

Optimization of Stocking Densities, Water Quality and Carrying Capacity of Sustainable Culture of the Vanamei Shrimp *Penaeus vannamei* Ponds in Indonesia

Mochammad Farkan^{1*}, Gusti Aries¹, Maria Goreti Eny Kristiany¹, Reza Shah Pahlevi¹,
Lakonardi Nurraditya¹, Nina Meilisza²

¹Department of Aquaculture, Jakarta Technical University of Fisheries, Ministry of Marine Affairs and Fisheries, Jl. Raya Pasar Minggu, Jakarta – 12520, Indonesia

² Research Institute for Ornamental Fish Culture, Ministry of Marine Affairs and Fisheries, Jl. Perikanan Raya No.13 16436 Depok, West Java, Indonesia

Corresponding author: mochfarchan2@gmail.com

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ABSTRACT

The productivity of sustainable vanamei shrimp farming in ponds is increased by engineering the stocking density according to the carrying capacity. Therefore, this study aimed to analyze the optimal stocking density, water quality and carrying capacity in the productivity of vanamei shrimp farming in sustainable ponds. The study was conducted from February 2024 to January 2025 to using a randomized group design (RGD) and four replications integrated with descriptive and quantitative statistics. Vanamei shrimp farming in ponds is located in five districts, namely Sumbawa, Situbondo, Probolinggo, Pacitan, and Pandeglang. The plot area is about $3000 \pm 300 \text{ m}^2$ and stocking densities of vanamei shrimp were 105, 128, 135, 136, 137, 144, 156, 157, 189, and 214 shrimp/ m^2 . Data were processed using Excel and SPSS through growth and production parameters. The results showed that the stocking density of 189 and 214 shrimp/ m^2 significantly obtained higher production results and the optimum was 205 shrimp/ m^2 . The final weight was relatively the same, amounting to $15.78 \pm 0.45 \text{ g/shrimp}$. The maximum production carrying capacity was 31.5 ton/ha and the cubic curve equation to describe the correlation between stocking density and production was $Y = 1.768 - 3.556x + 2.494x^2 - 53.55x^3$. The result also showed a relationship between stocking density, average body weight (ABW), and survival rate (SR). However, there was no relationship between stocking density and feed conversion ratio (FCR). The results of this study can be used as a reference for sustainable vanamei shrimp farming.

INTRODUCTION

The Vanamei shrimp (*Litopenaeus vannamei*) farming holds excellent potential to drive economic growth across upstream and downstream industries. Previous studies have shown that shrimp aquaculture is rapidly expanding and highly profitable, particularly in tropical coastal regions (Boyd, 2021). Shrimp production increased by 83.4% in Asia and 16.3% in Latin America over the past decade. Globally, two major species dominate production: Pacific white shrimp (*Litopenaeus vannamei*) and tiger

prawn (*Penaeus monodon*), contributing 83% and 12% of total output, respectively (Villarreal & Juarez, 2022).

A common problem is the fluctuation in production due to disease infection and poor quality of the cultivation environment as well as the application of inappropriate technology (Weitzman & Filgueira, 2019). Increasing stocking density in intensive or supra-intensive systems can increase production. However, the increasing feed waste poses an environmental risk, causing susceptibility to disease infection (Bardera *et al.*, 2021). Previous studies showed that increasing stocking density results in higher infection rates of white spot syndrome virus (WSSV), reaching up to 50%, and causes mortality to occur 2–3 days earlier. In addition, mortality increased significantly, and the feed conversion ratio (FCR) also rose (Kim *et al.*, 2024).

Efforts to increase vanamei shrimp production in productive, profitable, and sustainable ponds are carried out by balancing environmental ecosystem management and technology application. Therefore, aquaculture management was carried out by increasing stocking density with the optimum production according to the carrying capacity of the environment (Weitzman & Filgueira, 2019; Cahyanurani & Hariri, 2021; Irani *et al.*, 2022; Alauddin & Angkasa, 2023). Stocking density is a factor that affects good stocking density was 24.8 shrimp m^{-2} (Bardera *et al.*, 2021), while 3,000 post larvae/ m^3 was better than 5,000 and 4,000 post larvae/ m^3 (Mohammadi *et al.*, 2023). Furthermore, stocking density of 100 shrimp/ m^3 was feasible compared to 100, 200, 300, and 400 shrimp/ m^3 (Irani *et al.*, 2022). A stocking density of 70,000 post larvae at day 26 (PL26) was better than 15,000 post larvae 26 (PL26) (Eid *et al.*, 2020). While the optimum shrimp density was 175 shrimp/ m^3 compared to 225 and 275 shrimp/ m^3 (Marlina & Panjaitan, 2022).

