentrations showed the same pattern as the nitrite with the maximum value of 0.82±0.05 mg L^{-1} found in the ponds at 108 days of rearing (Figure

2c). In addition, a highly significant concentration orthophosphate, 0.25±0.06 mg L^{-1} ($P<0.05$), was discovered in the pond plots with the rearing period of 46 days (Figure 2d). Lastly, the lowest concentration of TOM, 95.60±5.43 mg L^{-1}, was detected at the pond with the rearing period of 92 days, with a significant difference compared to the other shrimp rearing periods ($P<0.05$) (Figure 2e).

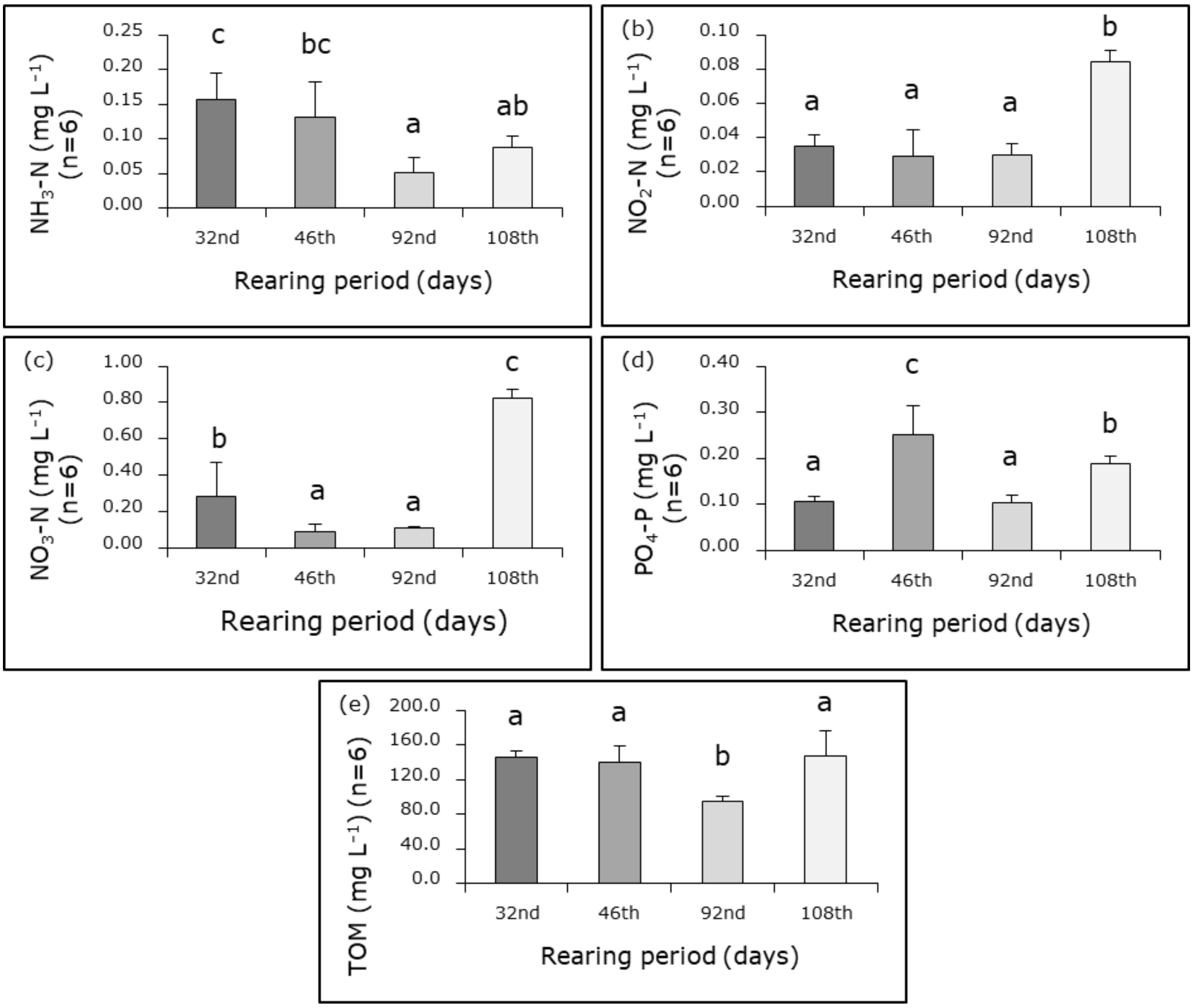

Figure 2. Characteristic water nutrients of the *Penaeus vannamei* ponds at different rearing periods. (a) NH_3-N, (b) NO_2^--N, (c) NO_3^--N, (d) PO_4^{3-}P, (e) TOM. *Different superscript letter notations show different responses (Duncan test, p<0.05). Error bars are standard deviations (SD).

