The sustainability of the financial and environmental aspects of whiteleg shrimp (*Penaeus vannamei*) production

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Abstract. In the last decade, whiteleg shrimp (*Penaeus vannamei*) farming has developed rapidly in Indonesia. As a result, the products have made a relatively large contribution to the value of aquaculture production. However, this activity has had a negative impact on the environment, namely producing waste or pollutants, which will affect the sustainability of farming. The aim of this study is to analyze the impact of whiteleg shrimp production inputs on output (yields), income and environmental aspects, and simulating the use of production inputs that generate the highest income, but produce waste and pollutants according to recommendations. The study was conducted in Kolaka Regency, Southeast Sulawesi Province for 4 months, namely May to August 2024. The study population was 70 whiteleg shrimp cultivators who successfully harvested during the May-August production period. Sample determination was carried out by census. The data collected includes: financial aspects and environmental aspects in whiteleg shrimp farming. The data collection method was carried out by interviews, recording, observation and measurement. The collected data was analyzed using an econometric approach with simultaneous system equations. Estimation of model parameters was carried out using Two Least Squares (2SLS). The study results show that stocking density has a positive and significant effect on the amount of feed used. Furthermore, the amount of feed has a positive and significant effect on output, revenue and income from whiteleg shrimp farming. The amount of feed also had a positive and significant effect on the number of *Vibrio* spp. bacteria, but did not have a significant effect on total ammonia nitrogen (TAN). The production inputs that generate the highest income and produce TAN and *Vibrio* spp. bacteria in the recommended range or within water quality standard values is are comprised by a stocking density of 208 ind m^{-2}, with a probiotic amount of 327 liters ha^{-1}, and 55 units ha^{-1} of aeration points.

Key Words: environmental aspects, financial aspects, stocking density, sustainability, whiteleg shrimp.

Introduction. Whiteleg shrimp (*Penaeus vannamei*) is one of the leading commodities in the fisheries sector in Indonesia. In 2021, Indonesia's whiteleg shrimp production was 768.8 thousand tons with a value of 3060.74 million USD (Central Statistics Agency 2022a). Whiteleg shrimp production contributes 5% to the volume of national aquaculture production. However, in terms of production value, whiteleg shrimp can contribute 25% of the value of national aquaculture products (KKP 2022). This shows that whiteleg shrimp is a commodity with high economic value (Rimmer et al 2013; Fitri & Septiadi 2023).

In the last decade, whiteleg shrimp farming has spread throughout Indonesia (Yustianti et al 2013). This is because whiteleg shrimp have several advantages compared to other aquaculture commodities. Whiteleg shrimp have a wide market share, can be marketed in small or medium sizes as an export commodity, are responsive to feed, resistant to disease, and have high productivity (Fitri & Septiadi 2023). In addition, whiteleg shrimp are more tolerant of salinity and more efficient in land use (Briggs et al 2004; Erlangga 2012; Engle et al 2017; Nguyen et al 2019; Riani et al 2023).

One of the development areas for whiteleg shrimp farming in Indonesia is Southeast Sulawesi Province. In 2020, whiteleg shrimp production in Southeast Sulawesi Province was 83.728 tons (Central Statistics Agency 2022b). This amount of production comes from ponds located in 14 districts (Lestari et al 2023). The farming technology applied is formed by traditional, semi-intensive and intensive systems (Riani et al 2023). The application of whiteleg shrimp farming technology will have an impact on the financial aspects of the business and the farming environment (Fitri & Septiadi 2023).

Like other producers, the aim of farmers cultivating whiteleg shrimp is to obtain maximum income. This goal can be achieved by implementing an intensive farming system, namely by increasing the use of production inputs. However, implementing an intensive farming system will produce waste or pollutants which can reduce the carrying capacity of the environment (Chevakidagarn & Danteravanich 2017; Mohanty et al 2018; Samadan 2018; Arambul-Muñoz et al 2019; Hidayat et al 2019; Tantu et al 2020). Furthermore, this will reduce the productivity of whiteleg shrimp farming and be the main cause of failure in whiteleg shrimp farming (Heenatigala & Fernando 2016; Venkateswarlu et al 2019; Dauda et al 2019).

