Investigating the environmental carrying capacity of bio-floc white-leg shrimp (*Penaeus vannamei*) farming in small-scale household operations in Indonesia

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Abstract. White-leg shrimp *Penaeus vannamei* is widely cultured in Indonesia, including in Bangka Belitung Province. Growing out of this shrimp using a bio-floc system is typical for small-scale production, and the carrying capacity of this practice is a concern. This research aimed to investigate the shrimp growth patterns, elucidating the relationship between water quality parameters and shrimp growth, and developing a statistical model for optimal feedings. This research was conducted from April to November 2022 at a small-scale enterprise unit (UMKM) of Strategic Trade Center Agromaritim (STC Agro), Baluijuk Village, Merawang District, Bangka Regency, Bangka Belitung Province, Indonesia. Shrimps were kept for 65 days using a bio-floc tank with five regimes of feeding frequencies, and their water quality parameters were monitored daily and weekly. Shrimp growth was analyzed using an exponential model of length and weight relationship. The monitored water quality parameters were compared with three quality standards of farming shrimps. The quantity of feed per day was gained through growth parameters. Research variables were run using Software R-4.0 through some statistics analyses such as Anova, Ancova, one sample t-test, and PCA. This research indicates that shrimps grow slowly in the early stage and uplift rapidly at harvest time. Only three water quality parameters (DO, pH, and phosphate) significantly affect shrimp growth. Furthermore, about 93% of shrimp growth is affected by feeding quantity, and other factors influence 7%. These results should be considered when farming white-leg shrimp in small-scale production.

Key Words: aquaculture, Bangka Island, farming, feeding, growth, water quality.

Introduction. As the global population rises and capture fisheries continue to stagnate and decline, there is an urgent need to develop aquaculture production sustainably. The Blue Economy (BE), also referred to as Maritime Economy (MAE), Ocean Economy (OE), Marine Economy (ME), and Blue Growth (BG), is a sustainability framework for optimizing seawater resources. The framework aims to increase economic growth and food security through people's innovative activities, while ensuring business continuity and environmental sustainability (Senaratne & Zimbroff 2019; Martínez-Vázquez et al 2021; Adibrata et al 2022b).

One of the aquaculture commodities with high economic value is the white-leg shrimp (*Penaeus vannamei*) or vannamei shrimp (herein termed 'vannamei'), which has consequently been developed in many coastal areas around the world (Boyd et al 2021). In recent decades, there has been significant development of vannamei farming in Indonesia, 0.47% of which has occurred in Bangka Belitung Province. Most of the white-leg shrimp farming in these coastal areas belongs to corporates. Legally designated areas of white-leg shrimp farms in this province comprise 2560.7 ha, the totality of which is controlled by 123 business actors (DKP Babel 2022). Most farms are constructed on a large scale in the coastal areas, being land-based farms. Local people, due to constraints of land ownership, undertake small scale aquaculture, using tarpaulin tanks (3x1.5 m size) (Adibrata et al 2022b). This activity is an opportunity for local people because of a relatively low investment cost and affordability, lower production costs, utilization of marginal surrounding lands relatively far away from seawater sources, secure access to electricity, and better security. If planned, executed, and optimized appropriately, the aquaculture of marine-based resources can significantly contribute to livelihood security, poverty alleviation and environmental sustainability, while financing the provision of ecosystem services (Hughes 2021; Rahman et al 2022; Adibrata et al 2022b). However, inefficient methods, poor technology, low expertise, and financial investment capacity continue to hinder productivity in small-scale operations. While the vast majority of research on this topic has focused on large-scale commercial operations, there still needs to be more data concerning innovative aquaculture methods for small-scale farmers in developing countries (Lestariadi et al 2012). This case of white-leg shrimp farming in Bangka Belitung Province is a prime example of this small-scale entrepreneurship. As such, there is an urgent need to develop simple and innovative aquaculture technologies and systems that can stimulate backyard fish production for enhanced livelihood security among smallholder farmers (Ogello et al 2021).

In aquaculture, bio-floc technology (BFT) is considered an innovative culture system with great potential for fish production, including shellfish (El-Sayed 2021; Ogello et al 2021). BFT uses aggregates of bacteria, algae, or protozoa to recycle waste nutrients to improve shrimp aquaculture's sustainability and profitability (Rahman et al 2022). Applying bio-floc in aquaculture systems can significantly improve shrimp performance, health status, and survival rate and reduce feed costs (Arsad et al 2017; El-Sayed 2021). It can also restrain vibriosis and luminescent bacteria, bolstering soil and water quality and controlling pH in shrimp farming (Shamsuzzaman & Biswas 2012). This makes it an up-and-coming technology for household-scale operations like those described above. However, farming white leg shrimps at small-scale aquaculture is faced with some risks, such as disease outbreaks and inefficient farm inputs from feeding. Disease outbreaks frequently happen due to poor water quality parameters of cultured resources (Kumar et al 2014; Marlina et al 2018; Suguna 2020). The highest cost input of aquaculture comes from feed costs (Triyatmo et al 2016). To improve resource efficiency, efficient feed use should be a goal of shrimp production (Boyd et al 2021).

Environmental carrying capacity can be broadly described as the maximum level of use an area can tolerate before unacceptable degradation occurs (Weitzman & Filgueira 2019). More specifically, the environment can absorb substances, energies, and other components that enter or are placed in it. According to Indonesian Act No. 32 of 2009, the carrying capacity of the environment is an environmental capability to support human life and other living organisms and a balance between them. This concept often measures aquaculture developments' environmental and production limits.

