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Dynamics of water quality at different stocking densities and its effect on the growth of Vannamei shrimp (Litopenaeus vannamei) under intensive culture at PT Shihe Udang Industry Indonesia

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ABSTRACT

Vannamei shrimp (Litopenaeus vannamei) is a leading aquaculture commodity in Indonesia, with high market demand for both domestic consumption and export. However, cultivation continues to fail, primarily due to water quality problems. Water-quality parameters play a crucial role in the ecosystem of intensive shrimp ponds. This study aimed to determine the effect of stocking density on water quality and production outcomes. The research was conducted over one shrimp culture cycle at PT Shihe Udang Industry Indonesia. The results showed that the water-quality dynamics in all three observed ponds tended to increase as the day of culture progressed, and the parameters that most strongly influenced shrimp growth and production were $NH4^+$, total organic matter, and total Vibrio count. The data indicate that higher stocking densities strongly affect water quality: Pond A1 (361 shrimp/m²) had more stable water quality than ponds A5 (637 shrimp/m²) and C (1,296 shrimp/m²). Production in Pond A1 was the most optimal at 11,220.31 kg, with a survival rate of 68% and a feed conversion ratio of 1.47. The lowest production occurred in Pond C at 1,484.56 kg, with a survival rate of 25% and a feed conversion ratio of 2.43. The poor production performance in Pond C was driven by the very high stocking density, which deteriorated water quality; the high total Vibrio count also contributed to shrimp mortality.

Keywords: growth; production yield; Vannamei shrimp; water quality dynamics

1. INTRODUCTION

Vannamei shrimp (Litopanaus vannamei) is a leading commodity in Indonesia, with high market demand for both domestic and export purposes. High market demand has led to a continuous increase in vannamei shrimp production, which, according to the Director General of Aquaculture of the Republic of Indonesia, has increased by approximately 14.86% annually. Vannamei shrimp production will continue to increase because of the significant prospects for quality and technological innovation. Intensive vannamei shrimp cultivation in Indonesia is growing rapidly, using various types of ponds, including soil, cement, and HDPE. Obstacles in vannamei shrimp cultivation include excessive stocking volumes and excessive feeding, which can degrade water quality. Water quality conditions affect shrimp growth, and high production levels generate more waste from cultivation (Avnimelech, 2012; Boyd & Tucker, 1998; Cahyanurani & Edy, 2022).

Despite its many advantages, poor environmental conditions, such as water quality, can lead to mortality and losses. One technique to address this issue during vannamei shrimp cultivation is proper water quality management. Proper water quality management can maintain water quality to meet cultivation standards and increase pond productivity. To achieve the desired vannamei shrimp cultivation cycle, farmers must understand the dynamics of water quality development and routinely monitor water quality conditions through testing, including physical, chemical, and biological tests. Water quality parameters in ponds (Boyd & Tucker, 1998; Lazur, 2007). Unpredictable weather can also affect the stability of water quality. such as temperature, salinity, pH, dissolved oxygen and is one of the factors that can influence success cultivation shrimp vannamei. Cahyanurani and Edy (2022) reported that fluctuations in water quality can be significantly harmful to shrimp farming because they can cause shrimp stress and decomposition of organic matter due to feed at the bottom. Water levels will decrease (Cahyanurani & Edy, 2022; Yu et al., 2020).

Water quality parameters are determined through physical, chemical, and biological testing. Water quality management refers to the efforts to maintain water parameters according to cultivation media standards. The stages of water quality management include monitoring, checking, and treatment. Cultivators conduct manual checks by taking water samples and measuring them using standard tools. The water quality parameters tested include Clarity, Temperature, pH (Degree of Acidity), Dissolved Oxygen, Ammonia, Phosphate, Nitrite, Alkalinity, TOM (Total Organic Matter), TVC (Total Vibrio Count), and Plankton Density. Poor water quality can affect the growth rate, metabolic processes, and survival of shrimp. This encourages researchers to conduct research on the dynamics of water quality at different stocking densities to determine its effect on the growth and production of vannamei shrimp (Abakari et al., 2022; Khanjani et al., 2022).

2. RESEARCH METHOD

2.1. Time and Place

This study was conducted in August 2025, with a calculation of one period in the cultivation of vannamei shrimp at PT. Shihe Udang Industry Indonesia, Padang Pariaman Regency, West Sumatra Province (see Figure 1).

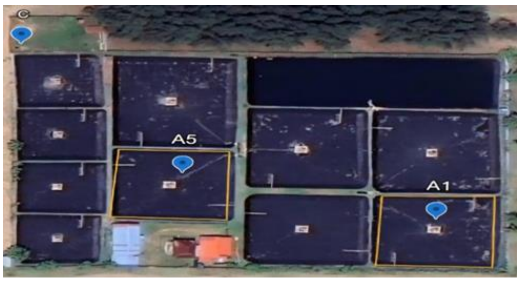

Figure 1. Research Location and Study Period of Vannamei Shrimp Cultivation at PT Shihe Udang Industry Indonesia, Padang Pariaman Regency, West Sumatra Province, August 2025

2.2. Tools and materials

In this study, temperature, brightness, and dissolved oxygen were measured in the field, whereas ammonia (NH_3), nitrite (NO_2), phosphate (PO_4), alkalinity, *total Vibrio count* (TVC), and total organic matter (TOM) levels were measured in the laboratory of PT. Shihe Udang Industry Indonesia. The tools and materials used in this study are listed in Table 1.

