Improving net returns of whiteleg shrimp (*Litopenaeus vannamei)* farming through the application of optimal stocking density in Kolaka District, Southeast Sulawesi, Indonesia

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Abstract. Stocking density might determine the productivity and net returns of vannamei shrimp (*Litopenaeus vannamei*) farming. This study aimed to determine the stocking density that provided the highest net returns in vannamei shrimp farming. The study was conducted from October 2019 to October 2020 in Kolaka District of Southeast Sulawesi Province, Indonesia. The population of the study represented all vannamei shrimp farmers who were active in 2019-2020, namely 58 farmers with 70 pond plots. Data were collected using surveys, interviews, review of literature, water sampling, and laboratory analysis. The data collected included the amount and price of each factor of production, yields, output price, water quality, mangrove area, pond size, level of pond management, and rainfall. The data were analyzed using an econometric model approach with a simultaneous equation system. The model was estimated using the Two Stage Least Squares (2SLS) method. The results showed that the factors that have a significant effect on production are the amount of feed, the amount of fertilizer, the amount of lime, and the total organic matter. The factors that have a significant effect on net returns are yields and the use of pond bottom cover. The conclusion of the model shows that the stocking density that provides the highest yield is 208 ind m^{-2}.

Key Words: bacteria, income, production, revenue, total ammonia nitrogen.

Introduction. Vannamei shrimp (*Litopenaeus vannamei*) was initially cultivated in Indonesia in 2001 and since then has developed rapidly throughout the country. Rapid expansion of vannamei shrimp farming is due to its advantages compared to other types of shrimp, such as high productivity, high stocking density, more efficient use of feed, faster growth, more disease resistance, and more tolerance to salinity (Briggs et al 2004; Erlangga 2012; Engle et al 2017; Minh et al 2019).

One area that has developed vannamei shrimp is Kolaka District in Southeast Sulawesi Province. The total pond area for vannamei shrimp farming in the district is 49,400 ha, with production that tends to increase yearly. Production was 112.70 tons in 2008, 18,256.02 tons in 2013, and continued to increase to 27,179.56 tons in 2018. However, there was a decrease of 1,008.19 tons and 2,731.72 tons in 2019 and 2020, respectively, compared to production in 2018 (BPS 2020b). Regarding the production system, most shrimp farms (98.8%) are in an extensive system (BPS 2020a) with low production units. This fact presents a considerable opportunity for further development of the farm into a more semi-intensive and intensive system based on the use of appropriate stocking density (Jusmiaty et al 2017; Cheal et al 2017; Filipski & Belton 2018; Fitriah et al 2020; Mekuo et al 2020; Pisi et al 2021).

In producing vannamei shrimp, farmers must consider several production factors such as land, fry, feed, fertilizer, lime, probiotics, aerators, High-Density Polyethylene (HDPE) plastic, and labor (Bakar 2008; Fuady 2013; Navghan et al 2015; Wulandari et al 2015; Triyatmo et al 2016; Cheal et al 2017; Jescovitch et al 2017; Junda 2018; Farionita et al 2018; Yuni et al 2018; Dauda et al 2019; Hidayat et al 2019; Xie et al 2019). In addition, it requires natural production factors, namely water sources with good water quality, appropriate water temperature, salinity, pH, dissolved oxygen (DO), alkalinity, and turbidity (Cao 2012; Ariadi et al 2019). The appropriate use of these factors of production can determine the yields.

The purpose of vannamei shrimp farming is to generate the highest returns, which can be realized from maximum yields. However, increased yields do not always lead to increased net returns. This is because an increase in production requires an increase in the use of production factors. Therefore, farmers can obtain the highest returns if they can optimally allocate production factors, including the use of appropriate stocking density. Nevertheless, since high stocking density might be associated with increased cost, it is necessary to conduct a study to identify the optimal stocking density that can generate the highest returns.

Material and Method

Description of the study sites. This study was conducted from December 2019 to September 2020 in Kolaka District, Southeast Sulawesi, Indonesia. The district is located at 3°37'-4°38' south latitude and 121°05'-121°46' east longitude.