Key performance indicators of vanamei shrimp farming include production, growth, survival, feed efficiency, water quality, and technology (Suryadi & Merdekawati, 2021; Hariyadi, 2023). A higher stocking density reduces the average weight gain of shrimp and increases the organic waste deposited into the waters. Therefore, increasing production must maintain sustainability to adjust to the environment and the carrying capacity of the waters (Dauda *et al.*, 2019; Ningsih & Muqsith, 2022). Optimizing stocking densities in shrimp farming ponds is important to match carrying capacity, promoting sustainable and healthy growth (Yunarty & Renitasari, 2022). Optimizing stocking density, considering carrying capacity and water quality, enables farmers to mitigate disease risk and minimize operational costs.

Based on this background, the present study aims to analyze the optimal stocking density for vanamei shrimp culture in relation to environmental carrying capacity and water Quality. The goal is to identify stocking levels that support sustainable production and healthy growth. This research evaluates stocking density thresholds to determine optimal conditions for maximizing yield while maintaining ecological balance in pond-based shrimp farming systems

MATERIALS AND METHODS

Location and time of study

The study was conducted from February 2024 to January 2025 at five vanamei shrimp farming industries, namely PT Rhee (Rhee) Sumbawa (West Nusa Tenggara), PT Suma Marina (SM) Situbondo (East Java), PT Anugrah Nusantara Kraksaan (ANK) Probolinggo (East Java), PT Tambak Karya Muda (TKM) Pacitan (East Java), and PT Sukses Damai Bahari (SDB) Lebak (West Java). Fig. (1) shows a detailed illustration of the study location map.

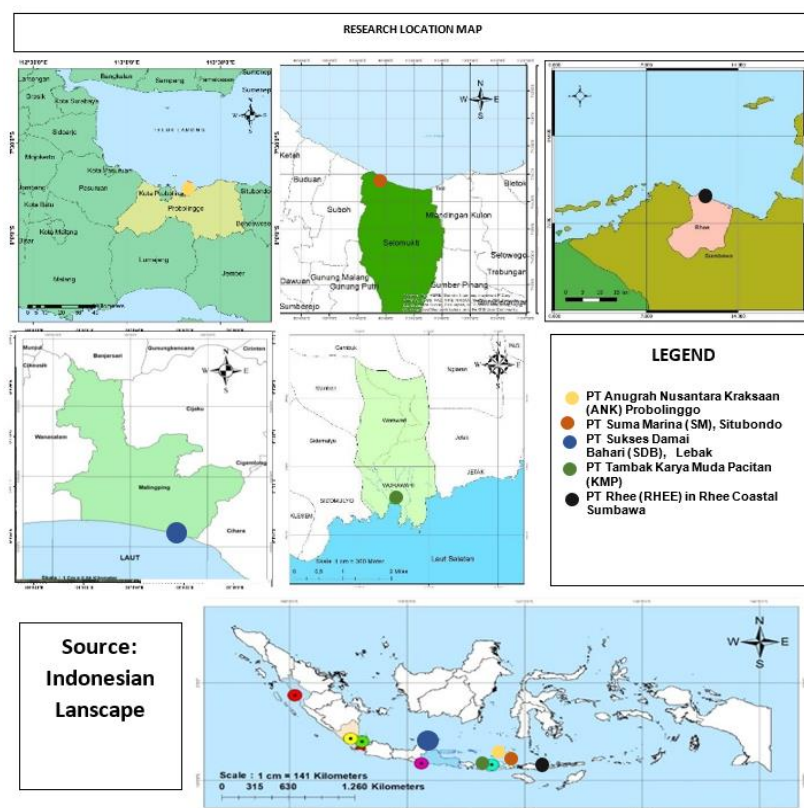


Fig. 1. Location map of the research ponds

Material

This research was conducted in industrially managed shrimp ponds using an intensive aquaculture system. The study site consisted of *Litopenaeus vannamei* (vanamei shrimp) farming ponds constructed with HDPE plastic liners, covering an area of approximately $3,000 \pm 300 \text{ m}^2$. Each location implemented the same technological protocol, beginning with pond preparation activities such as drying, pest eradication, water manajmen, installation of facilities and infrastructure. Following stocking, the culture process included artificial feeding, water quality management, pest and disease control, harvesting, and post-harvest handling. The culture period lasted 91 ± 6 days.