Bio-floc tanks or ponds are constructed from concrete cement, tarpaulin, or fibers with varied sizes, commonly not more than 3 m in diameter, and can be used to farm a variety of organisms, including white-leg shrimp or Pacific white shrimp (*Penaeus vannamei*). This shrimp is being raised in many different areas of Indonesia and contributes to aquaculture commodities (Mas'ud & Wahyudi 2018). In the wild, shrimp adults live in the sea, while the juveniles live in brackish waters. Some reasons to culture these shrimp include easier cultivation, specific pathogen-free (SPF) stocks, fast growth rate, and a high international market. Differences in water quality parameters can distinguish the maximal extent of tank capacity to raise cultivated biota optimally. Key water quality parameters in the context of aquaculture are dissolved oxygen (DO), temperature, pH, salinity, nitrate, nitrite, phosphate, and ammonia (Mateka et al 2015; Effendi et al 2016; Venkateswarlu et al 2019; Ariadi et al 2019; Kilawati et al 2020; Rahmawati et al 2021; Cavalheiro et al 2023). Water quality is generally perceived as a primary limiting factor and significantly influences the aquatic environment's health and subsequent productivity (Boyd 2015; Bhatnagar & Devi 2019; Zhang et al 2020; Tumwesigye et al 2022). It is usually dialed with carrying capacity in aquaculture. Estimating the carrying capacity can be done by determining the relationship between farming activity and the quality of the ecological, social, or economic environment (Weitzman & Filgueira 2019). In order to determine the relationship among shrimp growth, water quality, and optimal feeding administration, this research was split into three segments. These were investigating white-leg shrimp growth patterns, elucidating the relationship between water quality parameters and shrimp growth, and, using this information, developing a statistical model for optimal feedings.

Material and Method

Time and location. This research was carried out from April to November 2022 at a small-scale enterprise unit (UMKM) of Strategic Trade Center Agromaritim (STC Agro), Baluijuk Village, Merawang District, Bangka Regency, Bangka Belitung Province, Indonesia.

Method. White-leg shrimp larvae were sourced from the Central Protein Prima Hatchery Kalianda Inc. at Lampung Province and reared in standardized conditions for two months (60 days). After 60 days, shrimp were placed in a tarpaulin tank with a volume of 5.66 m^3 at a density of 300 individuals m^{-2} and raised for 65 days in experimental conditions. Bio-floc media was used in this research by fermenting probiotics of Probio_FmUBB. Materials for the probiotic fermentation process comprised 200 g of wheat flour, 2 bottle-cups of Probio_FmUBB, 2 teaspoons of yeast, and 500 mL of molasses. These ingredients were mixed with 5 L of brackish water in a container. The brackish water was poured gradually until the volume of water was 35 L and mixed well. 5 L per day of the fermented brackish water were taken out and then put into the tarpaulin tank, until the water barrel was empty. During this process, aeration was needed to optimize the living of microorganisms in the tarpaulin tank. After 7 days of probiotic work in the tarpaulin tank, the shrimp juveniles were introduced. Well-fermented brackish water in the tarpaulin tanks was indicated by water color (grey optimally), pH (optimal in a range of 6-8), and DO (>5 mg L^{-1}). Additional fermented probiotics were also delivered through the tanks daily and mixed well by aeration during growing shrimps. Flocs formed in tarpaulin in the tank exhibited good culturing probiotics in the water.

White-leg shrimp growth patterns. White-leg shrimp growth was recorded at intervals of 10 days, starting from day 25 until day 65, using a sub-sample of ten individuals of shrimps from the tank (Fendjalang et al 2016) using an Anco (a 50-cm rectangular lift nets setting in the bottom of the tank). White-leg shrimps were sampled to assess their health, average weight, biomass, and quantity of feed needed daily and to monitor the weight rate and feeding conversion ratio (FCR) (Ghufron et al 2017). Periods of measurement were set differently according to each assessed parameter. To monitor the growth rate, length and weight of the shrimp were checked four times during the rearing process. The length and weight were measured using a ruler and digital scales with two decimal places, respectively (Table 1).

Table 1

Shrimp growth measurement parameters

No	*Parameters*	*Unit*	*Tools*	*Time or period*
1	Weight (W)	g	Digital scale	By age
2	Length (L)	mm	Scale ruler	By age

Furthermore, in investigating the relationship between length and weight, samplings had been taken from some shrimp based on their prior observational age interval. Data exploration visually is used as an initial hypothesis in determining a proper mathematical model. This model is essential and widely applied to estimate the average weight of shrimp utilizing well-known parameters like the length of the shrimp. The shrimp growth also needs to be investigated isometrically and allometrically to understand the genuine shrimp growth concept. The length dealing with the weight growth of the shrimp refers to the exponential model (Helfman et al 1997):

$W=aL^b$

W is weight, L is length, and a and b are constants representing intercept and slope, respectively. Referring to Helfman et al (1997), the length and weight relationship pattern can be investigated from constant b. If b=3, the growth trait is isometric, indicating the weight growth is proportional to its length. When b>3, the growth is allometric positive, the weight growth being dominant compared to length. If b<3, the growth is allometric negative, with length growth being dominant. A one-way ANCOVA test was applied to ascertain significant differences between the length and weight of shrimp growth throughout the study period.

Water quality parameters and shrimp growth. Monitoring water quality was carried out daily (morning and evening) to determine whether there were statistically significant differences. It was important to ensure that the water quality parameters were suitable, not exceeding the allowable thresholds for water quality standards. In investigating the change trends of water quality parameters in the bio-floc tanks with white-leg shrimp, water quality parameters were measured periodically, starting from day 10 to 59. There were nine concerned environmental parameters in this research such as dissolved oxygen (DO), temperature, pH, salinity, phosphate, nitrate, nitrite, ammonia, and iron. Four water quality parameters (DO, temperature, pH, and salinity) were monitored twice a day in the morning (08.00 am) and afternoon (04.00 pm) starting from day 9 to day 65. These four parameters fluctuate daily and were presumed to seriously affect the growth of organisms drastically and become key parameters (Janna et al 2022). Other water quality parameters (nitrate, nitrate, phosphate, ammonia, and total Fe) were monitored weekly from day 10 to day 59, being also important (Supono 2018). All water quality parameters and toolkits used during the rearing of the white-leg shrimp are listed in Table 2.

Table 2

Water quality parameters observed during rearing white-leg shrimp shrimps

No	*Parameters*	*Unit*	*Tools*	*Period of measurement*
1	Dissolved oxygen	mg L^{-1}	DO meter	Twice per day
2	Water temperature	°C	Thermometer sensor	Twice per day
3	Water pH	-	pH meter	Twice per day
4	Salinity	‰	Hand refractometer	Twice per day
5	Nitrite (NO_2)	mg L^{-1}	Nitrite (NO_2) test kit	Weekly
6	Nitrate (NO_3)	mg L^{-1}	Nitrate (NO_3) test kit	Weekly
7	Phosphate (PO_4)	mg L^{-1}	Phosphate (PO_4) test kit	Weekly
10	Ammonia (NH_3)	mg L^{-1}	Ammonia (NH_3) test kit	Weekly
11	Total Fe in water	%	Fe test kit	Weekly

Data gathered on the water quality parameters were tabulated and compared with three standards of water quality parameters such as the MMAF Degree Number 28 of 2004, BSN-SNI 8037.1 of 2014, and Governmental Regulation Number 22 of 2021 in Appendix VIII.