Table 1. Research Tools and Materials

No.	Parameter	Unit	Tools/Materials/Methods	Analysis
Physics				
1	Brightness	Meter	Secchi disk	In situ
2	Water temperature	oC	DO meter	In situ
Chemistry				
1	DO	mg/l	DO Meter	In situ
2	pH	-	pH Meter	In situ
3	Salinity	mg/l	Refractometer	In situ
4	Ammonia	mg/l	Test kit	Ex situ
5	TOM	mg/l	Titration	Ex situ
6	Alkalinity	mg/l	Titration	Ex situ
7	Phosphate	mg/l	Test kit	Ex situ
8	Nitrite	mg/l	Test kit	Ex situ
Biology				
1	Plankton	Cell/ml	Microscopic	Ex situ
2	Total Vibrio Count (TVC)	CFU/ml	ChromAgar	Ex situ

3. RESULTS AND DISCUSSION

3.1. Water Quality

Based on the results of water quality monitoring conducted over 105 days of culture, the dynamics of physical, chemical, and biological parameters were observed in three ponds with different stocking densities: A1 (361 shrimp/m²), A5 (637 shrimp/m²), and C (1,296 shrimp/m²). In general, temperature, pH, Dissolved Oxygen (DO), salinity, nitrite, and phosphate levels remained within acceptable standards for vannamei shrimp culture. However, parameters associated with organic matter accumulation, such as ammonia, Total Organic Matter (TOM), and Total Vibrio Count (TVC), showed a more pronounced increase as the culture period progressed, particularly in ponds with higher stocking densities (Rajkumar et al., 2016; Xu et al., 2016).

Pond A1 exhibited the most stable water quality conditions, with relatively controlled parameter fluctuations throughout the culture cycle. Pond A5 showed an increase in several organic-related parameters during the mid-to late-culture period. Pond C consistently recorded the highest average values of ammonia, TOM, and TVC, indicating greater water quality stress than the other two ponds (Huang et al., 2021) (see Table 2).

Table 2. Water Quality Parameter Results

No.	Parameter	A1	A5	C	Ministerial Regulation No. 75 of 2016
1	Temperature	26 - 30	26 - 30	26 - 30	>27
2	Brightness (cm)	30-60	30-60	30 - 60	30-50
3	pH	7.4 - 8.5	7.3 - 8.4	6.9-8.3	7.5-8.5
4	DO (mg/l)	4 - 9.6	4-8.9	5-12.9	≥ 4
5	Salinity (ppt)	24 - 34	24 - 34	28 - 35	26-32
6	Ammonia (mg/l)	0 - 2	0 - 2	0 - 2	≤ 0.1
7	TOM (mg/l)	71 – 126	64 - 128	72 - 128	≤ 90
8	Phosphate	0 - 0.5	0 - 0.5	0 - 0.5	0.1-5
9	Nitrite	0 - 0.25	0 - 0.46	0 - 0.5	≤ 1

10	Alkalinity (mg/l)	94 - 183	112 - 195	128 - 245	100-150
11	Total Vibrio (CFU)	0 - 1.1 x 10^4	0 - 1.1 x 10^4	0 - 1.0 x 10^4	≤ 1x10^3

3.2. Physical Parameters

For clarity, see Table 3 and Table 4.

Table 3. Temperature Measurement Data

DOC	Temperature (C)		
	A1	**A5**	**C**
1	29.1	26.9	29
5	28.4	28.9	29.4
10	28.4	28.4	27.5
15	27.6	29.4	27.9
20	29.6	29.4	29.3
25	29	28.1	28.9
30	26.7	27,2	28,1
35	28,2	27,8	28,2
40	27,2	27,2	28,3
45	28,4	29,2	29,4
50	28,3	29,1	29,8
55	28,1	28,2	29,3
60	27,6	28,2	28,2
65	27,6	27,9	27,1
70	29,6	28,7	28.1
75	27.7	29.1	28
80	28	28.4	27.2
85	28.1	28.6	27.2
90	28.8	27.3	26
95	27.4	27.2	25.1
100	27.3	27.4	26.1
105	26.7	25.6	25.2
Love it	28.08	28.10	27.88

Table 4. Regression and Correlation Table

No.	Pool	R	R^2	Regression Equation
1	A1	-0.207	0.043	Y = 116.84 - 3.486x
2	A5	0.0097	0.0001	Y = 6.56 + 0.041X
3	C	0.0815	0.0066	Y = -24.84 + 1.10X

The temperature during the study was in the range of 26–30°C with an average of 28.08°C in pool A1, 28.10°C in pool A5, and 27.88°C in pool C. Temperature fluctuations occurred following changes in the weather, especially during the rainy season, but the changes were not extreme (Boyd & Tucker, 1998; Lazur, 2007).

Regression analysis showed that the relationship between temperature and growth rate was very weak in all three ponds ($R^2 < 0.05$). This indicates that temperature variations during the study did not significantly contribute to changes in the shrimp growth rate.

3.3. Chemical Parameters

3.3.1. Salinity

For clarity, see Figure 2.