The main waste produced in whiteleg shrimp farming is organic material. A more intensive cultivation of whiteleg shrimp will increase the organic material produced (Chevakidagarn & Danteravanich 2017; Mohanty et al 2018; Samadan 2018). Under anaerobic conditions, decomposition of organic material produces total ammonia nitrogen (TAN). Likewise, the build-up of organic material also causes the development of *Vibrio* spp. bacteria, which causes disease in shrimp. Ammonia and *Vibrio* spp. are is the main cause of failure in the whiteleg shrimp farming business (Nur et al 2020; Mulyadi & Iba 2020).

Based on this description, it can be said that achieving production goals in whiteleg shrimp farming can have an impact on reducing the environmental carrying capacity. In this case, the increasing use of production inputs, especially fry and feed, will produce waste and pollutants. Furthermore, in the long term, this can reduce productivity and income from whiteleg shrimp farming. Thus, the question arises: what is the impact of increasing the use of production inputs on the financial and environmental aspects of whiteleg shrimp farming. Therefore, the purpose of this study is to analyze the impact of production inputs on financial and environmental aspects, and to simulate the use of production inputs that generate the highest income, but produce waste and pollutants according to recommendations.

Material and Method

Time, location and population. The study was conducted in Kolaka Regency, Southeast Sulawesi Province, Indonesia in May-August 2024. The study location was determined purposively, taking into account that Kolaka Regency is the largest producer of white shrimp in Southeast Sulawesi Province. The population in this study are whiteleg shrimp cultivators, who successfully harvested in the March–June 2024 production period. The total population is 70 farmers. Determination of samples or respondents was carried out by census, so that the number of respondents was 70 farmers.

Data types and sources. The types of data collected included: the number of production inputs used (pond area, fry, feed, fertilizer, working hours, probiotics, aeration points, plastic mulch), frequency of changing pond water, duration of cultivation, duration of resting phase and farming system (intensive/semi-intensive), production, variable costs, price of whiteleg shrimp, revenue and income from whiteleg shrimp farming. These data were obtained from the farmers. Other data, namely: temperature, salinity, pH, dissolved oxygen (DO), depth of pond water, rainfall, mangrove area, and pollutants (total ammonia nitrogen – TAN; *Vibrio* spp. bacteria) produced from whiteleg shrimp farming, obtained from the study location. Specifically, rainfall data was obtained from the Kolaka Regency Central Statistics Agency.

Data collection method. Data collection from respondents (farmers) was carried out using the interview method. Meanwhile, data collection from the field and related agencies was carried out using measurement and documentation or recording methods. The area of mangroves and ponds was measured using Google Earth, being then drawn in a map. Temperature and salinity were measured directly in each pond plot.

Temperature and salinity measurements were carried out 8 (eight) times during the cultivation period. The instruments used were thermometers and refractometers. Meanwhile, data on DO, pH, total organic matter (TOM), TAN, and total *Vibrio* spp. bacteria were obtained by carrying out laboratory analysis.

Laboratory analyses began with sampling in each pond plot (three times), namely at the beginning, middle, and end of cultivation. Each water sampling was carried out at 05.30-07.00 AM with a total sample of 70 units. Water samples were collected using a 500 mL sterile container. Aquatic bacteria samples were stored in a cool box containing ice cubes and then analyzed at the Kolaka Mandiri Laboratory. DO and water pH were measured using the titration method with the DO meter and pH meter. TOM and TAN measurements were carried out using a spectrophotometer and an ammonia meter. The measurement of *Vibrio* bacteria used the total plate count (TPC) method.

Data analysis. To achieve the study objectives, an econometric model approach with simultaneous system equations was used. The use of simultaneous system equations is due to the existence of a two-way relationship between endogenous variables (Koutsoyiannis 1982). Random or fixed effect tests on the data were not carried out because it was assumed that the data used included pooled data.