Water quality parameters were measured both in the field and in the laboratory, following standard procedures.

The tools and materials used for water quality assessment included test kits, a thermometer, a pH meter, a dissolved oxygen (DO) meter, and a refractometer. Ammonia ($\text{NH}_3\text{-N}$) levels were measured using the Hanna HI3826 ammonia test kit. pH was assessed using the Trans Instruments Digital pH Tester (Senz pH Resolution), and temperature was recorded using a glass alcohol thermometer with a range of 10–150°C. Chemical parameters such as DO and alkalinity were measured in situ using the YSI 556 NPS Water Quality Checker. Salinity was determined using an Atago refractometer, while total organic matter (TOM) was analyzed in the laboratory.

3. Study method

The study employed descriptive and quantitative statistical methods using a group randomized design (GRD) with four replicates. The design of the test stocking density shrimp/m² was 105, 128, 135, 136, 137, 144, 156, 157, 189, and 214. The parameter data measured for water quality were brightness, temperature, dissolved oxygen (DO), Salinity, pH, Ammonia, Total Organic Matter (TOM), and alkalinity. Carrying capacity data were taken from four shrimp rearing cycles in 2023 and 2024. Scheme of research activities as shown in Fig. (2) below.

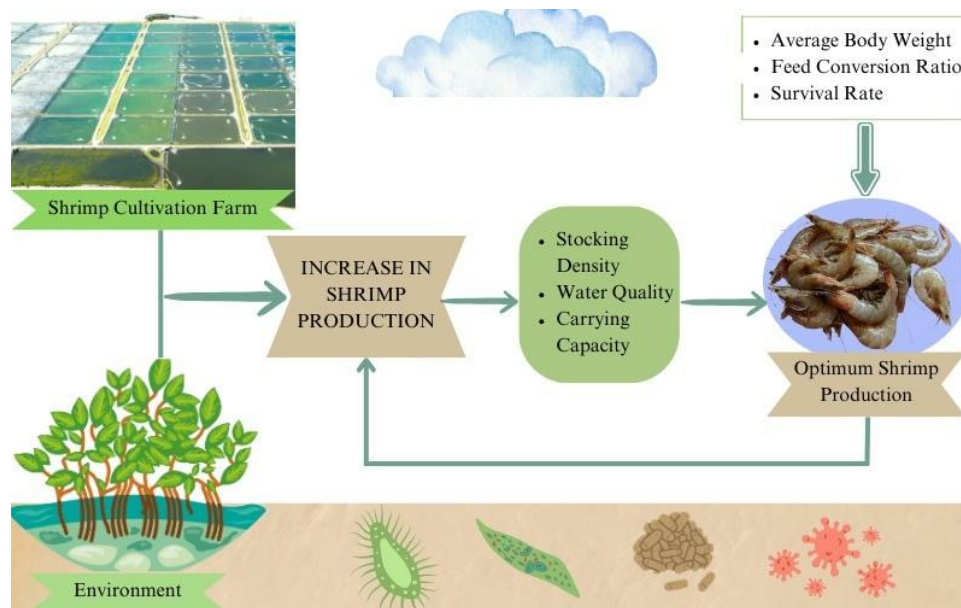


Fig. 2. Schematic Flow of Research Analysis

Data analysis

The data collected are the results of water quality measurements, stocking density, production, survival rate (SR), and shrimp growth rate, such as average body weight

(ABW) and feed conversion ratio (FCR) (Widanarni *et al.*, 2019). Water quality was determined by comparing the measurement results and the standards of aquaculture in ponds. The carrying capacity was determined by examining the maximum production capacity of several cycles (Song *et al.*, 2019; Weitzman & Filgueira, 2019). All statistical analysis was carried out using Data processing software, namely Excel and SPSS.

RESULTS

Shrimp live and perform various activities in the water of the maintenance media. Therefore, water is a decisive and dominant factor that affects the success of shrimp farming in ponds. The results of water quality measurements in each location are shown in Table (1).