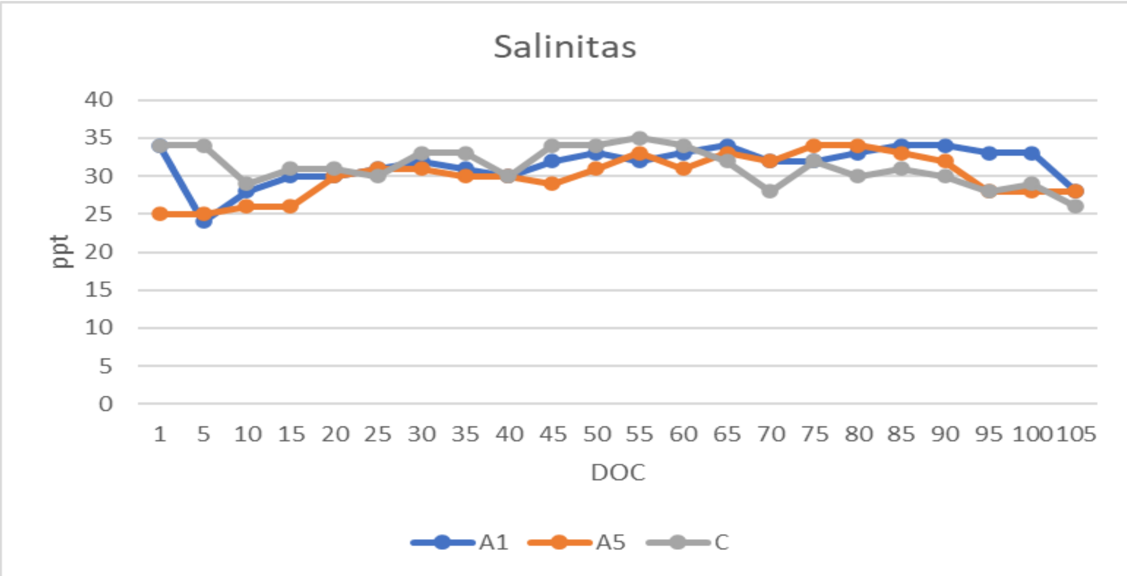

Figure 2. Salinity Measurement

The results of the study showed a salinity range of 24-35 ppt, with an average of ponds A1 (32 ppt), A2 (30), and C (31). The salinity of these three ponds is still suitable for the survival and growth of vannamei shrimp. Regression analysis between salinity and stocking density obtained a correlation value of r = 0.167, R2 = 0.026, with the equation Y = 30.02 + 0.0006 x. This value shows a very weak positive correlation, indicating that there is no significant relationship between stocking density and salinity. The R2 value shows that the stocking density variable has almost no effect on salinity variations. Each additional fish/m2 in stocking density only increases salinity by 0.0006 ppt (Cahyanurani & Edy, 2022).

3.3.2. pH (Degree of Acidity)

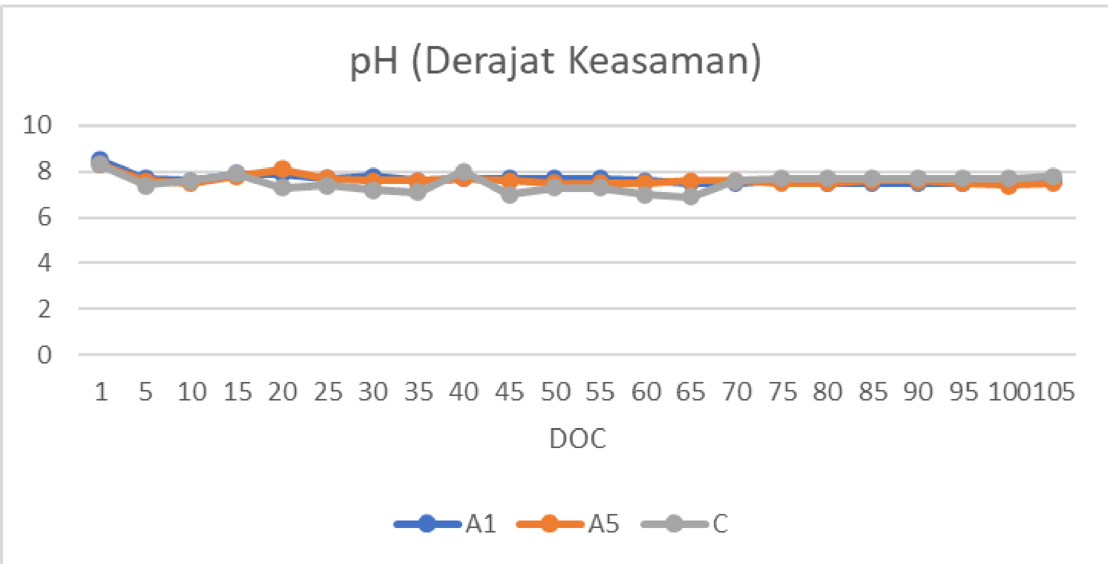

Figure 3. pH Measurement

As shown in Figure 3, the pH in the three ponds ranged from 6.9 to 8.5, with Pond A1 showing the highest value (7.4 to 8.5). Pond A5 had a similar range, while Pond C recorded a lower pH (6.9 to 8.3), with the lowest value at DOC 65. pH fluctuations occur due to rainwater and CO2 consumption during photosynthesis. The pH level is still tolerable for vannamei shrimp; however, an excessively high pH inhibits growth. The results of the pH regression analysis with stocking density showed a strong negative correlation ($r = -0.96$). The R2 value of 0.92 indicated that 92% of the pH variation was influenced by density. The equation $Y = 7.92 - 0.0003x$ indicates that the addition of 100 fish/m2 decreased the pH by 0.03. The decrease in pH at high stocking densities is due to greater metabolic accumulation (Yu et al., 2020).