The econometric model with simultaneous system equations used in this study was specified based on the hypothesis that the number of fry used in whiteleg shrimp farming will influence the amount of feed used. Furthermore, the number of fry and feed (production input) will influence the amount of production, costs, revenue and income (financial aspects). In the environmental aspect, the number of fry and feed will produce TAN and *Vibrio* spp. bacteria, which are pollutants in whiteleg shrimp farming. These pollutants will affect the sustainability of farming. Thus, the econometric model specifications regarding the sustainability of whiteleg shrimp farming are as follows:
Structural equations:

$$Af = a_0 + a_1\,Nf + a_2\,Mt + a_3\,Dvit + \mu$$

$$Qv = b_0 + b_1\,Wp + b_2\,Af + b_3\,Wh + b_4\,Dpin + b_5\,TOM + b_6\,Rf + b_7\,Ma + \mu$$

$$Cv = c_0 + c_1\,Qv + c_2\,Dcs + \mu$$

$$\begin{aligned}TAN = {} & g_0 + g_1\,Af + g_2\,Ncl + g_3\,Npin + g_4\,Npr + g_5\,pH + g_6\,DO + g_7\,Sal + g_8\,Tem + \\ & g_9\,Wd + g_{10}\,Dpb + g_{11}\,Fcw + g_{12}\,Rph + g_{13}\,Rf + g_{14}\,Ma + \mu\end{aligned}$$

$$\begin{aligned}Nbv = {} & h_0 + h_1\,Af + h_2\,Nfer + h_3\,Ncl + h_4\,Npin + h_5\,Npr + h_6\,Sal + h_7\,Tem + h_8\,Fcw + \\ & h_9\,Dpb + h_{10}\,Rf + h_{11}\,Ma + \mu\end{aligned}$$

Identity equation:

$$Rv = Qv\ .\ Pv$$

$$Iv = Rv - Cv$$

Where: Af - amount of feed (kg ha^{-1}); Nf - stocking density (individuals m^{-2}); Mt - duration of cultivation (days); Dvit - dummy of supplement (using supplement = 1, not using = 0); Qv - output (yields) (kg ha^{-1}); Wp - pond size (ha); Wh - working hours (hours ha^{-1}); Dpin - dummy of aeration points (using a aeration points = 1, not using = 0); TOM - total organic matter (ppm); Rf - rainfall (mm); Ma - mangrove area (ha); Cv - variable costs (USD ha^{-1}); Dcs - dummy of cultivation system (intensive = 1, extensive = 0); Rv - revenue (USD ha^{-1}); Pv - price of whiteleg shrimp (USD ha^{-1}); Iv - income (USD ha^{-1}); TAN - total ammonia nitrogen (ppm); Ncl - amount of lime (kg ha^{-1}); Npin - number of mills (units); Npr - number of probiotics (liter ha^{-1}); pH - degree of acidity; DO - dissolved oxygen (ppm); Sal - salinity (ppt); Tem - temperature (^{0}C); Wd - depth of pond water (cm); Fcw - frequency of changing pond water (times); Dpb - dummy of pond bottom cover (plastic = 1, non-plastic = 0); Rph - duration of the resting phase (days); Nbv - number of *Vibrio* spp. bacteria (cell ml^{-1}); Nfer - amount of fertilizer (kg ha^{-1}).

Model identification is determined based on the order condition as a necessary condition and the rank condition as a sufficient condition. According to Koutsoyiannis (1982), the identification results for each structural equation must be exactly identified or over identified to be able to estimate its parameters. The sufficiency requirement is stated in the rank condition for identification, which states that in an equation, it is identified if and only if it is possible to form at least one nonzero determinant of order (G-1) from the structural parameters of the variables that are not included in the equation.

The model includes: 2 identity equations and 5 structural equations (G), consisting of: 29 variables (K), as well as between 2 and 14 variables in an equation (M]; so that K - M = 15 and G - 1 = 4, then (K – M) > (G – 1). Therefore, based on the order condition criteria, the equation is declared over identified, so that the parameters can be estimated with the Two Stage Least Squares (2SLS) method.

Furthermore, the simulation was conducted considering that the use of whiteleg shrimp farming production inputs at the time of the study had produced output and income with profitable criteria, but produced waste or pollutants exceeding the recommended limits. In addition, the simulation also considered the recommended stocking density and maximum stocking density applied by farmers during the study. Thus, the simulation consists of I: constant stocking density, increasing the number of aeration points and probiotics; II: increasing stocking density according to recommendations, increasing the number of aeration points and probiotics; III: increasing stocking density equal to the maximum stocking density applied by the farmer, increasing the number of aeration points and probiotics.