Water temperature, salinity, pH and density of sediment bacteria on each research pond were presented in Table 1.

Table 1

Characteristics of water quality of the *Penaeus vannamei* ponds

Variable of water quality	*Rearing period (days)*			
	32nd	*46th*	*92nd*	*108th*
Salinity (g L^{-1})	3-5	3-5	6-8	6-8
Morning temperature (^{0}C)	27.1±0.05	27.2±0.05	27.2±0.05	27.2±0.04
Afternoon temperature (^{0}C)	29.9±0.09	29.9±0.08	30.1±0.10	30.2±0.12
pH	8.08-8.15	7.79-7.86	7.86–8.07	7.33-7.56
*Number of bacteria (log cfu g^{-1}) (n=3)	7.25±0.05[a]	7.40±0.08[a]	6.35±0.15[b]	7.44±0.33[a]

*Different letter notations on the same data line show different responses (Duncan test, p<0.05).

The dissolved oxygen level is related to the metabolism activity of *P. vannamei*. DO levels at 09:00 AM ranged from 5.73±0.37 to 7.75±0.23 mg L^{-1} at the water ponds surface and 5.32±0.40 to 7.29±0.31 mg L^{-1} at the bottom, at a depth of 1 m. At 04:00 PM, it ranged from 5.70±0.34 to 8.33±0.48 mg L^{-1} at the surface and 5.14±0.50 to 8.03±0.41 mg L^{-1} at the bottom. The dissolved oxygen level of *P. vannamei* pond parcels with shorter rearing periods was significantly higher compared to the parcels with longer rearing periods ($P<0.05$) (Figure 3).