Model for feeding consumption. This research utilized five regimes of feeding periods according to shrimp phases of growing, namely starter (day 5-15), grower (day 16-45), and finisher (day 45-60). The first regime is in the range of day 5 to day 15. This regime fed shrimps with factory artificial feeds in powder form (IRAWAN 683 SP, CP Prima) twice daily (07.00 am and 3.00 pm) with 17 g daily. In the second regime (days 16-32), shrimps were fed three times a day (07.00 am, 3.00 pm, and 11 pm) with factory artificial feeds in the form of crumble (IRAWAN 683 SP, CP Prima) with an average of 173 g daily. The third regime was from day 33 to 44. An average total of 322 g of factory artificial pellets (IRAWAN 683 SP, CP Prima) daily were delivered four times per day (07.00 am, 11 am, 3.00 pm, and 11 pm). The fourth regime was from day 45 to 58 with pellet feed (IRAWAN 683 SP, CP Prima). In this regime, a total of 609.64 g was given with five frequencies daily (07.00 am, 11 am, 3.00 pm, 7 pm, and 11 pm). The last regime (day 59 – day 65) averaged 690 g of pellets delivered to shrimps four times (07.00 am, 11 am, 3.00 pm, 7 pm, and 11 pm) per day.

Feeding management significantly considers the economic and environmental status of the shrimp farm (Carvalho & Nunes 2006). The achievement of maximal feeding efficiency plays an essential role in the economics of commercial aquaculture. Furthermore, feeding management is vital to minimize the accumulation of feed leftovers impacting the water quality in the tank (Akbarurrasyid et al 2023). Getting a proper model of feed consumption for rearing white-leg shrimps can be acquired through the growth parameters (length and weight). These parameters were used to estimate white-leg shrimp's daily optimum feeding needs in the experimental bio-floc tanks. Modeling utilized the sigmoid mathematic function (Castille et al 1993) by linking independent factors, namely shrimp growth parameters, represented by multiplying length and weight (in the conversion of Ln), and a dependent factor, in this case, the daily quantity of feed provision (g) as follows:

$$Quantity\ of\ feed\ per\ day = a/(1 + \exp(-(x - x0)/b))$$

Where: a and b are constants, x is the independent factor, namely shrimp growth acquired from conversing the Ln of shrimp length and weight, and x0 is an association value starting from the x variable.

All parameters recorded during this research were analyzed using descriptive statistics. Some important statistic parameters were displayed, such as average, standard deviation (SD), minimum and maximum values. Furthermore, in exploring the research model, an inferential statistical analysis was used. This analysis was conducted in Software R-4.0 to extrapolate data and test hypothesis. Graphics in boxplot (Chambers et al 1983) and trend line were employed to visualize the results. The following tests were executed for the established models consisting one-way variance analysis (ANOVA) (Welch 1951), covariant analysis (ANCOVA) (Tabachnick et al 2007), HSD Tukey test (Tukey 1949), one sample t-test (Welch 1951). The growth of white-leg shrimps referred to an exponential growth model (Castille et al 1993; Helfman et al 1997). Furthermore, the relationship between growth and environmental variables was analyzed using a PCA (primary component analysis) (Wold et al 1987). This analysis also indicates the most affecting factors from water environmental parameters.

Results

White-leg shrimp growth patterns. The length and weight growth of shrimp, from day 25 to 60, were significantly different (p<0.001). The average length was 7.4±3.21 mm, ranging from 3.1 to 14.4 mm. Furthermore, the average weight was 5.45±4.29 g, ranging from 1.22 to 18.9 g (Table 3).

Table 3

Growth parameters of white-leg shrimp shrimp

Parameters	*N*	*Average*	*SD*	*Minimum*	*Maximum*	*P-value*
Length	50	7.40	3.21	3.10	14.40	< .001**
Weight	50	5.45	4.29	1.22	18.90	< .001**

The length growth for the mentioned intervals had a significant difference (p<0.01), with the highest significant averages being 2.87 and 3.02 mm on two specific days, namely days 55 and 65, respectively. For weight growth, the values between day 25 versus day 35, and day 35 versus day 45 were not significantly different (p>0.05). The average of the highest weight on day 55 and day 65 was 1.899 g. The length and weight growth for the reared white-leg shrimp follows an exponential growth pattern, signifying that the shrimp grows slowly in the early stages and then escalates rapidly at the end of observation. The Tukey HSD test results on comparing both ages versus length and weight are listed in Table 4.

Table 4

Tukey HSD test

The age and length comparison of shrimp					*The age and weight comparison of shrimp*				
Age	*Length deviation*	*df*	*t*	*P-value*	*Age*	*Weight deviation*	*df*	*t*	*P-value*
25 - 35	-1.53	40	-8.080	<.001**	25 - 35	-0.933	40	-1.90	0.335^{ns}
- 45	-2.88	40	-15.22	<.001**	- 45	-2.083	40	-4.24	<.001**
- 55	-5.9	40	-31.17	<.001**	- 55	-5.735	40	-11.7	<.001**
- 65	-8.77	40	-46.34	<.001**	- 65	-11.286	40	-23.0	<.001**
35 - 45	-1.35	40	-7.130	<.001**	35 - 45	-1.15	40	-2.34	0.154^{ns}
- 55	-4.37	40	-23.09	<.001**	- 55	-4.802	40	-9.77	<.001**
- 65	-7.24	40	-38.25	<.001**	- 65	-10.353	40	-21.1	<.001**
45 - 55	-3.02	40	-15.96	<.001**	45 - 55	-3.652	40	-7.43	<.001**
- 65	-5.89	40	-31.12	<.001**	- 65	-9.203	40	-18.7	<.001**
55 - 65	-2.87	40	-15.16	<.001**	55 - 65	-5.551	40	-11.3	<.001**

Note: ** - significant difference for α=0.01; * - significant difference for α=0.05; ^{ns} - not significant difference at α=0.05.

The growth of shrimp in 10-day intervals, starting from day 25 until day 60, indicates an exponential pattern (Figure 1) with an average growth of 3.2% per day. The specific length and weight growth are, on average, 3.6% and 5% per day, respectively. An exponential relationship between the length and weight of the shrimp growth has also been identified by plotting individual samples and averaged samples on a graphic that indicates a similar pattern (Figure 2).