3.3.3. DO (Dissolved Oxygen)

For clarity, see Figure 4.

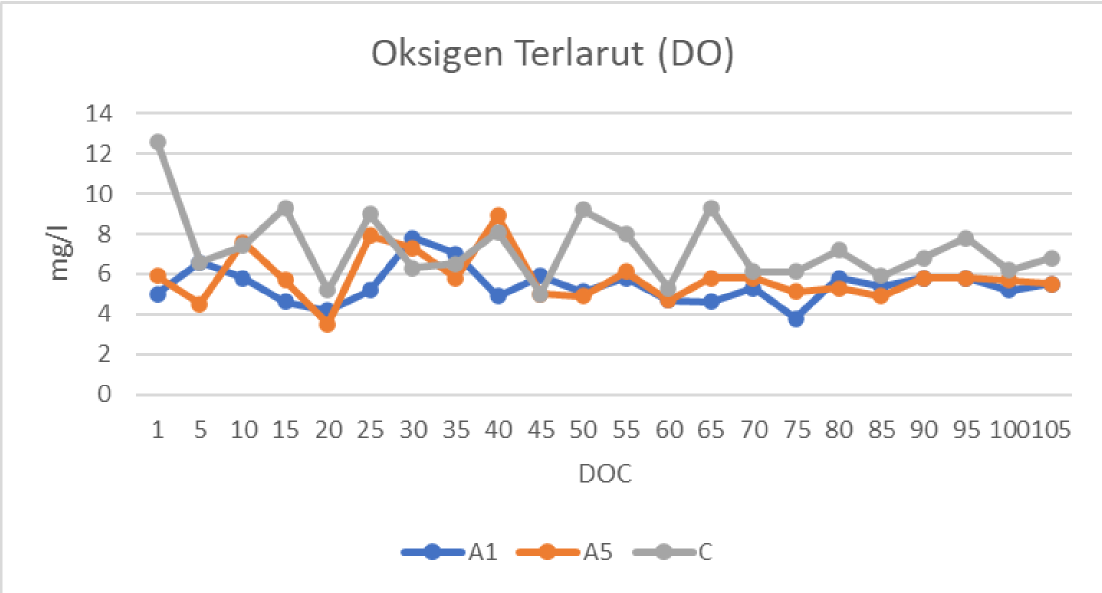

Figure 4. Dissolved Oxygen

Based on dissolved oxygen measurements during the study, there were differences in dissolved oxygen content in ponds A1, A5, and C. Pond C had a higher dissolved oxygen value (5-12 mg/l) than ponds A1 and A5. The dissolved oxygen content decreased with increasing shrimp age because an increasing shrimp weight requires higher oxygen consumption. The dissolved oxygen content decreased with increasing shrimp age because increasing shrimp weight requires higher oxygen consumption. Based on the regression analysis between dissolved oxygen parameters and stocking density, a correlation value of $r = 0.934$ was obtained, *indicating* a very strong positive correlation, the coefficient of determination value *R2* = 0.861, which means that 86% of the difference in dissolved oxygen measurement results in this study can be explained by differences in stocking density in the three observation ponds. The regression equation obtained is $Y = 5.14 + 0.0016x$, meaning that if every 100 fish/m2 of stocking density is added, the dissolved oxygen in the research data tends to increase by 0.16 mg/L due to the oxygen supply system applied to the observation pond. The oxygen supply provided to the pond with high density (pond C) will be greater than ponds A1 and A5 to compensate for the much greater respiratory needs of organisms (Avnimelech, 2012).

3.3.4. Alkalinity

For clarity, see Figure 5.