Data collection. The population in this study accounted for 58 farmers with 70 ponds. All farmers were selected as respondents. The data collected included the amount and price of each production factor (number of fry, pond size, amount of feed, amount of fertilizer, amount of pesticide, amount of probiotics, number of workers, number of working hours, number of supplements and number of windmills), total production, selling price, water quality management and water quality (total organic matter, total ammonia nitrogen, number of vibrio bacteria), mangrove area, pond area, semi-intensive and intensive pond area, and rainfall.

The collection of data regarding production factors, yields, prices, water quality management, mangrove area, pond area, semi-intensive and intensive pond area, and rainfall was carried out using survey methods, interviews, and literature studies. Water quality data were collected by taking water samples and analyzing them in the lab. Water samples were taken at 04.00-07.00 am using a sterile 500 mL bottle and then analyzed by technicians at the Kolaka Independent Pond Laboratory, Southeast Sulawesi, Indonesia. Measurement of total organic matter (TOM), total ammonia nitrogen (TAN), and vibrio bacteria (*Vibrio* spp.) was done according to the American Public Health Association (APHA) procedure (Rice et al 2017).

Data analysis. To answer the research question, an econometric model approach with a simultaneous equation system was used. The model was estimated using the Two Stage Least Squares (2SLS) method (Budiyanto et al 2014; Dirgantoro et al 2018; Imués-Figueroa et al 2022). Furthermore, simulations of different stocking densities were carried out to calculate returns. The analysis used the computer software program SAS version 9.1 at a confidence level of 95 percent. The simultaneous equation models in this study are as follows:

Structural model:

1. Pduv = a0 + Puv + Ddsb + Dddt
2. Bva = b0 + Puv + Ddsb
3. Puv = c0 + Ll + Jpa + Jjk + Ddki + Ddpes + TOM +TAN + Jbv+ Ch + Lmg + Lat + Ltis
4. Jpa = d0 + Jpt + Lp + Ddpr + Ddsup

Identity model:

1. Pduv = Pnuv + Bva
2. Bva = Bva + 0

Where:
Pduv = net returns; Pnuv = revenue; Bva = operational cost; Puv = yields; Ll= plot size; Jpt = stocking density; Lp = culture period; Jpa = amount of feed; Jjk = Amount of working hours; TOM = total organic matter; TAN = total ammonia nitrogen; Jbv = amount of vibrio bacteria; Ch = rainfall; Lat = pond size; Ltis= size of intensive and semi-intensive ponds; Lmg = size of mangrove area; Ddpr = dummy of probiotic; DdSup = dummy of supplement; Ddki = dummy of aerator; Ddsb = production system; Dddt = dummy of pond bottom cover (plastic, non-plastic).

Results and Discussion

Stocking density. The stocking density was the average number of shrimp post-larvae in one square meter of the pond area. The stocking density of shrimp post larvae that farmers applied ranged from 1 to 208 per m^{-2}. The criteria for stocking density were based on the Regulation of the Minister of Maritime Affairs and Fisheries of the Republic of Indonesia no. 75 (KKP 2016) that includes (i) low stocking density corresponding to an extensive cultivation system, (ii) medium stocking density corresponding to a semi-intensive cultivation system, and (iii) high to very high stocking density corresponding to an intensive and super-intensive cultivation system. The size of ponds with an extensive cultivation system ranged from 0.5 – 3 ha per plot. Semi-intensive to super-intensive ponds ranged from 0.25 to 0.40 ha per plot. The stocking density and its criteria are summarized in Table 1.

Table 1
Stocking density of vannamei shrimp (*Litopenaeus vannamei*) in Kolaka District

No	*Category*	*Stocking density (ind m^{-2})*	*Mean stocking density (ind m^{-2})*	*Standard criteria of stocking density (ind m^{-2})*
1	Low stocking density	1-17	5.0	1-30.
2	Medium stocking density	38-48	42.8	31-50
3	High stocking density	65-100	86.2	51-100
4	Very high stocking density	108 - 208	162.8	>100
	Mean Stocking Density		32.5	

Shrimp farmers in the study area predominantly applied low stocking densities. The bottom of the ponds that used low to moderate stocking density was covered only with sandy-loam soil, whereas ponds with high to very high stocking densities used plastic mulch to cover the bottom. Aerators and reservoir plots (special plots for managing water before being channeled to rearing plots) are only applied at ponds with medium to very high stocking densities.