Results and Discussion

Financial aspects of whiteleg shrimp farming. In addition to natural resource production factors, whiteleg shrimp cultivation requires production inputs in the form of: land/ponds, labor, fry, feed, lime and fertilizer. However, farmers also often add production inputs: supplements, probiotics, aeration points and others. To achieve production goals, namely maximizing income per unit area of ponds, farmers increase the use of production inputs, especially fry. However, increasing the use of fry will be followed by an increase in the number of other production inputs. The activity of increasing the use of production inputs is usually called intensification.

Available production inputs are allocated in the production process to produce output. Furthermore, the output is sold in the market to generate revenue. After deducting production costs, revenue generates income. The financial aspects of whiteleg shrimp farming in Kolaka Regency, Southeast Sulawesi Province are presented in Table 1.

Table 1

Financial aspects of whiteleg shrimp farming in Kolaka Regency

No	*Variables*	*Range*	*Average*
1	Production input		
	Pond size (ha)	0.12–3	0.78
	Number of fry (ind ha^{-2})	10000-2083300	327513.12
	Stocking density (ind ha^{-2})	1–208.33	33.23
	Amount of feed (kg ha^{-1})	50–83333	11364.34
	Amount of fertilizer (kg ha^{-1})	67–41061	1162.7
	Amount of lime (kg ha^{-1})	25-20000	3367.54
	Number of probiotics (L ha^{-1})	0–200	43.93
	Number of aeration points (units ha^{-1})	0–67	9.98
	Number of workers (people)	1-25	4.28
2	Output (yields) (kg ha^{-1})	75-28124	3829.7
3	Cost (USD ha^{-1})		
	Cost of purchasing fry (USD ha^{-1})	61.35–7413.09	1138.27
	Cost of purchasing feed (USD ha^{-1})	3.07–36809.82	5291.30
	Total variable costs (USD ha^{-1})	136.35–66315.68	8340.84
4	Revenue (USD ha^{-1})	234.66–151073.62	18348.29
5	Income (USD ha^{-1})	31.35–113851.35	10007.45

The average stocking density at the research location was in the moderate criteria (33.23 ind m^{-2}). This stocking density produced an average production of 3772.6 kg ha^{-1} (Table 1), higher than what was observed by Junda et al (2018), with an average stocking density of 52.4 ind m^{-2}, with a production of 2426 kg ha^{-1}. However, it is lower than the research results of Mohanty et al (2018), with an average stocking density of 50 ind m^{-2}, producing an average production of 10286.7 kg ha^{-1}.

The average survival rate for fry until harvest was 46.17% (mortality rate was 53.83%). In addition to being influenced by the survival rate, whiteleg shrimp production is also influenced by stocking density (Fuady & Nitisupardjo 2013; Utami et al 2014; Navghan et al 2015; Triyatmo et al 2016; Cheal et al 2017; Jescovitch et al 2018; Junda 2018; Dauda et al 2019; Xie et al 2019). The largest production input value in whiteleg shrimp farming is for feed. The cost of purchasing feed reached 63.44% of the total variable costs. If added to the cost of fry, the cost of purchasing the two inputs reaches 77.09%. The remainder (22.1%) is allocated for labor costs, fuel, electricity, fertilizers, pesticides, lime, probiotics and supplements.

The size of the product determines the amount of whiteleg shrimp per unit weight. The larger the product size, the less the amount of white shrimp per unit weight, and vice versa. Every 1 kg of whiteleg shrimp contains around 29–150 individuals. In addition to determining the weight, the size of the product also determines the price of whiteleg shrimp. The larger the size of the product, the more expensive the whiteleg shrimp. Based on the size of the product, the price of whiteleg shrimp ranges from 1.84 - USD 6.75 kg^{-1}. Table 1 shows that the average income from whiteleg shrimp farming is 10007.45 USD ha^{-1}, with a stocking density of 33.23 ind m^{-2}. This income is higher than the results of the study by Sutra et al (2018), with a stocking density range of 28-32 ind m^{-2}, resulting in an income of 1884.22 USD ha^{-1}, but lower than the results of the study by Mohanty et al (2018), with a stocking density of 40 ind m^{-2}, resulting in an income of 18378.32 USD ha^{-1}.