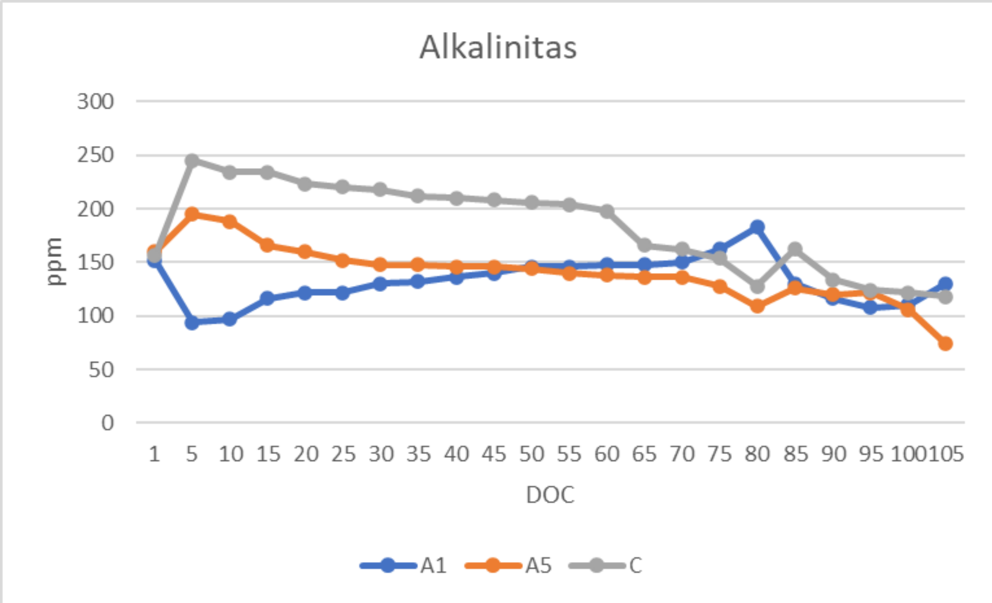

Figure 5. Alkalinity Measurement Results

Based on the measurement of dissolved alkalinity during the study, the alkalinity value in pond A1 ranged from 94 to 183 ppm (lowest DOC 8, highest DOC 20), pond A5 ranged from 112 to 195 ppm (lowest DOC 80, highest DOC 23), and pond C ranged from 128 to 245 ppm (lowest DOC 80, highest DOC 16). The range of alkalinity values is still reasonable for shrimp growth, and alkalinity levels around or above 100 mg/L are commonly recommended to maintain buffering capacity and support nitrification in intensive shrimp culture (Avnimelech, 2012; Ebeling et al., 2006).

The results of the regression analysis between alkalinity and stocking density showed r = 0.981, R2 = 0.963, and equation Y = 88.43 + 0.103 x. The r value approaching 1 indicates a very strong correlation, where 96% of the stocking density affects the alkalinity value. Alkalinity increased in the high-density pond as an effort to maintain water stability with a higher mineral supply in pond C.

3.3.5. Ammonia

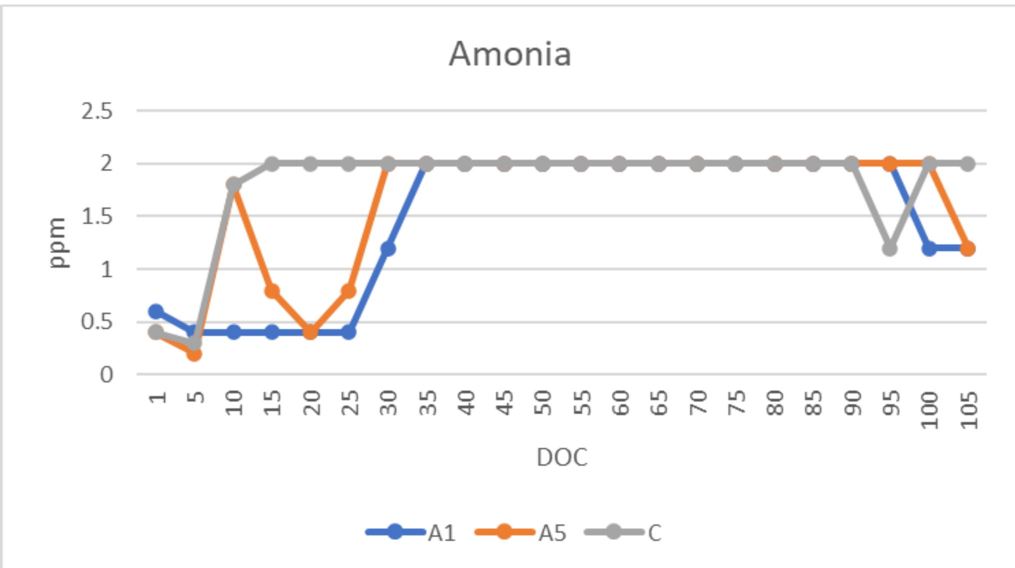

Figure 6. Ammonia Measurement Results

As shown in Figure 6, ammonia levels fluctuated in ponds A1, A5, and C. As shrimp aged, ammonia fluctuations increased owing to the feces and remaining feed of vannamei shrimp. At DOC 1–20, the ammonia level in pond C ranged from 1–2 ppm, which was higher than that in ponds A1 and A5 because of the high stocking density, resulting in the uncontrolled accumulation of inorganic substances. Increasing shrimp age increases feed consumption, risking the accumulation of leftover feed and the formation of ammonia in the water, and elevated ammonia is widely recognized as a physiological stressor for L. vannamei (Ebeling et al., 2006; Qiu et al., 2018; Sui et al., 2023). Regression analysis between ammonia parameters and stocking density produced a correlation coefficient of r = 0.992, determination R2 = 0.981, and the equation Y = 0.59 + 0.0009x, indicating a strong relationship between water quality and stocking density. Ninety-eight percent of ammonia levels were influenced by differences in stocking density, with each additional shrimp/m2 increasing ammonia by 0.0009 mg/L. Pond C (1,296 fish/m2) had the highest average ammonia level, proving that density impacts the accumulation of ammonia from metabolism and feed residue.

3.3.6. Nitrite

For clarity, see Figure 7.