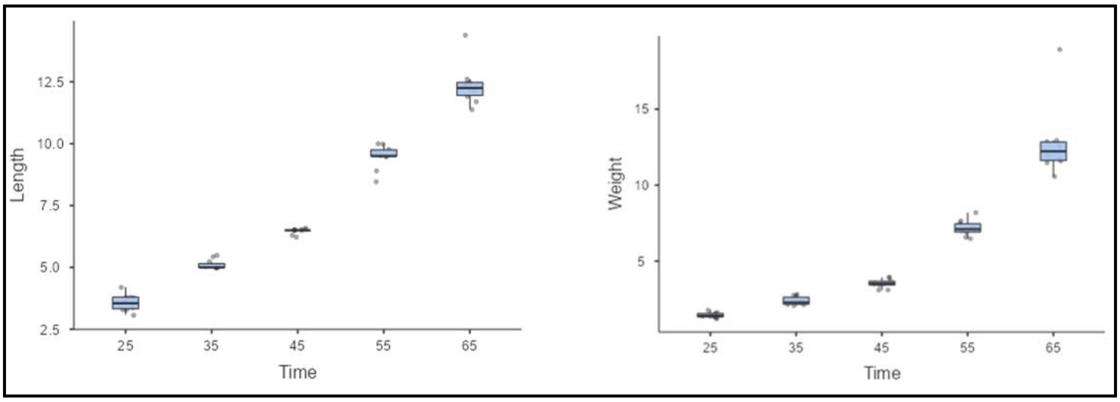

Figure 1. The progression of white-leg shrimp (*Penaeus vannamei*) length (left) and weight (right) from day 25 to day 65.

The primary component analysis (Figure 3) evidences a correlation between the ages and growth parameters of the reared shrimp. The length and weight growth of the shrimp starting from day 25 to day 45 denotes significant discrimination with the growth in ages from day 55 to day 65. The graph also shows that the changes in length and weight from days 55 to 65 significantly differ from the shrimp's previous ages.

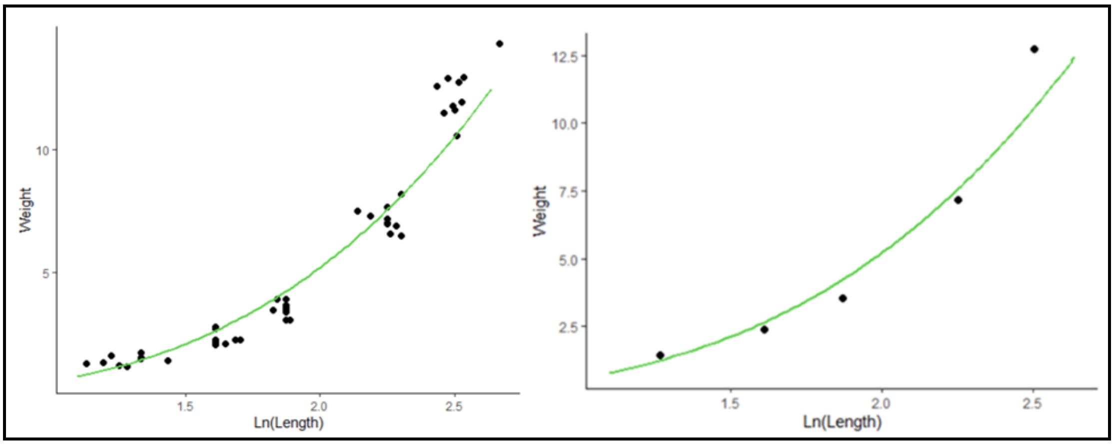

Figure 2. During observation, there is an exponential relationship between length and weight growth, individual distribution (left), and averaged distribution (right).

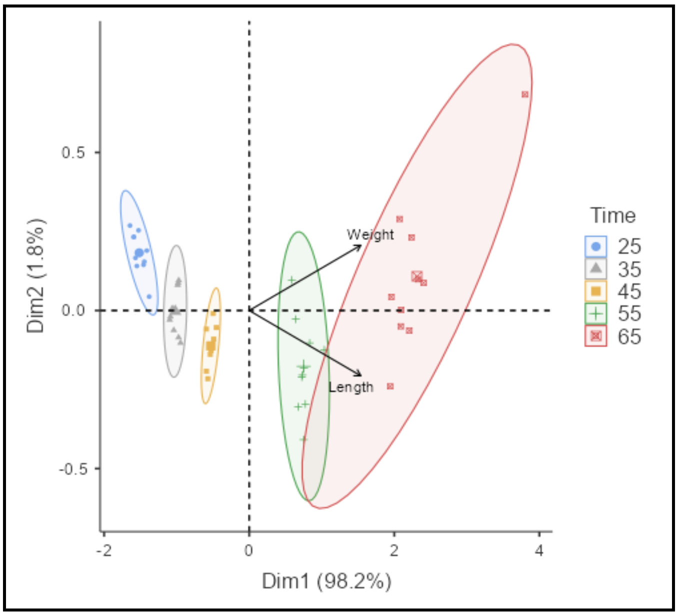

Figure 3. PCA-Biplot discrimination between age development and growth of white-leg shrimp (*Penaeus vannamei*).

The analysis results (Table 5), according to the t-test, point out an exponential regression ($p<0.01$) between the length and weight growth of the shrimp with a determinant coefficient $R^2>94\%$. This result shows that 94% of shrimp weight growth can be estimated from the shrimp length, and the other 6% is affected by other factors like age and water quality.

Table 5

White-leg shrimp (*Penaeus vannamei*) length and weight relationship

Data	*Exponential model*	*a*	*b*	*R^2*	*P-value*
Individual Group	$L=0.6029W^{3.077}$	0.6029	3.077	94%	$<.001^{**}$
Individual Average	$L=0.5920W^{3.139}$	0.5920	3.139	95%	$<.001^{**}$

Note: ** - significant difference for α=0.01; * - significant difference for α=0.05; ^{ns} - no significant difference for α=0.05.

Based on the exponential model presented in Table 5, both individual and average calculations of b values are 3.077 and 3.139, higher than 3. This condition infers that reared shrimps have a positively allometric growth, meaning their weights gain is faster than length growth.