Environmental aspects of whiteleg shrimp farming. One environmental aspect that determines the success of whiteleg shrimp farming is the quality of pond water. Pond water quality elements that influence the survival, growth and production of whiteleg shrimp are temperature, pH, salinity, DO, alkalinity, hardness, nitrite, ammonia and disease-causing bacteria (Kordi & Tancung 2005; Pirzan & Utojo 2013; Utami et al 2014; Chakravarty et al 2016; Jaganmohan & Kumari 2018; Abdelrahman et al 2019). The elements of water quality in whiteleg shrimp ponds in Kolaka Regency, Southeast Sulawesi Province are presented in Table 2.

Table 2

Elements of water quality in whiteleg shrimp ponds in Kolaka Regency

No	*Water quality elements*	*Average*	*Farm laboratory standards*	*Quality standards for shrimp farming waste*
1	Water depth (cm)	79.14	60–260	-
2	Water brightness (cm)	7.89	-	-
3	Temperature (°C)	26.24	27–31	-
4	Salinity (ppt)	25.84	9-40	-
5	pH	8.38	7.5-8.5	-
6	Alkalinity (ppm)	96.65	120-150	-
7	Hardness (ppm)	5717.66	≥2500	-
8	DO (ppm)	3.76	≥4	-
9	TOM (ppm)	98.07	<90	-
10	NO_2 (ppm)	0.12	≤0.1	<2.5
11	TAN (ppm)	0.39	<0.2	<0.10
12	*Vibrio spp*. (cell mL^{-1})	894.86	$<3x10^3$	<102

Note: DO – dissolved oxygen; TOM – total organic matter; TAN – total ammonia nitrogen.

The results of laboratory measurements and analysis in Table 2 show that, in general, pond water quality parameters are in a range that is in accordance with the standards set in whiteleg shrimp farming. However, several elements, namely TOM and NO_2 values, exceeded the recommended limits for whiteleg shrimp farming. Likewise, the value of

TAN and the number of *Vibrio* spp. bacteria also crossed the threshold for discharging shrimp farming wastewater into public waters. The value of water quality elements that exceeded the recommended limits for farming and the threshold for quality standards for waste discharge will cause the unsustainability of whiteleg shrimp farming.

Impact of production inputs on financial and environmental aspects. The results of estimating the model parameter of the impact of production inputs on financial and environmental aspects in whiteleg shrimp cultivation show that around 80% or 4 structural equations have a coefficient of determination value of more than 0.7, and only 20% or 1 structural equation had a coefficient of determination value of less than 0.5 (Table 3). Thus, in general, it can be said that the explanatory variables in the equation are able to explain the endogenous variables well.

Table 3
Results of structural equation parameter estimation for financial and environmental aspects of whiteleg shrimp farming in Kolaka Regency