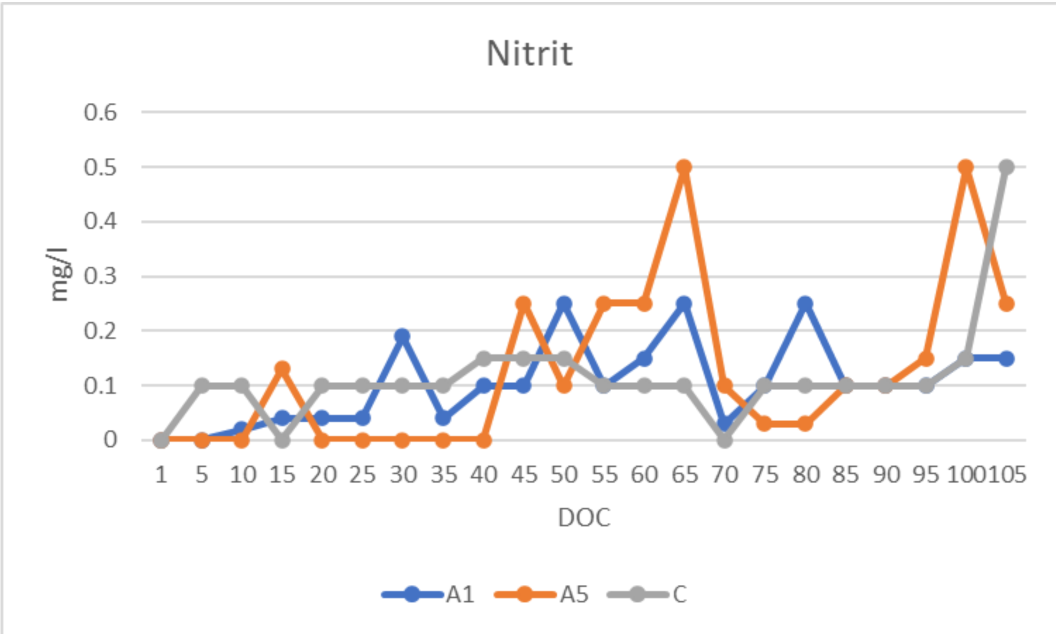

Figure 7. Nitrite Measurement Results

The nitrite (NO2) level measurements obtained during the observation period ranged from 0 to 0.5 mg/l. Nitrite levels in pond A1 ranged from 0-0.25 mg/l, pond A5 0-0.5 mg/l and Pond C 0-0.46 mg/l. Analysis showed an increase in nitrite levels as the shrimp age increased, the high nitrite levels in pond A5 (0.5 mg/l) were caused by high ammonia levels. Ammonia levels in the three ponds were within safe limits according to the Permen-KP No. 75 TH 2016. 75 TH 2016. 75 TH 2016. 75 TH 2016. 75 TH 2016. According to Lazur (2007) the increase in nitrite was caused by the pond ecosystem starting to become unstable (Ebeling et al., 2006; Lazur, 2007).

Regression analysis between nitrite and stocking density showed a correlation of r = 0.99, R2 = 0.98, and the equation Y = 0.72 + 0.0008 x. The correlation coefficient indicates a strong positive relationship between stocking density and ammonia levels. The determination value also shows that 98% of the variation in ammonia levels is influenced by stocking density. Each additional fish per square meter increased ammonia levels by 0.0008 mg/L. Pond C had the highest average ammonia (1.75 mg/L) because the stocking density reached 1,296 fish/m2, indicating that at high densities, maximum water management is needed to maintain water quality.

3.3.7. Phosphate ($_{PO4}$)

Phosphate (PO4) measurements revealed that the total phosphate levels in the three ponds were different. The total phosphate levels in ponds A1, A5, and C ranged from 0 to 0.5 mg/l, according to shrimp growth quality standards. According to PERMEN-KP No. 75 TH 2016, the total phosphate standard for shrimp enlargement ranges from 0.1-5 ppm, but if the phosphate concentration does not decrease it will potentially cause algae blooms and impact shrimp growth (Kumar et al., 2018).

Regression analysis between phosphate and stocking density parameters yielded r=0.98, R2=0.96, with the equation Y=0.0142+0.0001x, indicating a very strong correlation between the two. The coefficient of determination value showed that 96% of the variation in phosphate levels was influenced by stocking density, indicating density as the main factor. This was evident from the highest average phosphate in pond C with the highest density, as indicated by a higher feed volume and metabolic results.

3.3.8. TOM (*Total Organic Matter*)

Based on the TOM measurement results, similar fluctuations were observed in the three observation ponds (A1, A5, and C); the TOM value increased from DOC 10 to 60 and decreased at DOC 65. Pond C had a higher TOM range (72–128 mg/l) than ponds A1 (71–126 mg/l) and A5 (64–128 mg/l) (Kumar et al., 2018; Luis-Villaseñor et al., 2015).

The regression results between total organic matter and stocking density showed an r value of 0.91, R2 = 0.82, with the equation Y = 106.32 + 0.0056 x. There was a strong positive relationship between stocking density and organic matter content, with higher population densities resulting in greater accumulation of organic matter. The coefficient of determination indicated that 82% of the variation in TOM levels was influenced by stocking density. Each additional fish per square meter increased TOM levels by 0.0056 mg/L. In pond C, which had the highest stocking density, TOM fluctuations tended to be high, indicating that at densities above 1,000 fish/m2, the risk of water quality decline due to organic matter decomposition becomes higher.