Water quality parameters for shrimp growth. The results of measuring nine water quality parameters are listed in Table 6. The average of each parameter is detailed to describe its condition in the water during the observation period.

Table 6

Water quality parameters and recommended standards

Parameters	*n*	*Standard of BSN-SNI 8037.1:2014 & SNI 01-7246-2006*	*Average*	*SD*	*Minimum*	*Maximum*	*P-value*
DO (mg L^{-1})	8	>4	6.20	0.18	6.00	6.50	0.155^{ns}
Temperature (^{0}C)	8	28-33	26.50	0.48	25.90	27.20	0.573^{ns}
pH	8	7.5-8.5	7.76	0.12	7.59	7.92	0.478^{ns}
Salinity (ppm)	8	30-33	24.30	0.61	23.40	25.10	0.780^{ns}
Phosphate (mg L^{-1})	8	>0.1	0.28	0.14	0.10	0.50	0.351^{ns}
Nitrate (mg L^{-1})	8	<0,5	0.64	0.17	0.50	1.00	0.495^{ns}
Nitrite (mg L^{-1})	8	<0.01	0.09	0.05	0.05	0.15	0.077^{ns}
Ammonia (mg L^{-1})	8	<0.01	0.24	0.19	0.05	0.50	0.113^{ns}
Iron (mg L^{-1})	8	<0.1	0.23	0.15	0.10	0.50	0.099^{ns}

Note: DO - dissolved oxygen; ** - significant difference for α=0.01; * - significant difference for α=0.05; ^{ns} - not significant difference for α=0.05.

Comparing average values of the water quality parameters with the standards of BSN-SNI 8037.1:2014 indicates that only three parameters (DO, pH, and phosphate) met the minimum recommended levels. In contrast, all other parameters (temperature, salinity, nitrate, nitrite, ammonia, and iron) were outside of recommended standards.

Weekly observation from days 10 to 59. Figure 4 shows the dynamic water quality changes happening for DO, nitrate, ammonia, and iron, while other parameters (pH, salinity, phosphate, nitrate, and temperature) did not fluctuate dramatically.

Daily observation from days 9 to 65. Both pH and temperature were significantly different ($p<0.01$) on a daily period (Table 7; Figure 5). The average pH in the morning and evening was 7.77 and 7.82, respectively. Temperature average in the morning and evening were 26.9 and 25.6^{o}C, respectively. Other parameters, such as DO and salinity, were not significantly different ($p>0.05$) in either observation time.

PCA for water quality parameters. All water quality parameters affect white-leg shrimp growth, including temperature, DO, ammonia, nitrite, nitrate, phosphorus, and salinity. The closeness among these parameters can be seen in the analysis results displayed in Figure 6.

The first primary component (PC-1) represents a variety of parameter factors, in the range of 48.4–60.9%, and the second primary component (PC-2) shows a variety of parameter factors in the range of 18.4–29.1%. The biplot graphics (Figure 6) denote the variety of all water quality parameters in a range of 77.5–79.3%. According to the analysis (Figure 6 left), there are three established clusters as a result of reducing the grouping parameters where Cluster 1 consists of DO, pH, and salinity, Cluster 2 consists of nitrite, nitrate, ammonia, phosphate, and iron; and Cluster 3 is represented only by temperature.

Furthermore, these three clusters can also be reduced into some crucial variables influencing the length and weight of white-leg shrimp, such as pellet feed and DO. These three clusters consist of pH and salinity in Cluster 1, temperature in Cluster 2, and four other parameters (feed, length, weight, and DO) in Cluster 3. The last cluster (cluster 3) describes how shrimp feeds affect growth parameters (weight and length). Due to shrimps growing gradually according to age, the consumption of DO for shrimp respiration in the water also escalated. This increase is also related to the need for digestion and food absorption.