Table 1. Water quality measurement results and recommended standards

Parameters	Location						Reference
	RHEE	SM	TKM	ANK	SDB	Standard	
Brightness (cm)	45±15.5	49±16	47±14	41±8	42±13	35±5	Ariadi <i>et al.</i> (2023)
Temperature (°C)	31±3.1	29.2±2.3	29.5±2.5	29.2±3	29.5±2.5	28.5±1.5	(Renitasari and Musa, 2020)
DO (mg/L)	4.8±0.9	5.1±1.1	4.9±0.7	5.5±1.1	6.2±0.4	>3.54	Araujo <i>et al.</i> (2024)
Salinity (g/L)	34±2.5	32±2.8	28±2	31±2.5	25±5	20±5	Pratiwi <i>et al.</i> (2024)
pH	7.7±0.35	8.0±0.4	8.0±0.3	7.8±0.4	8.2±0.6	7.5±0.5	Jaffer <i>et al.</i> (2020)
Amonia (mg/L)	0.02±0.01	0.04±0.3	0.03±0.1	0.03±0.2	0.03±0.1	0.01	Araujo <i>et al.</i> (2024)
TOM (mg/L)	109±17	115±14	122±40	125±21	125±35	127-32	Pratiwi <i>et al.</i> (2024)
Alkalinity (mg/L)	135 ±27	122±22	129±31	122±22	123±25	125 ±25	Pratiwi <i>et al.</i> (2024)

Comparison between field measurements and standards shows that water quality was at the threshold required for shrimp farming. The productivity of sustainable shrimp ponds was improved by increasing the stocking density. The growth and production parameters included average body weight (ABW) and survival rate (SR), while cost efficiency was evaluated using the feed conversion ratio (FCR). The results for the different stocking density treatments are presented in Table (2).

Table 2. Stocking density, ABW, SR, FCR and production

No ·	Stocking density Shrimp/m ²	ABW (g)	SR (%)	FCR	Production (ton/ha)	Repeat	Average
1	105	22,53	77	1,25	17.75	1	14,63
2	105	21,81	62	1,39	14.61	2	
3	105	16,67	86	1,49	14.19	3	
4	105	18,58	63	1,64	11.97	4	
5	128	19,61	64	1,1	12.73	1	19,07
6	128	21,74	82	1,6	22.51	2	
7	128	21,5	71	1,64	19.45	3	
8	128	20,88	81	1,51	21.6	4	
9	135	24,28	83	1,28	14.66	1	21,85
10	135	23,28	80	1,44	27.11	2	
11	135	22,28	73	1,52	24.21	3	
12	135	24,28	80	1,41	21.42	4	
13	136	19,46	50	1,3	9.71	1	12,72
14	136	18,16	54	1.2	13.2	2	
15	136	16,67	72	1	15.79	3	
16	136	16,44	60	1,5	12.21	4	
17	137	18,87	61	1,1	11.29	1	16,23
18	137	17,24	52	1,1	12.53	2	
19	137	22,28	71	1,4	21.12	3	
20	137	21,08	70	1,52	20.01	4	
21	144	20	88	1,4	26.21	1	22,98
22	144	19,01	85	1,5	23.43	2	
23	144	17,6	81	1,4	19.31	3	
24	144	17,8	87	1,3	22.22	4	
25	156	23,28	72	1,31	13.43	1	22,23
26	156	23,28	78	1,32	25.2	2	
27	156	22,5	80	1,3	28.08	3	
28	156	22	75	1,2	28.06	4	
29	157	14,43	73,8	1,8	14.31	1	18,87
30	157	14,28	83,8	1,38	18.75	2	
31	157	15,06	82,4	1,27	19.41	3	
32	157	20,2	74	1,4	23.02	4	
33	189	22,81	83,3	1,25	35.84	1	35,42
34	189	23,64	85,6	1,33	34.81	2	
35	189	23,78	80,2	1,32	35.62	3	
36	189	21,73	81,3	1,28	31.83	4	
37	214	19,23	69,6	1,32	27.22	1	31,04
38	214	21,26	68,6	1,32	30.24	2	
39	214	25,03	64,4	1,25	34.4	3	

Stocking Densities, Water Quality and Carrying Capacity of Vanamei Shrimp Culture

40	214	21,22	70,7	1,33	32.33	4
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This study calculated the average yield of each stocking density. Correlations between ABW, SR, and production variables were analyzed using SPSS. Table (3) shows the average results and correlations between variables.