3.4. Biological Parameters

3.4.1. Plankton

Based on the results of plankton measurements during the study, plankton abundance varied, with green algae (GA) and blue-green algae (BGA) dominating the three observation ponds. The highest plankton abundance was found in pond C, with fluctuations in ponds A1, A5, and C driven by nutrient concentrations, weather, and interspecific competition. The presence of plankton is influenced by seasonal factors, with some species being more abundant during the dry season and others during the rainy season. Other factors include temperature, pH, light, and nutrient concentration (Khanjani et al., 2022; Pacheco-Vega et al., 2018).

Regression analysis between plankton density and stocking density yielded a correlation coefficient of r=0.72, R2=0.52, with the equation Y=933,200 + 121.5 x. This indicates a strong correlation between the two variables, with 52% of the plankton density being influenced by stocking density and the remainder by external factors. Each additional fish/m2 of stocking density increased plankton density by 121.5 cells/mL. Pond C had the highest average plankton count because increasing stocking density caused an increase in leftover feed and feces, which acted as organic fertilizers.

3.4.2. *Total Vibrio Count* (TVC)

The analysis results showed Vibrio instability in the three ponds, especially in pond A1 DOC 50, which increased drastically to 1.1 × 104 CFU/mL. The TVC range in pond A1 was 0–1.1 × 104 CFU/mL, with the highest value at DOC 50 and the lowest at DOC 1; in pond A5, the range was 0–1.1 × 104 CFU/mL, with the highest value at DOC 75 and the lowest at DOC 1; and in pond C, the range was 0–1.0 × 104 CFU/mL, with the highest value at DOC 45 and the lowest at DOC 1. The increase in TVC occurs with increasing shrimp age (Cardona et al., 2016; Krummenauer et al., 2014; Kumar et al., 2020; Pinoargote et al., 2018).

Regression analysis between the total Vibrio count and stocking density showed a correlation of r = 0.98, R2 = 0.96, with the equation Y = 3,935.6 + 1.14 x. There was a strong positive relationship between TVC and stocking density, with 96% of the variation in total Vibrio being influenced by stocking density. Each additional 1 tail/m2 increased the total Vibrio count by 1.14 CFU/mL. The increase in bacteria occurred because a high stocking density produced more metabolic waste. Pond C had the highest average bacteria count, according to the analysis results, which showed that stocking density was strongly correlated with bacterial growth. High-density systems require maximum waste management to control bacterial populations (see Table 5).

Table 5. Specific Data Growth Rate (SGR)

No.	Pool Code	SGR (%/day)
1	A1	2.16
2	A5	2.0
3	C	1.82

Based on the research data, the SGR values in the three ponds were A1 (2.16%/day), A5 (2.0%/day), and C (1.82%/day). The SGR value of pond A1 was higher than the others, in line with the sampling data *of average Body Weight* (ABW) and *Average Daily Growth* (ADG) indicates superior growth in pond A1. The lowest growth rate was in pond C, with an SGR of 1.82%/day, influenced by poor water quality, which inhibited shrimp growth. Based on the regression analysis between SGR and stocking density, a correlation coefficient of r = − 0.98 was obtained, indicating a strong negative relationship. The coefficient of determination R2 = 0.96, where 96% of the decrease in SGR was influenced by stocking density. The regression equation Y = 2.28 − 0.00036x, where each additional fish/m2 caused a decrease in SGR of 0.00036%/day. The low SGR of pond C proves the effect of population density on growth, where competition for space, oxygen, and food is higher (Rajkumar et al., 2016; Xu et al., 2016).

3.5. The Relationship between Water Quality and Production Results, FCR (*Feed Conversion Ratio*) and SR (*Survival Rate*)

For clarity, see Table 6.

Table 6. Production, Feed, FCR and SR Data

No.	Pool Code	Production Yield (Kg)	Cumulative Feed (Kg)	FCR	SR (%)	
1	A1	11,220.31	16,555	1.47	68	
2	A5	12,234.76	21,117	1.72	49	
3	C	1,484.56	3,617	2.43	25	

The data show a comparison of vannamei shrimp production among three ponds: A1 (2,500 m2) with a stocking density of 361 individuals/m² and an initial population of 902,128 individuals, A5 (2,500 m2) with a stocking density of 637 individuals/m² and a population of 1,591,672 individuals, and pond C (314 m2) with a stocking density of 1,296 individuals/m² and a population of 407,048 individuals. The 105-day rearing period resulted in an average final weight of 22.81 g (A1), 20.60 g (A5), and 19.20 g (C). The daily growth rate was 0.5 g/day (A1), 0.21 g/day (A5), and 0.42 g/day (C), with specific growth rates of 2.16%/day (A1), 2.0%/day (A5), and 1.82%/day (C), respectively. The survival rate reached 68% (A1), 49% (A5), and 25% (C). The total feed administered was 16,555 kg (A1), 21,117 kg (A5), and 3,167 kg (C), with feed conversion ratios of 1.47 (A1), 1.72 (A5), and 2.43 (C), respectively. The total harvest yield was 11,220.31 kg (A1), 12,234.76 kg (A5), and 1,484.56 kg (C).

Pond A1 showed more optimal production results in terms of feed efficiency, survival rate, and SGR, even though the total harvest yield of A5 was higher (Cahyanurani & Edy, 2022; Huang et al., 2021).