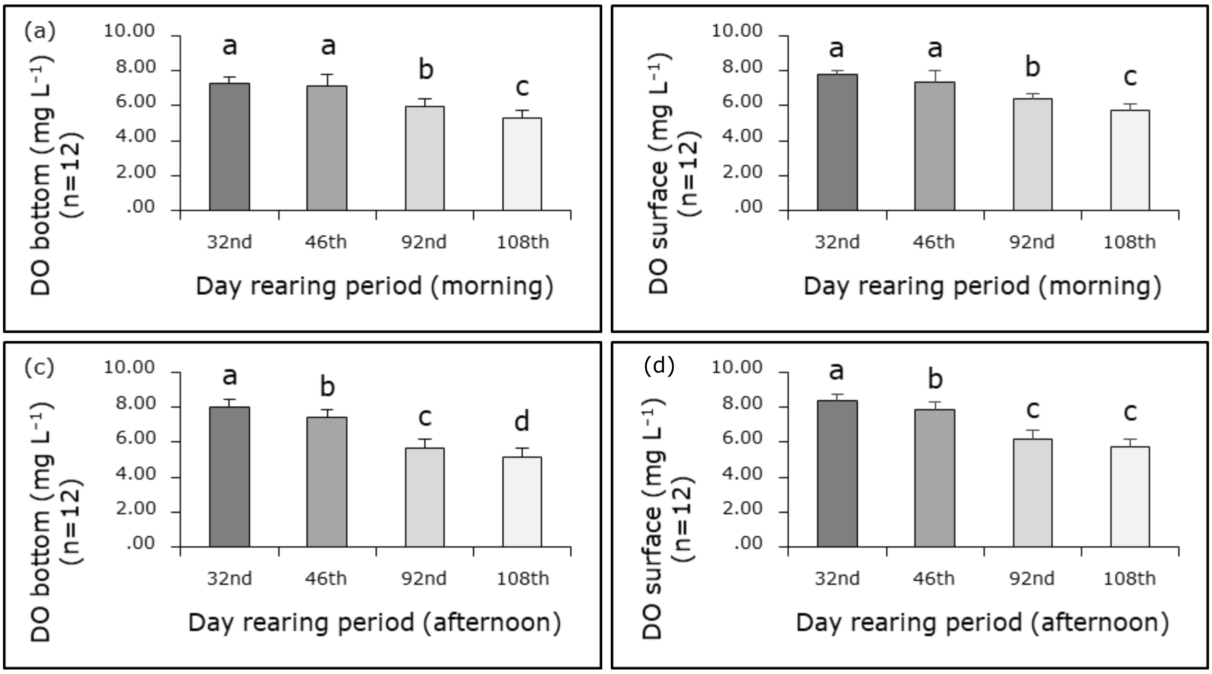

Figure 3. Dissolved oxygen (DO) in the morning (08:30-09:30 AM) and afternoon (03:30-04:30 PM). (a) DO at the bottom, in the morning, (b) DO at the surface, in the morning, (c) DO at the bottom, in the afternoon, (d) DO at the surface, in the afternoon. *Different letter notations show different responses (Duncan test, p<0.05). Error bars are standard deviations (SD).

Sedimentation rate and total sediment nutrients. Total sediment material (V_{sed}), total organic carbon (TOC), total nitrogen (TN), and total phosphorus (TP) in the 4 categories of *P. vannamei* rearing periods were provided as minimum, maximum, and median amounts (Table 2).

Table 2

Total sediment (V_{sed}), total carbon organic (TOC), total nitrogen (TN) and total phosphorus (TP) released of *Penaeus vannamei* ponds at different rearing period

Rearing period (days)	*V_{sed} (t ha^{-1})*			*Sediment nutrients (t ha^{-1})*									*C/N ratio*
				TOC			*TN*			*TP*			
	Min.	*Max.*	*Med.*	*Min.*	*Max.*	*Med.*	*Min.*	*Max.*	*Med.*	*Min.*	*Max.*	*Med.*	*Med.*
32nd	2.63	3.52	3.08	0.321	0.430	0.376	0.039	0.052	0.045	0.008	0.010	0.009	8.34
46th	10.97	14.63	12.80	1.931	2.575	2.253	0.213	0.284	0.248	0.030	0.040	0.035	9.08
92nd	125.56	153.46	139.51	8.086	9.882	8.984	1.677	2.049	1.863	0.448	0.548	0.498	4.82
108th	157.58	189.29	173.43	10.035	12.054	11.044	2.376	2.854	2.615	0.673	0.808	0.740	4.22

Min.- Minimum; Max.- Maximum; Med.- Median.

The total sediment nutrients (TOC, TN, and TP) in the four age groups of shrimp were influenced by the amount of sediment material released. Although the concentration of organic carbon and nitrogen contained in the sediment in shrimp with a shorter rearing time is higher, the total value is smaller, because the amount of sediment material in *P. vannamei* pond parcels with shorter rearing periods has smaller total sediments than for longer rearing periods. Previous studies reported that the formation of sediment materials in shrimp farming activities in brackish water and seawater ponds are provided in Table 3.

Table 3

Research on shrimp farming sediment material accumulation

Reference	Location	Shrimp farming method	Salinity levels	Amount of solid sediment (t ha^{-1})
Boyd (1992)	Thailand	Intensive	High	157-290
Satapornvanit (1993)	Thailand	Intensive	High	144-461
Martin et al (1998)	New Caledonia	Intensive	High	291
Briggs & Smith (1994)	Thailand	Intensive	High	185-199
Suwoyo et al (2015)	Indonesia	Super-intensive	High	182-219
This research (2019)	Indonesia	Intensive	Low	158-189

Profile of P. vannamei production. The production profile of *P. vannamei* at the four rearing period categories was provided in Table 4. The average body weight of *P. vannamei* with rearing periods of 108 days was significantly higher compared to the specimens reared for 46 and 32 days (P<0.05), but not significantly different compared to the specimens reared for 92 days (P>0.05). These results indicate that, between the 92 and 108 days rearing periods, the shrimp body weight gain was relatively smaller and had a lower impact on the feed efficiency, as indicated by the increase of FCR. The lowest FCR was observed in *P. vannamei* a reared for 32 days, while shrimp with a longer rearing period showed fluctuating values. The high FCR value is a sign of the high amount of feed energy lost to the environment and not assimilated by the *P. vannamei*.