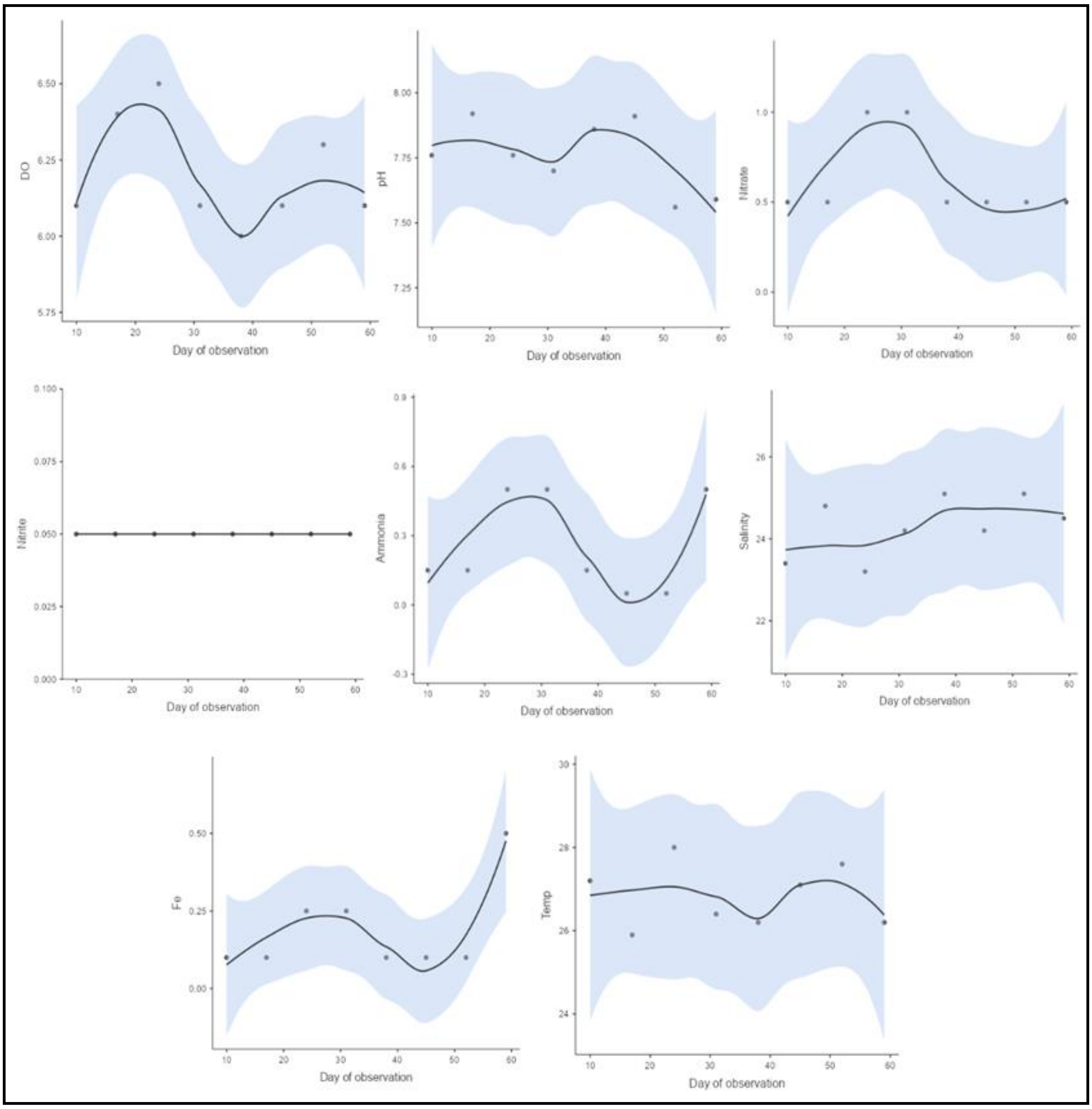

Figure 4. Trend changes in water quality: (a) dissolved oxygen, (b) pH, (c) nitrite, (d) nitrate, (e) phosphate, (f) ammonia, (g) salinity, (h) iron, and (i) temperature from days 10 to 59.

Table 7

Water quality parameters for morning and evening observations

Parameter	*Morning*					*Evening*					*P-value*
	n	*Average*	*SD*	*Min*	*Max*	*n*	*Average*	*SD*	*Min*	*Max*	
Dissolved oxygen	57	6.26	0.243	5.90	7.00	57	6.25	0.242	5.5	6.80	0.878^{ns}
pH	57	7.77	0.102	7.52	7.95	57	7.82	0.086	7.62	8.07	0.005^{**}
Salinity	57	24.2	0.616	22.9	25.6	57	24.2	0.587	22.4	25.4	0.429^{ns}
Temperature	57	26.9	0.616	25.2	28.0	57	25.6	0.763	24.3	27.5	$<.001^{**}$

Note: ** - significant difference for α=0.01; * - significant difference for α=0.05; ^{ns} - not significant difference for α=0.05.

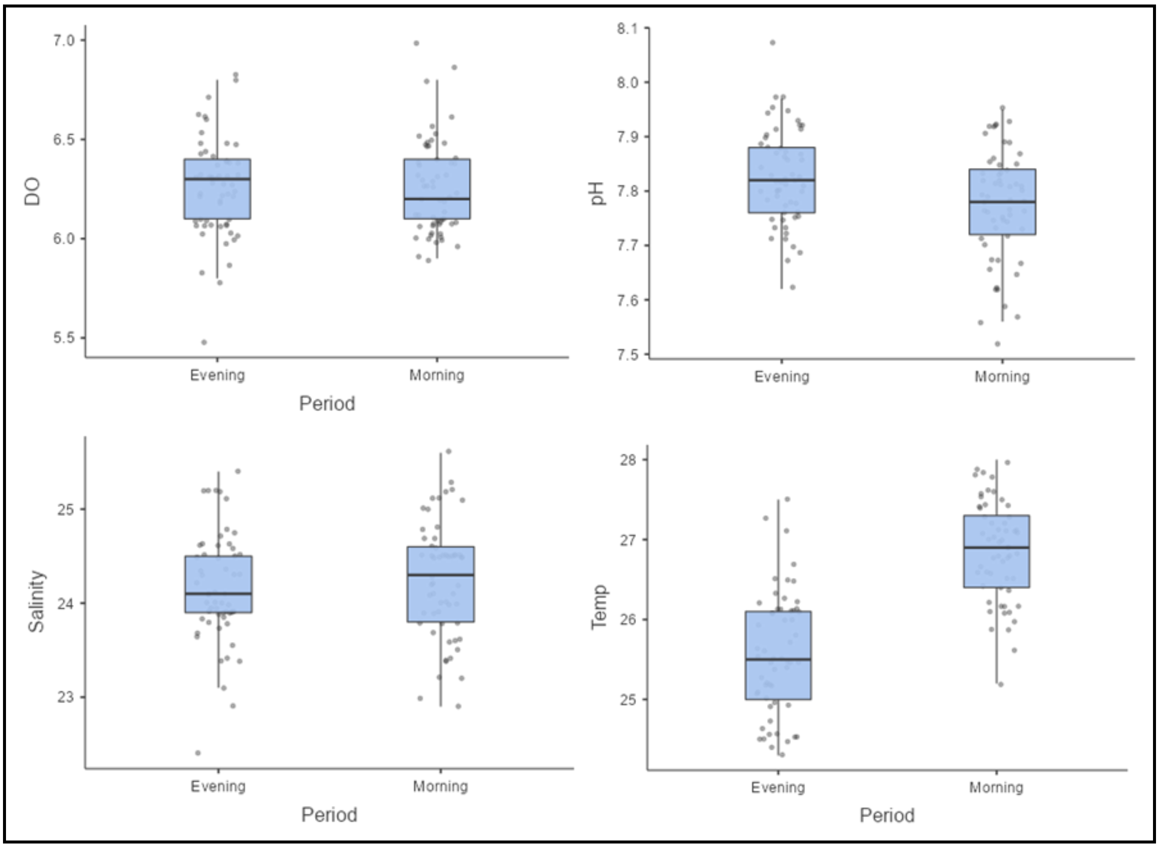

Figure 5. Water quality parameters in daily (morning and evening) observations.