High levels of ammonia, TOM, and TVC at the beginning of cultivation impacted shrimp immunity, making them susceptible to disease and death. Ammonia levels in pond C were high (0.4 mg/l) and continued to increase. The trends of all three water quality parameters in pond C continued to increase without a significant decrease, presumably due to excessively high stocking densities, which led to the accumulation of toxic inorganic substances and suboptimal water exchange processes. TVC in pond C continued to rise with increasing DOC, with a drastic increase in DOC 20 compared to other ponds, causing decreased shrimp immunity. Mortality occurred in DOC 40 due to uncontrolled growth of Vibrio parahaemolyticus, exacerbated by high ammonia and TOM levels. The minimum threshold for Vibrio sp. bacteria in water is 104 CFU/ml, and exceeding this threshold can cause mass mortality. Increased TOM increases the abundance of Vibrio sp. due to the high use of feed and metabolic waste that supports the growth of pathogenic bacteria (Krummenauer et al., 2014; Kumar et al., 2020; Pinoargote et al., 2018).

4. CONCLUSION

Based on the results of this study conducted at PT. Shihe Udang Industry Indonesia, it can be concluded that water quality dynamics during the 105-day culture period showed an increasing trend in organic load as the culture age (DOC) progressed. Physical and chemical parameters, such as temperature, salinity, water transparency, pH, dissolved oxygen, nitrite, phosphate, and alkalinity, in the three experimental ponds (A1, A5, and C) generally remained within acceptable ranges to support the growth of vannamei shrimp. However, parameters associated with organic matter accumulation, namely ammonia, Total Organic Matter (TOM), and Total Vibrio Count (TVC), exhibited a more pronounced increase, particularly in ponds with higher stocking densities. This condition indicates a gradual decline in environmental quality that may negatively affect shrimp performance and survival.

Pond A1, with a stocking density of 361 shrimp/m², demonstrated the most stable water quality conditions throughout the culture cycle and produced the most optimal culture performance. The total production was 11,220.31 kg, with a survival rate (SR) of 68% and a feed conversion ratio (FCR) of 1.47, reflecting efficient feed utilization and higher survival. Pond A5, stocked at 637 shrimp/m², achieved the highest total production at 12,234.76 kg; however, it showed lower culture efficiency, with an SR of 49% and an FCR of 1.72. In contrast, Pond C, with the highest stocking density of 1,296 shrimp/m², experienced greater water quality pressure owing to elevated levels of ammonia, TOM, and TVC. This condition resulted in the lowest survival rate (25%), the highest FCR (2.43), and the lowest production yield of 1,484.56 kg.

These findings demonstrate that stocking density plays a dominant role in influencing water quality dynamics and overall production performance. Increasing the population density directly intensifies the accumulation of metabolic waste and organic matter in the culture system, which subsequently reduces growth efficiency, increases feed conversion ratios, and lowers survival rates. Therefore, the recommended stocking density for vannamei shrimp culture at the study site is 200–350 shrimp/m². Maintaining the stocking density within this range is considered optimal for water quality management, improving feed efficiency, and providing sufficient space for shrimp growth. Furthermore, continuous evaluation and improvement of water circulation and treatment systems are necessary to control organic accumulation and pathogenic bacterial growth, thereby ensuring a sustainable and productive shrimp culture.

Ethical Approval

This study did not require formal ethical approval as it constitutes normative legal research and does not involve medical experimentation or vulnerable populations. The research was conducted in accordance with generally accepted ethical standards in social science and legal research. Data collection relied on document analysis of legislation, legal doctrines, and regulations of international sports organizations, as well as publicly accessible institutional documents.

Informed Consent Statement

Not applicable. This study did not involve direct interaction with human participants. All materials analyzed were obtained from publicly available legal sources and institutional documents.

Confidentiality Statement

Not applicable. The study did not collect personal or sensitive data. All legal materials and documents used are publicly accessible and were utilized solely for academic and research purposes.

Authors' Contributions

AQ contributed to the conceptualization of the study, formulation of the research objectives, research design, data collection during the culture period, statistical analysis including regression analysis, interpretation of water quality dynamics in relation to stocking density and shrimp growth performance, and preparation of the original draft of the manuscript. NT contributed to methodological supervision, validation of water quality measurements, critical review of data analysis procedures, interpretation of findings within the framework of aquaculture and environmental management, and substantial revision of the manuscript to strengthen scientific rigor. NR contributed to data verification, evaluation of production performance indicators (SGR, FCR, and SR), analytical refinement of the discussion on environmental carrying capacity, and critical revision of the manuscript for clarity and academic coherence. IF contributed to field data acquisition, operational management of the intensive culture system, provision of production data and technical documentation, and validation of practical interpretations related to commercial shrimp farming operations.

Disclosure Statement

The author declares no conflict of interest related to this research.

Data Availability Statement

All data supporting the findings of this study are derived from publicly available legal materials, including legislation, academic publications, and official regulations of international and national sports organizations. No additional datasets were generated or analyzed.

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Ainul Qadri is a researcher in the field of aquaculture with a focus on water quality management, intensive shrimp culture systems, and the relationship between stocking density and growth performance. His research interests include environmental dynamics in aquaculture systems, organic matter accumulation, microbial ecology in shrimp ponds, feed efficiency analysis, and sustainable shrimp production practices.

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