Production. Vannamei shrimp (*Litopenaeus vannamei*) production in this study was the total weight of vannamei shrimp in one hectare of pond produced in one production cycle. Vannamei shrimp production on various stocking density criteria is summarized in Figure 1.

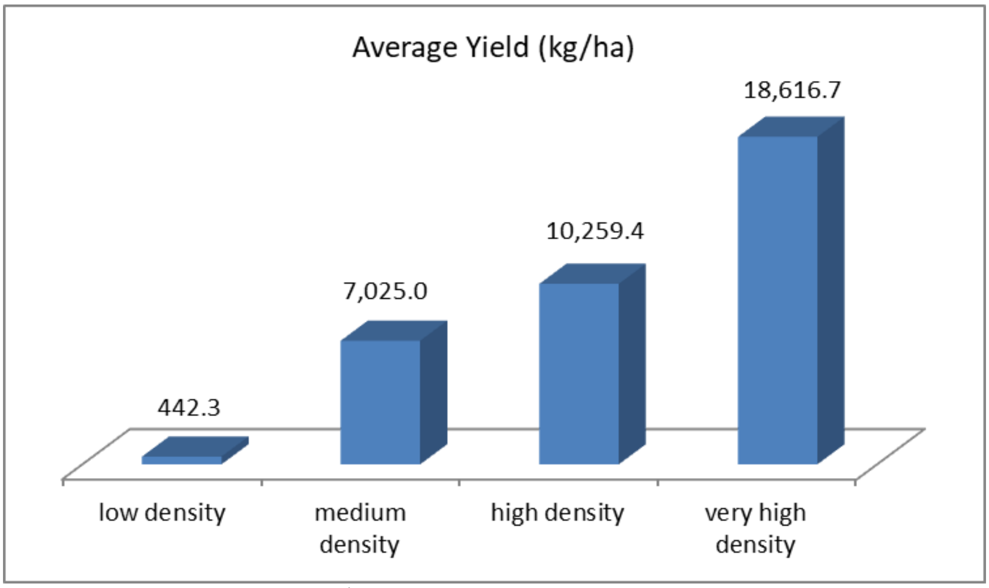

Figure 1. Production (kg ha^{-1}) of vannamei shrimp according to stocking density.

As shown in Figure 1, differences in shrimp production are due to differences in stocking densities. This is in line with previous research, which suggested that yield is influenced by stocking density (Bakar 2008; Fuady 2013; Navghan et al 2015; Triyatmo et al 2016; Cheal et al 2017; Jescovitch et al 2017; Junda 2018; Yuni et al 2018; Dauda et al 2019; Xie et al 2019). The average stocking density of fry at the study site is in the category of medium stocking density (32.5 ind m^{-2}), with an average yield of 3,772.6 kg ha^{-1}. This yield is higher than the results by Junda et al (2018), who reported an average stocking density of 52.4 ind m^{-2} and an average yield of 2,426 kg ha^{-1}. However, the result is much lower than that by Mohanty et al (2018), who reported an average stocking density of 50 individuals m^{-2} and an average yield of 10,286.7 kg ha^{-1}.

Net returns. Net returns in this study are the value of revenue minus the total cost per hectare of the pond in one production cycle. The net returns obtained from various stocking density criteria are summarized in Figure 2.