Table 3. Measurement and correlation results of ABW, SR, FCR, and production of different stocking densities

Stocking density (shrimp/ m ²)	Parameters			
	ABW (g)	SR (%)	FCR	Production (ton/ha)
105	19,90 ^{abcd}	72,00 ^{abcd}	1,44	14,93 ^a
128	20,88 ^{bcd}	74,50 ^{abcd}	1,46	20,02 ^{abc}
135	23,53 ^d	79,00 ^{bcd}	1,41	25,13 ^{cd}
136	17,68 ^{ab}	59,00 ^a	1,25	14,12 ^a
137	19,87 ^{abcd}	63,50 ^{ab}	1,28	17,48 ^{ab}
144	18,60 ^{abc}	82,60 ^{cd}	1,40	22,82 ^{bcd}
156	22,77 ^{cd}	76,25 ^{bcd}	1,28	27,07 ^{de}
157	15,99 ^a	78,50 ^{bcd}	1,46	19,61 ^{abc}
189	22,99 ^d	82,50 ^d	1,30	35,90 ^f
214	21,69 ^{bcd}	68,33 ^{abc}	1,31	31,61 ^{ef}
<i>P-value</i>	0,00	0,00	0,38	0,00
<i>Pooled Standard Error</i>	0,45	1,58	0,03	1,14

The result shows that different stocking densities affected ABW, SR, and production, but not FCR. The best stocking density to produce high ABW, SR, and production was 189 shrimp/m². The strength of correlation between variables is shown in Table (4).

Table 4. Correlation between stocking density (shrimp/m²) with ABW (g), SR (%), FCR, and Production (Ton/ Ha)

X (Stocking density)	Y			
	ABW	SR	FCR	Production
Sig. (2-tailed)	0,165	0,528	0,182	0,000
Pearson Correlation	0,224	0,103	-0,216	0,781

Information:

Significance <0,05

Correlated

Significance >0,05

Not correlated

Based on the result in Table (4), there was no relationship between stocking density, ABW, SR, and FCR, as evidenced by $P > 0.05$. Table (3) shows that stocking

density significantly impacts ABW and SR, but the relationship remains unclear. This causes the resulting Pearson correlation value to be uncorrelated and weak, such that the best stocking density cannot be concluded to produce significant parameter values. A strong and significant correlation exists between stocking density and production, as evidenced by significance values of 0.000. The closeness of this relationship was also characterized by a strong Pearson Correlation value of 0.781, as shown in Table (4). Therefore, there was a strong relationship between stocking density and production. The appropriate curve to illustrate the relationship between stocking density and production is a cubic curve with the equation $Y = 1.768 - 3.556x + 2.494x^2 - 53.55x^3$ (R^2 cubic = 0.663; $P < 0.05$). Based on the model, the optimum level of stocking density to obtain optimal production values in vanamei shrimp was 205 shrimp/m² (Fig. 3).

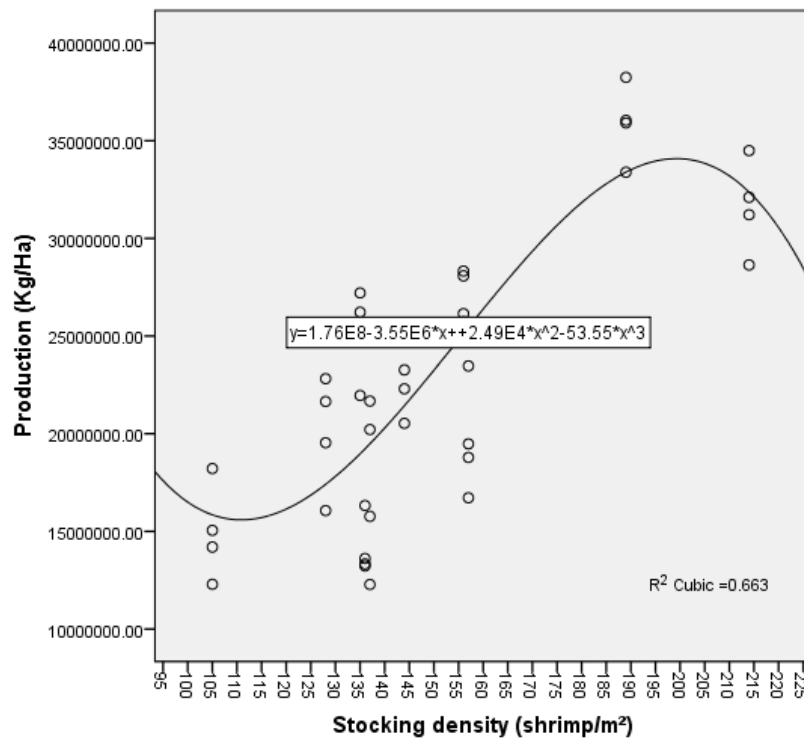


Fig. 3. The relationship between stocking density (shrimp/m²) and production (Kg/Ha) of Vanamei shrimp

While the description of the relationship between stocking density and production in some industrial shrimp farming ponds can be seen in Fig. (4) below.