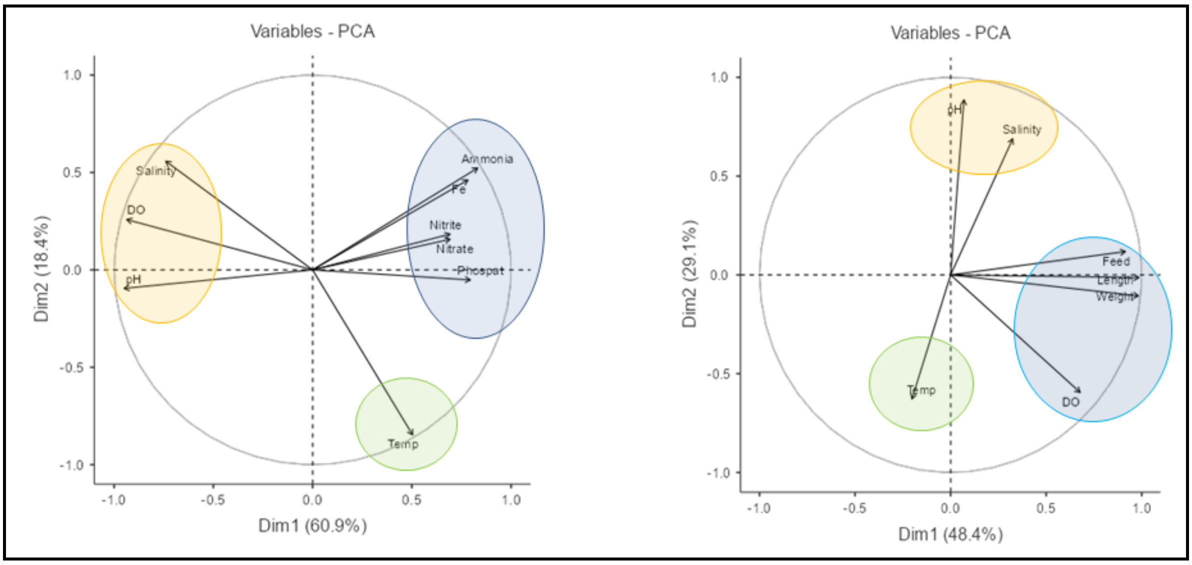

Figure 6. Primary component analysis using biplot graphics. (a) water quality parameters; (b) water quality parameters, feeding administration, and shrimp growth.

Feeding management model. Based on the relationship between the feeding frequency and shrimp growth, the optimal quantity of feeding in rearing shrimp can be elucidated through this research. The growth of shrimp is highly affected by the number of feeds delivered through the observational period. The result of modeling feeding management in this research is represented in Table 8. The model shows a determinant coefficient R^2 of 93%. This infers that 93% of proper feeding quantity influences the shrimp growth in length and weight, while the 7% left is affected by other factors such as water quality and feeding competition in the rearing tank.

Table 8
Mathematic equation of the relationship between shrimp growth and number of feedings

Sigmoid formula	*a*	*b*	*x0*	*R^2*	*p-value*
Quantity of feed per day $Y = a/[1+\exp(-(x-x0)/b)]$	646.469	0.894	2.43	93%	< .001**

Note: ** - significant difference for α=0.01; * - significant difference for α=0.05; ^{ns} - no significant difference for α=0.05.

Furthermore, there is a significant relationship (p<0.01) between shrimp growth and the number of feedings. A simple mathematical equation of this relationship is displayed in Figure 7. Feed (in g) increases significantly with escalating shrimp growth.

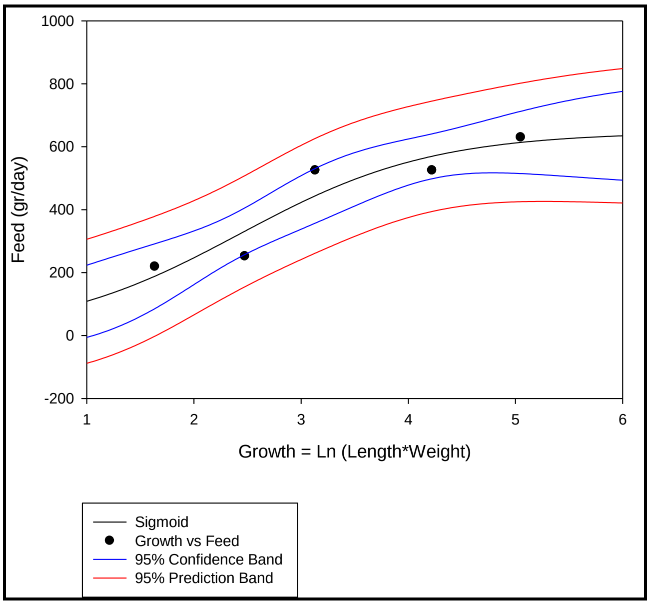

Figure 7. Sigmoid mathematic equation regarding shrimp growth towards required feeding.

Discussion. Farming white-leg shrimp on a small scale in Indonesia could be more efficient in using production inputs such as labor, fertilizer, feed, and stock density. The main causes are the high cost of inputs, lack of bank credits, and inadequacy of cash to purchase feed and shrimp fries (Lestariadi et al 2012). The present study observes shrimp farming in a small-scale unit for household operations. It is challenging due to limiting operational budgets and production scale. Three main elements in this production scale should be considered: shrimp growth, water quality, and feeds. These elements are interrelated with each other. The first element indicates the growing process of shrimp from day one in the grow-out tanks until the harvesting time. The second element describes the environmental condition, in this case, the water, which affects the growth of shrimp. The last element deals with a feed management model regarding when and how much feed is delivered to the reared animal during observation.

The present study figures out the shrimp growth pattern that follows an exponential pattern, growing slowly in the early stage and then escalating rapidly at the harvesting time (day 65). The length-weight relationship indicates that the b value is higher than 3 in individuals and average groups. This result possesses a positively allometric growth pattern, meaning shrimp's weight gain is quicker than its length growth. The isometric and allometric growths can show if the shrimp growth is being stunted or not, respectively (Rukimin et al 2022). This result also indicates a similar pattern for wild-caught *P. vannamei* in Thailand using three fishing gear types in five locations (Panutrakul & Senanan 2021). The current research also found a specific growth rate of about 5% daily. This result is different from that of Khademzadeh & Haghi (2017), who found a growth rate of 4.9% per day and a negative allometric pattern. The isometric growth demonstrates that the shrimp is healthy from infection of LSS (loose shell syndrome) (Raja et al 2015). The results of Mohanty et al (2013) show an allometric growth (b<3) for *P. monodon*. In cases of positive allometric growth (b>3), the a (intercept) parameter can also be considered an indicator of good physiological condition in a population, given the conditions of a specific water environment. The density of reared organisms should be considered as it may affect water quality.