Table 4

The production profile of intensive *Penaeus vannamei* culture reared at a salinity of 3-8 g L^{-1}

Rearing period (days)	Stocking amount (shrimp)	Average weight of shrimp (g) n=5	Feed (t ha^{-1})	SR estimation (%)	Biomass estimation (mt ha^{-1})	FCR
32-P1	235,750	3.32 ± 0.13^{a}	2.756	73.01	2.289	1.20
32-P2	235,750	3.34 ± 0.21^{a}	3.445	85.27	2.690	1.28
46-P1	235,750	5.54 ± 0.43^{b}	5.519	72.63	3.850	1.43
46-P2	235,750	5.26 ± 0.30^{b}	5.915	72.58	3.589	1.65
92-P1	235,750	18.68 ± 0.33^{c}	16.285	71.22	12.566	1.46
92-P2	235,750	18.76 ± 0.33^{c}	16.506	71.99	12.782	1.32
108-P1	235,750	20.12 ± 0.65^{cd}	20.148	69.57	13.965	1.45
108-P2	235,750	20.38 ± 3.16^{d}	22.748	66.67	14.706	1.55

P1-pond 1; P2-pond 2; SR-survival rate; FCR-food conversion ratio. * Different letter notations on the same data column show different responses (Duncan test p<0.05)

Discussion. Similar to the shrimp reared in high salinity, the assimilation rate of feed by the shrimp kept in low salinity levels appears to be influenced by the feeding frequency. The setting of the feed frequency need to consider that the used feed pellets contained 34.89% protein, producing shrimp specimens with 20.38±3.16 g average weight at harvest, a SR of 67-70% and a FCR value of 1.45-1.55. *P. vannamei* uses feed energy as a source of nutrients to increase their somatic growth. The shrimps prefer using protein as source of energy, rather than carbohydrates and fats. The more protein that can be digested, the more feed is converted into body protein and growth in white shrimp (Widanarni et al 2015). Furthermore, Nunes et al (2019) reported that an increase in feeding frequency significantly affected survival, growth performance and feed efficiency. As an osmoregulator species, shrimp can adapt to low salinity environments. The level of salinity and ion composition of their ambient has a profound effect on feed consumption, osmoregulation, nutrient utilization, molting and the growth level, due to the ability to actively maintain internal homeostasis under hypersaline conditions. The osmoregulation mechanism in this condition is categorized as hyper-osmoregulation, therefore the daily salinity fluctuations in a small range were highly recommended in the shrimp culture. According to Jiang et al (2000), the maintenance of internal ionic homeostasis under hyper-osmoregulation conditions needs 20-50% of the metabolic energy. The growth performance of *P. vannamei* reared in low salinity results in lower body weight (Laramore et al 2001; Venkatesan et al 2001; Gao et al 2016). Li et al (2007) stated that the ability of shrimps to utilize energy to maintain their bodies iso-osmotic in hypo-osmotic environmental conditions tends to be higher due to its optimal growth performance at the isotonic point. We suspect that the effect of salinity on shrimp growth is not caused by high or low salinities, but more specifically by the range of daily salinity fluctuations. Shrimp will grow faster at short range of daily salinity fluctuations. The greater the range of daily salinity fluctuations, the higher the utilization of the feed's energy for maintenance.

P. vannamei survival in this study is 66.67% and 69.57% for pond 1 and 2, respectively, indicating a lower value compared to those reared in higher salinity media. For example, the survival rate of intensive *P. vannamei* culture in Pangkep at 12-23 g L^{-1} of salinities was 88-91% (Juanda 2018). Laramore et al (2001) reported that the survival of the post-larva reared at 30 g L^{-1} was higher, but not significantly different from a 4 g L^{-1} salinity ($P>0.05$). Other research reported by Jusadi et al (2011) showed that white shrimp reared in high salinity, whose given feed was enriched with taurine, had a survival of 44.1±4.4% and 53.5±2.8%, lower than shrimp survival in this study. This study confirmed that *P. vannamei* can be cultured in low salinity waters. The productivity profile of *P. vannamei* in this study was the same as for *P. vannamei* reared in ponds with high salinities. Different salinity levels affect shrimp production, however, their response is variable: sometimes it is difficult to obtain 67-70% survival in high salinity ponds (Effenddy et al 2016; Gitterle et al 2005).