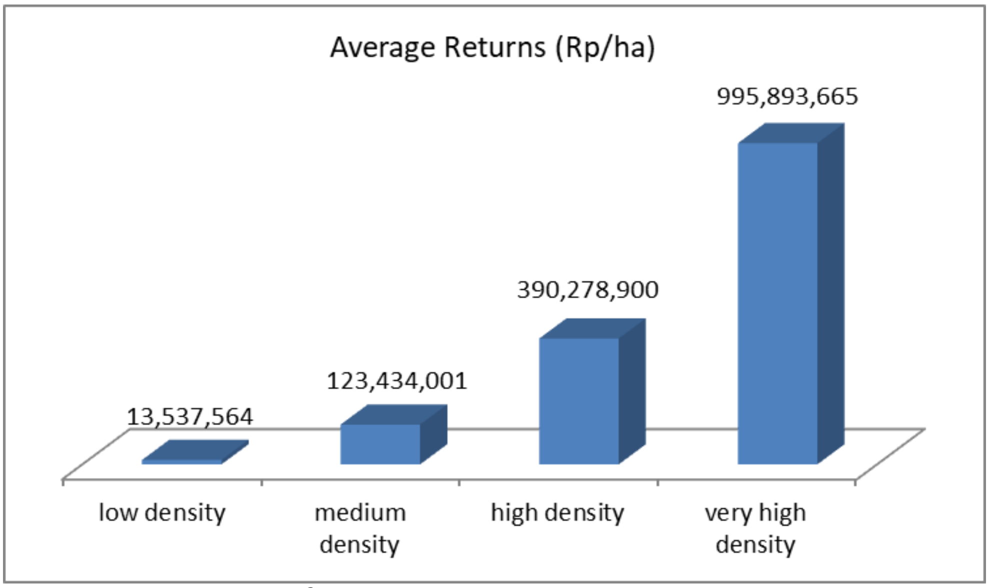

Figure 2. Net returns (IDR ha^{-2}) of vannamei shrimp farming according to stocking density.

Figure 2 shows that a very high stocking density of 162.8 individuals m^{-2} resulted in the highest average net returns. However, farmers predominantly applied low stocking density with a range of 1-17 individuals m^{-2}. The reasons might be that they lack capital and skills to finance and operate ponds with higher stocking densities.

The average net returns is 153,542,383 IDR ha^{-1}, which corresponds to the category of medium stocking density of 32.5 individuals m^{-2}. This agrees to a study by Sutra et al (2018), who reported a range of stocking density of 28-32 ind m^{-2} with net returns of 30,712,766 IDR ha^{-1}. However, this result is lower than that reported by Mohanty et al (2018), with a stocking density of 40 individuals m^{-2} and net returns of 299,566,625 IDR ha^{-1}.

Model estimation. The estimation results of the production model and net returns of the vannamei shrimp farming showed that the average value of the coefficient of determination (R^2) was high, namely 91.12 percent. The F statistics ranged from 32.38 to 112.26 with $F < 0.0001$, which means that the variation of the explanatory variables altogether can explain well the variation of the endogenous variables at the level of $\alpha = 0.0001$. The results of the t-statistical test indicate that several explanatory variables have no significant effect on the endogenous variables at 5 percent level of significance. The estimation results provided the following equation model:

1) Pduv = -2,26E10 + 80245,79Puv - 1,21E11Ddsb - 2,99E11Dddt
2) Bva = -2322549 + 26578,84Puv + 84990859Ddsb
3) Puv = 7,337413 + 5,678271Ll + 0,989663Jpa + 2,3493Jjk + 2,2765Ddki - 463,5260Ddpes - 191,9610TOM + 7,24837TAN + 0,158111Jbv - 689,0530Ch - 122,0390Lmg + 0,054588Lat - 241,255Ltis
4) Jpa = -6360,63 + 3,74893Jpt + 8,72494Lp - 3021,32Ddpr -131,746Ddsup

The estimation results show that the stocking density of vannamei shrimp has a positive and significant effect on the amount of feed. Furthermore, the amount of feed has a positive and significant effect on yields. This indicates that the feeding is provided according to the stocking density of fry. In this regard, shrimp use feed for growth and energy to adapt to environmental changes. Therefore, the amount of feed is one of the determining factors in the vannamei shrimp culture (Bakar 2008; Navghan et al 2015; Triyatmo et al 2016; Yuni et al 2018; Dauda et al 2019).

The amount of lime applied also has a positive and significant effect on yield. Lime is used to neutralize the pH of the water. The pH concentration determines other water qualities, such as dissolved oxygen and ammonia. The results of other studies show that pH correlates with salinity, DO, and ammonia (Kordi & Tancung 2007; Zafar 2015; Supriatna et al 2017) and that water quality affects vannamei shrimp production (Kordi & Tancung 2007; Pirzan & Utojo 2013; Chakravarty et al 2016; Abdelrahman et al 2018; Jaganmohan & Kumari 2018).