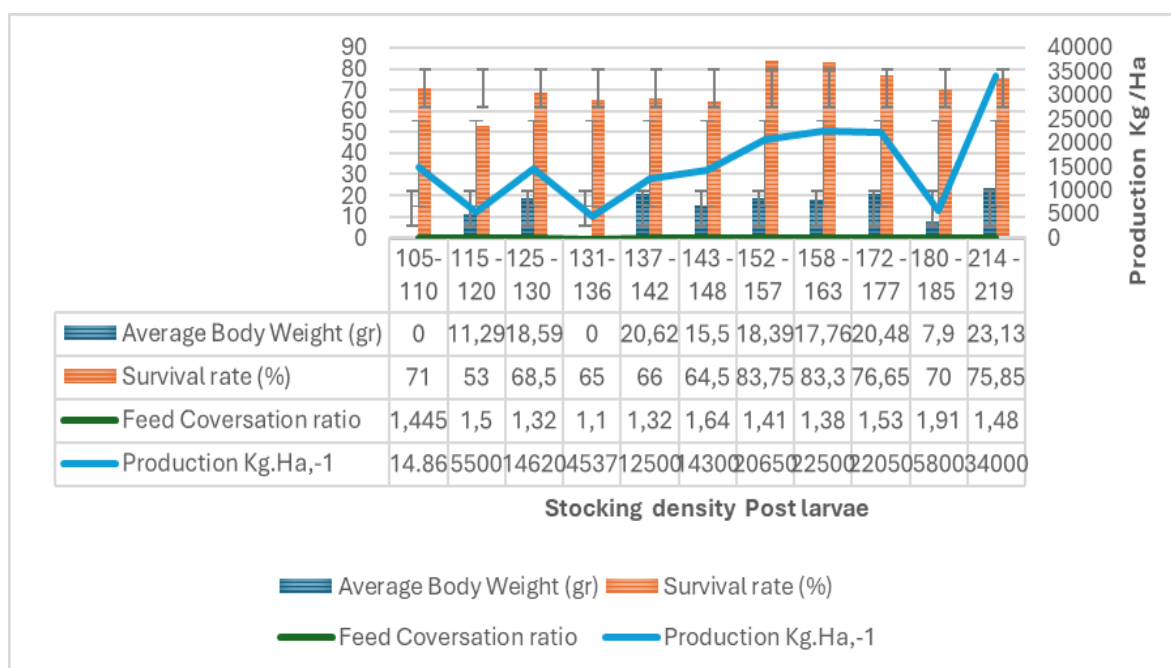


Fig. 4. Relationship between stocking density and cultivation performance

A between-subjects effects analysis was conducted to determine the optimal stocking density. The results show a significant effect of stocking density on production ($F(9,27) = 14.41$, $P < 0.001$), suggesting substantial differences in production across various stocking densities. These results were followed up with BNJ test, showing that shrimp production with stocking density 214 and 189 shrimp/m² was significantly higher. The R^2 value of 0.957 shows a close relationship between the dependent variable of 0.95 closer to 1.