P. vannamei reduces the concentration of dissolved oxygen at the bottom of the pond (Figure 2) and the total ammonia nitrogen in the water. The increase in nutrients released from sediment into the above water due to shrimp bioturbation affects the dynamics of nitrogen in ponds (Zhong et al 2015). High nitrite concentrations in water, as it occurs in shrimp with 108 days of rearing, indicate that nitrification is inhibited, where the activity of bacteria that oxidizes ammonium to nitrite is higher.

Intensive culture of *P. vannamei* in low salinity ponds requires large amounts of feed, as shown in Table 4. Highly FCR in older shrimp has an impact on the massive feed nutrients accumulation as sediment waste. In this study, the hectare density of the feed given to *P. vannamei* reared for 108 days (at a density of 118 specimens m^{-2} and at a FCR of 1.55) was approximately 22.75 t.

The results of the present study showed that the highest phosphorus concentration was found in *P. vannamei* with rearing periods of 108 and 92 days, namely 0.43±0.04% and 0.36±0.01%, respectively, in salinity conditions of 6-8 g L^{-1}. The highest carbon and nitrogen levels found in the sediment sampled from pond parcels with *P. vannamei* reared for 46 days were of 17.60 and 1.94%, respectively, in salinity conditions of 3-5 g L^{-1} (Table 2). The higher the water salinity level, the higher the amount of nitrogen released as ammonium. Meanwhile, in lower salinity water, the absorption of ammonium by sediment particles is higher, causing relatively long residence time for nitrogen in the sediment. The nutrients in pond sediments are influenced by the salinity, as shown by the percentage of nitrogen diffused in higher saline seawater and producing ammonium, while at lower salinity the organic nitrogen is potentially nitrified by bacteria and often released from the sediments as nitrogen gas (Gardner et al 1991). Furthermore, the vertical migration of ammonium from the sediments of low salinity ponds could be inhibited by the interaction between cations and sediments. On the contrary, in higher-salinity ponds the formation of ion pairs of seawater ammonium with anions can block the exchange of cations between sediments and seawater, allowing the diffusion of greater ammonium fractions, before the nitrification process by bacteria. According to Seitzinger et al (1991), lower salinity generally has a higher sulfide concentration and this compound inhibits the nitrification process, so that the release of nitrogen from the sediment is lower. Therefore, this means the total organic carbon, total nitrogen and total phosphorus detected in this study were influenced by the diffusion process of seawater concentrations and the nitrification/denitrification process of bacteria. The number of bacteria found in sediment in the 32nd day of rearing period was 7.25±0.05 log CFU mL^{-1}. Except for the 92nd day samples, where the sediment nitrogen concentration was low, the number of bacteria found in the sediment increased as the rearing period became longer (Table 1).

The amount of accumulated sediment material formed in the 32nd day of *P. vannamei* rearing was 0.89 times higher than the total amount of feed provided and was also observed to be 8.95 times higher in the 92 days of the *P. vannamei* rearing period. This shows that feed was not the only factor determining the quantity of the sediment to be formed. It also involves the deposition of organic matter particles from the remaining feeds, shrimp feces, dead plankton, or other organisms, as well as the dissolved mud particles carried by the water supply into the pond (Briggs & Smith 1998; Paena et al 2018). Ponds up to 92 days of rearing were siphoned 16 times and replaced with a volume of water up to 4,928.02 m^3, which was 31.6 times higher than the total amount of sediment produced. This is in line with the findings of Briggs & Smith (1998) that the soil particles eroded during water supply contributed in a proportion of 88-93% to the formation of sediment material and in a proportion of 40-60% to the formation of organic matter in the pond. Although feeds are also a significant source of organic matter in the sediment, with approximately 31-50%, they only contributed with 4-7% to to the solid materials formed. Previous studies reported the formation of sediment materials during shrimp farming in brackish water and seawater ponds (Table 3).