The amount of fertilizer has a negative and significant effect on yields. This might be related to the fact that fertilizer can increase pond fertility, but too fertile ponds might lead to plankton blooms. Plankton blooming along with unconsumed feed and shrimp feces at the pond bottom can increase the total organic matter.

The total organic matter has a negatively significant effect on yield. Organic matter in low oxygen conditions causes an increase in ammonia and vibrio bacteria, which are the main factors for shrimp culture failure (Chakravarty et al 2016; Abdelrahman et al 2018; Jaganmohan & Kumari 2018; Ariadi et al 2019). However, the estimation results show that total ammonia nitrogen (TAN) and vibrio bacteria has no significant effect on yield. This might be because farmers overcome ammonia and vibrio bacteria by adding chlorine, probiotic bacteria, and aerators.

Yield has a positive and significant effect on net returns. High yields mean high revenue, leading to high returns as well. This result agrees with previous studies that yields determine net returns of vannamei shrimp farming (Chusnul et al 2010; Farionita et al 2018).

The pond bottom cover (plastic/non-plastic) has a negatively significant effect on net returns. The use of plastic mulch to cover the pond bottom can increase shrimp production (Hidayat et al 2019). Using plastic cover facilitates water quality management as farmers can easily remove the pile of solid waste and other sediments using a water pump connected to a pipe. However, using a pump means increasing production costs, which will affect net returns.

Stocking density that provides the highest net returns. The results of model estimation in simultaneous equation show that the stocking density of fry has a significant effect on the amount of feed applied. Further, the amount of feed has a significant effect on yields, which in turn significantly affect net returns. Therefore, a simulation of applying different stocking densities to generate the highest net returns was conducted. The results of the simulation are presented in Table 2.

Table 2
Simulation results of production and net returns of vannamei shrimp farming in various levels of stocking densities

Stocking density (ind/m^2)	*Variables*	*Actual mean*	*Predicted mean*	*Difference*	*% of change*
Simulation to decrease stocking density by 10 % from the average stocking density of 33 individual m^{-2}					
30	Net returns (IDR)	168,260,000	152,260,000	(16,000,000)	-0.10
	Operational cost (IDR)	128,630,000	123,330,000	(5,300,000)	-0.04
	Production (kg)	3,940	3740	(200)	-0.05
	Feed (kg)	11,681	10,419.1	(1,262)	-0.11
Simulation to increase stocking density by 10 % from the average stocking density of 33 individual m^{-2}					
36	Net returns (IDR)	168,260,000	184,270,000	16,010,000	0.10
	Operational cost (IDR)	128,630,000	133,930,000	5,300,000	0.04
	Production (kg)	3,939.5	4,139	200	0.05
	Feed (kg)	11,680.7	12,942.3	1,262	0.11
Simulation to increase stocking density by 40 % from the average stocking density of 33 individual m^{-2}					
46	Net returns (IDR)	168,260,000	232,290,000	64,030,000	0.38
	Operational cost (IDR)	128,630,000	149,840,000	21,210,000	0.16
	Production (kg)	3,939.5	4,737.4	798	0.20
	Feed (kg)	11,680.7	16,727.1	5,046	0.43
Simulation to increase stocking density by 140 % from the average stocking density of 33 individual m^{-2}					
92	Net returns (IDR)	168,260,000	456,390,000	288,130,000	1.71
	Operational cost (IDR)	128,630,000	224,060,000	95,430,000	0.74
	Production (kg)	3,939.5	7,530	3,591	0.91
	Feed (kg)	11,680.7	34,389.4	22,709	1.94
Simulation to increase stocking density by 500 % from the average stocking density of 33 individual m^{-2}					
198	Net returns (IDR)	168,260,000	96,860,000	(71,400,000)	-0.42
	Operational cost (IDR)	128,630,000	393,720,000	265,090,000	2.06
	Production (kg)	3,939.5	13,913.1	9,974	2.02
	Feed (kg)	11,680.7	74,760.5	63,080	5.40
Simulation to increase stocking density by 531% from the average stocking density of 33 individual m^{-2}					
208	Net returns (IDR)	168,260,000	1,018,200,000	849,940,000	5.05
	Operational cost (IDR)	128,630,000	410,150,000	281,520,000	2.19
	Production (kg)	3,939.5	14,531.5	10,592	2.69
	Feed (kg)	11,680.7	78,671.5	66,991	5.74