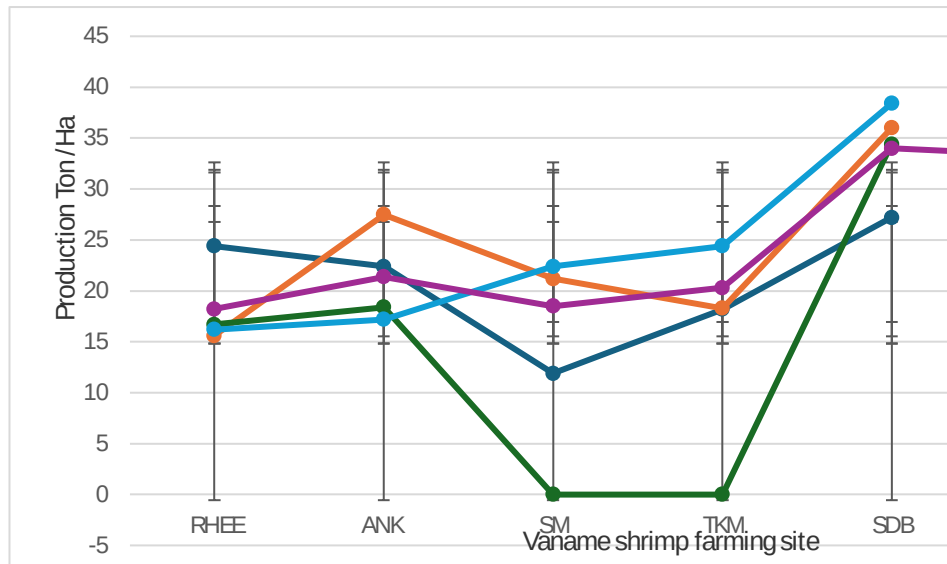
Carrying capacity

Farming carrying capacity is the level of ecological suitability that can accommodate the maximum capacity of a biomass or waste load in the aquaculture ecosystem (**Wafi et al., 2021**). In intensive ponds, the carrying capacity of aquaculture is a key factor in determining the maximum capacity of the environment to accommodate the amount of waste load generated by aquaculture activities (**Song et al., 2019**). Evaluation of carrying capacity is necessary to ensure that aquaculture production can use natural resources sustainably (**Fisher et al., 2023**). Various methods were used to calculate carrying capacity. Maximum production carrying capacity can be achieved through consistent use of technology, facilities, and infrastructure across multiple cycles, thereby optimizing production. Simulation of carrying capacity scenarios can be done by assessing the capacity of shrimp farming to obtain optimal economic and ecological benefits (**Song et al., 2019**). Therefore, the optimum capacity can be used to assess the carrying capacity. The results of production measurements in four cycles are shown in Table (5).

Table 5. Four-cycle production

Cycle	Research Location					Optimum Production (Ton/Ha)
	RHEE	ANK	SM	TKM	SDB	
Cycle 1 (Ton/Ha)	24.4	22.4	11.9	18.2	27.2	
Cycle 2(Ton/Ha)	15.6	27.5	21.2	18.3	36	
Cycle 3(Ton/Ha)	16.7	18.4	17.7	19.4	34.4	
Cycle 4 (Ton/Ha)	16.2	17.2	22.4	24.4	38.4	
Average (Ton/Ha)	18.2	21.3	18.5	20.3	34	31.04

Processing occurred at the optimum stocking rate, derived from a density of 205 shrimp/m². The results of comparing the production at stocking densities of 189 and 214 shrimp/m² averaged 31.04 ton/ha. When the optimum stocking density and production levels are used as the standard for determining carrying capacity, the conditions of the RHEE, ANK, SM, and TKM ponds can be improved accordingly (Fig. 5).

**Fig. 5.** Relationship between carrying capacity and production at shrimp farming sites

DISCUSSION

The parameters of water quality measured were brightness, temperature, DO, salinity, pH, ammonia, TOM alkalinity (Table 1). The measurement results at each location differed, but were still in accordance with the shrimp farming water quality standards set by experts. Only the average salinity at each location was above the standard of 25 g/L. Based on this result, production is very closely influenced by stocking density. Production and profit of vanamei shrimp farming activities are influenced by SR, ABW, and FCR (Farkan *et al.*, 2017). The results showed that the SR production

varied between 50 - 85.6%. The data showed that 50% SR was produced at a stocking density of 136 shrimp/m² and a high SR of 85.6% at 189 shrimp m⁻². Furthermore, the SR shown varied and fluctuated at each stocking density. Although SR showed significant differences between treatments (Table 3), there was no consistent pattern due to low stocking density. These results show that stocking density has no relationship with SR. The result is further supported by the Pearson correlation test which showed no correlation with a value of 0.103.

Stocking density plays a significant role in producing the SR of a vanamei shrimp farming activity. This is because during the cultivation period, the SR value experiences a decreasing graph caused by the deterioration of environmental conditions due to increased aquaculture waste and is influenced by feed management and water quality management, and shrimp health (**Suryadi & Merdekawati, 2021**). However, another influencing factor is that an increase in stocking density can reduce shrimp survival rates. High stocking density will increase shrimp competition for food, space, living space, oxygen, and cannibalism (**Kotiya & Vadher, 2021**). The result also showed that differences in stocking density cause differences in costs. The higher the stocking density the greater the fry required (**Muchtar et al., 2020**).