Total organic carbon, total nitrogen and total phosphorus in longer shrimp rearing periods are a consequence of the amount of feed and of the volume of water change and circulation in the pond. The TOC, TN, and TP values in each shrimp rearing period are directly influenced by the amount of sediment formed (Table 2). The number of waste nutrients from shrimp ponds will increase with the feeding rate and feed protein level (Yang et al 2017). TOC, TN and TP, in this study, are higher than those reported by previous studies conducted in estuarine, with 10-20 g L^{-1}, and seawater ponds, with salinity >20 g L^{-1}. For example, a study of semi-intensive *P. vannamei* farming in Gaoqiao China, with stocking densities 19.7 individuals m^{-2}, at a salinity of 16-25 g L^{-1}, a feed conversion ratio of 2.1 and with 2 production cycles per year, reports a total nitrogen of 712.84 kg N ha^{-1} year^{-1} and a total phosphorus of 353.86 kg P ha^{-1} year^{-1} (Wu et al 2014). Another research in Brazil estimates at 830,000 kg N year^{-1} and 69,250 kg P year^{-1} nutrient pollution levels in coastal waters released by 3,009 ha of semi-intensive shrimp culture in estuary salinity conditions (Lacerda et al 2008). Moreover, a total of 111.4 kg N and 32.0 kg P ha^{-1} year^{-1} were recorded in semi-intensive vannamei shrimp ponds in Mexico (Osuna et al 1999). Yang et al (2017) reported that in 1639 ha of estuarine shrimp ponds with 1.4 m water depth, 30,450 kg N and 2,400 kg P were produced, which led to the assumption that for a total area of 2,570,000 ha of ponds in China, at 1.4 m pond depth, there were produced 47,700 tons of N year^{-1} and 3,750 tons P year^{-1}. Moreover, in another research by Silva et al (2010), 4,514.6 kg N and 1413 kg P were estimated as the sources of nutrient pollution released into the environment by 1 ha of catfish (*Pangasianodon hypophthalmus*). According to Suwoyo et al (2015), the nutrient load in the sediments of super-intensive *P. vannamei* pond there were 20,820 to 23,340 kg C ha^{-1}, 3,030 to 3,620 kg N ha^{-1}, and 2,530-2,990 kg P ha^{-1}. Furthermore, for the same type of pond with 600 shrimp m^{-2} stocking density, Syah et al (2014) reported that the waste load per kilogram of shrimp was 112.85 to 126.85 g of carbon, 43.09 to 50.12 g of nitrogen, and 14.21 to 15.73 g of phosphorus.

One kilogram of sediment waste (wet weight) released by the four age groups of *P vannamei* contained nutrients ranging from 63.68 to 175.01 g of organic carbon, 13.33 to 19.4 g of nitrogen and 2.7 to 4.3 g of phosphorus. The organic matter of aquaculture effluents can be transformed into inorganic nutrients that can be used as a source of nutrition (Graneli et al 1999). Based on the nutritional content, *P. vannamei* sediment waste can potentially be used as feed and source of organic fertilizer for the cultivation of other important fish commodities. The application of environmentally friendly fish culture technology uses the integrated multi-trophic aquaculture (IMTA) and Recirculating aquaculture system (RAS) method for fish species that occupy the second trophic level in the energy pyramid such as *Holothuroidea* animals and fish species that occupy primary producers such as seaweed. Thus, using organic waste from shrimp pond sediments can be simultaneously developed, in order to prevent negative environmental impacts.

Conclusion. The concentrations of organic carbon and nitrogen in sediment waste and orthophosphate in the water column of *P. vannamei* ponds in the 46th day of rearing were significantly higher compared to the other age groups (P<0.05). One kilogram of sediment waste (wet weight) released by the four age groups of *P vannamei* contained nutrient levels ranging from 63.68 to 175.01 g of organic carbon, 13.33 to 19.4 g of nitrogen and 2.7 to 4.3 g of phosphorus. The overall wastes produced by 1 ha of pond during the production cycle of *P. vannamei* were estimated: (1) at their 32 days of rearing, there were found 2.63 to 3.52 t of solid sediment material, of which: 0.321-0.430 t were organic carbon, 0.039 to 0.052 t were nitrogen and 0.008 to 0.01 t were phosphorus; (2) at 108 days of rearing (ready-to-harvest), there were found 157.58 to 189.29 t of solid sediment material, of which: 10.03 to 12.05 t were organic carbon, 2.38 to 2.85 t were nitrogen and 0.6 to 0.81 t were phosphorus.The ready-to-harvest *P. vannamei* had an average body weight of 20.38±3.16 g, an estimated survival of 66.67-69.57%, an FCR of 1.45-1.55 and a total biomass of 13.96-14.71 mt ha^{-1}.

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