In general, the level of production rises when stocking density increases. The simulation results show that every 10 percent increase in stocking density will increase yields by 5 percent. Higher stocking densities resulting in higher vannamei shrimp production are consistent with earlier studies (Barros et al 2014; Clark et al 2010; Engle et al 2017; Nakorn et al 2017; Mohanty et al 2018; Dauda et al 2019; Tantu et al 2020). However, the simulation results show that the stocking density of 198 ind m^{-2} causes a decrease in net returns. This is in line with the results of previous studies that an increase in the stocking density can reduce the income from vannamei shrimp farming (Zhou & Hanson 2017), despite an increase in yields (Barros et al 2014; Mohanty et al 2018). Mohanty et al (2018) reported that vannamei shrimp culture with a stocking density of 50 ind m^{-2} generates net returns of $23,316.3 per ha, whereas a stocking density of 60 ind m^{-2} results in a decrease in net returns, which is $21,796.1 per ha despite an increase in yields. This is because an increase in stocking density also means increased use of other production factors, particularly feed and technology. In fact, high stocking density requires higher operational costs (Engle et al 2017; Filipski & Belton 2018), which could lead to declining net returns.

The simulation results show that a 10 percent increase in the stocking density will increase the amount of feed by 11 percent and yields by 5 percent. This result indicates that cultured shrimp may eat not all feed provided, or after a certain density is achieved, more feed is required to produce the same unit of body weight gain. In addition, yields are not only determined by the stocking density, but result from the combined and interrelated effects of many variables such as stocking density, water exchange rates, aeration levels, and feeding rates (Engle et al 2017).

The use of feed is an essential component and constitutes the most significant cost in vannamei shrimp culture (Erlangga 2012; Suyanto & Mujiman 2006; Deslianti et al 2016; Ulumiah et al 2020; Hai et al 2018). In this study, feed cost is 63.44% of the total operational costs for a production cycle of 75 days. The average stocking density of 33 ind m^{-2} requires feed of 11,364.34 kg ha^{-2}.

One of the methods that farmers had employed to optimize feed use was the application of probiotics at the amount being adjusted according to the stocking density of fry. Hamsah et al (2017) reported that probiotics could produce exogenous enzymes that can help the digestive process. Vannamei shrimp growth is significantly higher when using probiotics (Xie 2019). However, the results of the analysis show that probiotics have no significant effect on the amount of feed provided. This is probably because the use of probiotics has not been optimal.

The simulation results of the stocking density of fry show that the optimal yield that provides the highest returns is obtained at a density of 208 ind m^{-2}. This level of stocking density requires the highest operational costs, but the cost per kilogram of yields is lower (Engle et al 2017; Zhou & Hanson 2017; Filipski & Belton 2018). Tantu (2020) argued that an optimal stocking density enables a maximum response to shrimp survival since it involves space use competition, feed competition, and individual contact opportunities related to cannibalism and pathogen distribution. Nevertheless, some production inputs are relatively similar in number at different stocking densities, namely pesticides, fuel, and labor.

Conclusions. Factors that have a significant effect on vannamei shrimp (*Litopenaeus vannamei*) production are the amount of feed, the amount of fertilizer, the amount of lime, and the total organic matter. Factors that significantly affect net returns are yields and pond bottom cover. The stocking density that provides the highest net returns is 208 ind m^{-2}. Considering the results of this study, vannamei shrimp farmers are suggested to use a stocking density of 208 ind m^{-2} to pursue sustainable and cost-effective shrimp culture practices. Government support in providing credit or loans to shrimp farmers is needed to promote further development of vannamei shrimp farming.

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

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