Suitable water quality parameters influence productivity and minimize the distribution of disease infections in ponds (Febriyani et al 2022). Optimal water quality parameters as recommended criteria can affect farming media and increase aquaculture productivity (Tumwesigye et al 2022). The results of the present study regarding water quality parameters indicate that only three of nine parameters met the minimum recommended levels, while others fell outside the standards. Those parameters are DO, pH, and phosphate. Low levels of DO in the water create significant problems for shrimp growth, with solubility decreasing in line with increasing temperature and salinity, as well as blooming plankton. Decreasing DO may result from escalating temperature and density of organisms (Zhang et al 2020). Low DO in the water is indicated by the slow movement of the shrimp emerging to the water surface. Harlina et al (2022) suggested that DO in a 5–6.8 mg L^{-1} range is good for shrimp growth in a pond. Increased DO concentrations can improve the growth of vannamei shrimp and the aquatic environment. DO levels can be maintained in the range of 4–6 mg L^{-1} (Rahmawati et al 2021). The pH, in natural water is highly affected by carbon dioxide concentration, an acidic gas (Boyd 2015). In research by Harlina et al (2022), pH in the range of 5.5–7 produces impaired shrimp growth in certain ponds. The current research maintains a pH of 7.56–7.92, an ideal pH for rearing white-leg shrimp. Furthermore, Mulis & Habibie (2022) stated that phosphate usually has a range between 0.08–0.2 mg L^{-1}, tolerable for shrimp. Bhatnagar & Devi (2019) recognized that a phosphate range of 0.3–2 mg L^{-1} is suitable for plankton and shrimp production. Zhang et al (2020) express that according to PCA, some parameters influencing the aquaculture water quality are salinity, DO, and antibiotic resistance genes (ARG).

Six other parameters (temperature, salinity, nitrate, nitrite, ammonia, and iron), although they do not perform as the recommended standards in this research, still affect the cultured organisms. The water temperature is below the recommended standards in the current research due to the sheltered rearing tank. Shrimp can live at an optimum of 26-32°C (Harlina et al 2022) in ponds and a range of 25-30°C for effective production (Kir et al 2023), as well as grow well in a range of 23-30°C (Mahasri et al 2020). The shrimp can tolerate extreme water temperatures up to 34°C and 37°C in sudden and gradual temperature increases, respectively, in experimental conditions (Dayalan et al 2022). The present study displays fluctuating salinity in a range of 23.4– 25.1 ppm. The water salinity is lower than the recommended standards because it comes from an estuary with an already low salinity. The reared organisms accept a broad salinity range. Shrimp has the best survival rate in a salinity of 20 ppm (Supono et al 2022). Even though shrimp can tolerate a high range of salinity from 32-33 ppm in small islands (Verdian et al 2019), it can also live under cultured conditions in freshwater in some places. The nitrate concentrations obtained in the current research range from 0.5 to 1 mg L^{-1}. The recommended nitrate concentration for intensive culture is 0.5 mg L^{-1} (Ramadhona et al 2016), and nitrate concentration for rearing fries' shrimp is recommended in a range of 0.04-0.08 mg/L (Mangampa & Suwoyo 2010). However, nitrate concentration below 50 mg L^{-1} is not poisonous to the reared shrimp (Makmur et al 2018; Boyd and Clay 2002). Even, the nitrate concentration up to 177 mg/L is acceptable for rearing the *L. vannamei* without renewal water, at a salinity of 23 in systems with bioflocs (Furtado et al 2015).

Nitrite and ammonia concentrations in the present research are in ranges of 0.05-0.15 mg L^{-1} and 0.05-0.5 mg L^{-1}, respectively. However, this condition can be tolerated by the reared organisms. More than 1 mg L^{-1} of ammonia and nitrate will influence the prevalence of parasitic infection in shrimp ponds (Nkuba et al 2021; Cahyanurani & Edy 2022). The concentration of Fe in the water during this research is higher than the recommended standards. For crustaceans, Fe is assigned as an essential element. In some places, an increasing concentration of Fe in the soil of *P. vannamei* ponds leads to a significant decline in production. Fe can also be accumulated in the tissue of the cultured shrimps (Kotiya & Vahder 2020). Fe concentration ranges from 78.6–91.1 mg g^{-1} in diets (Kotiya et al 2019). Additional Fe in the shrimp diet is believed to be necessary for metabolism activities. The Fe concentration of the basal diet (12 mg kg^{-1}) was considered satisfactory in *P. vannamei* (Davis et al 1992; Truong et al 2022).

Feed plays a significant role in farming shrimps. It should be managed well regarding economic and environmental status, dealing with fundamental aspects like when, where, and how much to feed (Carvalho & Nunes 2006). In the present research, the feeding quantity affected 93% of shrimp growth. Feed (in g) should increase significantly with escalating shrimp growth. This research used commercial feed. Shrimps have grown well by feeding on commercial pellets (Aalimahmoudi et al 2016). This research also utilizes microbial food organisms ('floc'). This floc is believed to contribute to high shrimp growth rates within zero-exchange culture systems (Tacon et al 2002) and by adding probiotics to feed with a balanced proximate nutrient content (Adibrata et al 2022a). The most optimal feeding frequency for a high growth rate of white-leg shrimp is obtained using an on-demand system (Ihsanario & Ridwan 2021). *L. vannamei*, in cultured conditions, is categorized as a non-selective opportunistic feeder. Therefore, it has a broad spectrum of feeds. To grow faster, a balanced protein composition is suggested (Varadharajan & Pushaparajan 2013). Time of feeding is also an essential factor for growing shrimps. The current research applies five regimes of feeding times, indicating that the shrimp grows increasingly in the two last regimes. This research also displays the feed (in g) escalating according to shrimp growth (Figure 7). Protein content in the feed is essential for the grow-out process stage of shrimp. This research used commercial pellets with a 32% crude protein level. An optimum dietary crude protein level in feed for shrimp in the growing-out process is 32.2% (Lee & Lee 2018).

Conclusions. The environmental capacity of small-scale shrimp farming practices has been investigated through this research. Three research directions were followed: growth patterns, the relationship between water quality parameters and shrimp growth, and the optimal feeding model. The growth of shrimps follows an exponential pattern that grows slowly in the early stage and then uplifts rapidly at the time of harvesting. Three water quality parameters significantly affected shrimp growth: DO, pH, and phosphate. 93% of shrimp growth was affected by feeding quantity, and other factors like water quality and competing density influenced growth by 7%. This research indicates that the three directions should be considered for *L. vannamei* culture in small-scale production. Information gathered through this research may benefit new candidates for shrimp growers.

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Conflict of Interest. The authors declare that there is no conflict of interest.

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