In ABW, biomass increase is strongly influenced by shrimp weight gain (**Nguyen et al., 2019**). The results of the ABW study can still be improved, as a comparison of the stocking density of 170 shrimp/m² produced an average weight and SR of 29.23 g/shrimp and 86.70%, respectively. A stocking density of 175 shrimp/m² produces an average weight of 29.18 g/shrimp and a SR of 82.35 % (**Purnamasari et al., 2017**). According to the results of previous studies, FCR was influenced by SR, shrimp growth rate, shrimp health, and water quality conditions (**Liu et al., 2017; Anand et al., 2019; Ariadi et al., 2020**). FCR in the good category was 1.5 - 1.9 (**Rahim et al., 2021**) and the most influential cost was feed, requiring more than 60% of all operational costs (**Wahyudi et al., 2022**). Based on these data, the FCR of the study can be concluded to be in the good category. The treatment of stocking density also did not have a significant effect (significantly different) on FCR, as shown in Table (3). This result shows that the FCR generated from all differences in stocking density have equally good results. This result is consistent with the report of **Wahyudi et al. (2022)** that the tested stocking density affects the productivity of shrimp farming ($P < 0.05$). In the study, vanamei shrimp farming can be carried out with a super intensive system at a stocking density and FCR of 400 shrimp m⁻³ and 1.48, respectively. The FCR value produced in this study (1.28-1.46) was even better than the super intensive stocking density. In the report of **Hariyadi (2023)**, the FCR was also not significantly different from the study that used a low stocking density of 96 shrimp/m² yielding an FCR of 1.55. In another study with a density of 180 shrimp/m², the FCR value was 1.25% (**Iskandar et al., 2022**). The FCR obtained in this study is comparable to other result on stocking density. The results of previous studies also showed that stocking density does not significantly affect FCR

results.

Production is the amount of vanamei shrimp harvested produced in one hectare of ponds in one culture cycle. The highest and lowest production was 38.24 to/ha and 13.23 ton/ha at a stocking density of 189 and 136 shrimp/m², respectively. Meanwhile, the average was 35.89 ton/ha at a stocking density of 189 shrimp/m². This result shows that the higher the stocking density, the higher the production (Table 3). Stocking density also has a strong correlation to production, as shown in Table (4). Several studies have shown that high stocking density has an impact on increasing production in vanamei shrimp farming (**Mohanty *et al.*, 2018; Dauda *et al.*, 2019; Tantu *et al.*, 2020**). In comparison to the optimum results of previous studies, stocking densities of 170 and 175 shrimp/m² had better values of average weight and higher survival rates, ABW shrimp at harvest (**Purnamasari *et al.*, 2017**), and a density of 110 shrimp/m² provided the optimal level of carrying capacity (**Ningsih & Muqsith, 2022**). The stocking density of more than 150 shrimp/m² required super-intensive maintenance and used intensive technology (**Villarreal & Juarez, 2022**). Variations in study results show several factors that affect production other than stocking density. Previous studies reported that vanamei shrimp production was influenced by several factors, namely stocking density, technology, water quality, facilities and infrastructure, water quality, and land carrying capacity, as well as the conditions of natural and human resources (**Jescovitch, 2017; Dauda *et al.*, 2019**).

Water quality was generally perceived as a primary limiting factor and significantly influenced the health and subsequent productivity of the aquatic environment (**Zhang *et al.*, 2020; Tumwesigye *et al.*, 2022**). The increase in sustainable shrimp farming production was influenced by both stocking density and carrying capacity. The average optimal production at several study sites as a benchmark for carrying capacity was 31.04 ton/ha (Table 5). Each site must be adjusted to the characteristics of each region. Carrying capacity of intensive shrimp cultivation ponds in Sarjo District, Pasangkayu, West Sulawesi Regency with an estimated maximum production of 42.63 ton/ha (**Tamsil *et al.*, 2024**). However, when environmental conditions and technology are the same, and production is compared to the optimum level, there are four companies whose production can still be increased. This result is consistent with the findings of **Song *et al.* (2019)** and **Wafi *et al.* (2021)**, which show that carrying capacity directly affects the normal growth of *vannamei* shrimp, as well as the opposite condition. Any increase in production must be aligned with the principles of aquaculture sustainability.

The technology applied should minimize environmental impacts and enhance pond water quality, as emphasized by **Khoa *et al.* (2020)**. Environmentally controlled aquaculture systems with effective waste management are expected to support productive, profitable, and sustainable *vannamei* shrimp farming (**Alauddin & Putra, 2023**).

CONCLUSION

In conclusion, the water quality of the shrimp culture environment was suitable to support optimum growth. Differences in stocking density had a significant effect on production and a strong correlation. Stocking density with ABW and SR had a very weak correlation. Despite the differences between the treatment of stocking density, there was no relationship between ABW and SR. The maximum production carrying capacity was 31.5 ton/ha while stocking densities of 214 & 189 shrimp/m² were significantly higher. Finally the optimum stocking and carrying capacity density was 205 shrimp/m².

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Conflict of Interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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