No	*Variables*	*Parameter*	*t_{-value}*	*Prob. t*	*F-$_{value}$*	*R-square*
	Financial aspect:					
1	*Amount of feed*				227.97	0.93538
	Intercept	-5935.21	-2.37	0,0206		
	Stocking density	3.793651	17.86	<0.0001		
	Duration of cultivation	7.982384	2.06	0.0435		
	Dummy of supplement	-2915.4	-1.27	0.2086		
2	*Output (yields)*				82.52	0.92525
	Intercept	7641	2.35	0.0219		
	Pond size	863.97	1.5	0.1378		
	Amount of feed	0.235934	3.57	0.0007		
	Number of working hours	3.045	2.03	0.0465		
	Dummy of aeration points	1850	1.46	0.1499		
	Total Organic Matter (TOM)	-10.471	-1	0.3237		
	Rainfall	-82.410	-2.36	0.0216		
	Mangrove area	11.638	1.58	0.1203		
3	*Variable costs*				345.76	0.91167
	Intercept	-2047273	-0.21	0.8327		
	Output (yields)	26211.74	12.53	<0.0001		
	Dummy of cultivation system	1.15E+12	3.94	0.0002		
	Environmental aspects:					
4	*Total Ammonia Nitrogen (TAN)*				2.08	0.4229
	Intercept	2.747708	1.27	0.2099		
	Amount of feed	0.000011	1.47	0.1476		
	Amount of lime	-8.5E-06	-0.47	0.6392		
	Number of aeration points	-0.01895	-1.56	0.125		
	Number of probiotics	0.003341	1.04	0.3053		
	Degree of acidity (pH)	-0.29771	-1.67	0.1008		
	Dissolved Oxygen (DO)	-0.0319	-1.09	0.279		
	Salinity	-0.01921	-2.21	0.0319		
	Temperature	0.000163	0.01	0.9939		
	Water depth	0.001254	0.17	0.8631		
	Dummy of pond bottom cover	-0.20875	-0.37	0.7109		
	Water change frequency	0.026474	0.9	0.3698		
	Duration of the resting phase	-0.1732	-1.09	0.2803		
	Rainfall	0.009163	1.44	0.1574		
	Mangrove area	0.002221	1.54	0.1292		
5	*Number of Vibrio spp.*				11.07	0.73815
	Intercept	5683.19	1.83	0.073		
	Amount of feed	0.065846	2.57	0.0128		
	Amount of fertilizer	0.085786	2.76	0.0079		
	Amount of lime	-0.31106	-5.06	<.0001		
	Number of aeration points	-36.1937	-0.93	0.3559		
	Number of probiotics	-12.4357	-2.28	0.0268		
	Salinity	-11.965	-0.4	0.6915		
	Temperature	-76.8888	-1.02	0.3109		
	Water change frequency	-79.9081	-0.79	0.4338		
	Dummy of pond bottom cover	7407.026	4.1	0.0001		
	Rainfall	-33.463	-1.85	0.0699		
	Mangrove area	-0.5615	-0.13	0.8978		

The F statistical value ranges from 2.08 to 345.76 with a prob. value F<0.0001 (Table 3), which means that the variations in the explanatory variables in each behavioral equation are jointly able to explain the variations in the endogenous variables well, at the level $\alpha=0.05$. In addition, each structural equation mostly has parameter quantities and signs in accordance with the criteria of economic and environmental theory. Several explanatory variables whose estimated parameters do not match expectations (economic and environmental theory) can be explained logically and in accordance with conditions in the field. The results of the t statistical test show that there are several explanatory variables that have no significant effect on the endogenous variables at the $\alpha=0.05$ or 0.1 level.

Table 3 shows that the stocking density and duration of cultivation have a positive and significant effect on the amount of feed. This means that the higher the stocking density and the longer the cultivation, the amount of feed used also increases. The dummy variable of probiotic use had a negative and no significant effect on the amount of feed. This is thought to be because probiotics only function as a catalyst to increase feed nutrition, not as a substitute for artificial feed.

The amount of feed and number of working hours have a significant effect and provide a positive response to output. Meanwhile, rainfall has a negative and significant effect, which means that the higher the rainfall, the lower the whiteleg shrimp production will be. Rainfall can quickly change the temperature, salinity, pH and DO in pond water, causing growth hampering of whiteleg shrimp. Variables that do not have a significant effect on output are pond size, dummy of aeration points, TOM, and mangrove area.

Furthermore, the amount of feed had a positive but not significant effect on the amount of TAN. Other variables that had no significant effect on the amount of TAN are the amount of lime, aeration points, probiotics, pH, DO, temperature, water depth, dummy of pond bottom cover, frequency of changing pond water, duration of the resting phase, rainfall, and mangrove area. The only variable that had a significant effect on the amount of TAN was salinity. However, the effect was negative, meaning the higher the salinity, the lower the amount of TAN. This is in accordance with a study conducted by Zafar et al (2015), which concluded that in whiteleg shrimp cultivation, salinity is significantly correlated with ammonia in the rainy season.

The amount of feed gave a positive and significant response to the number of *Vibrio* spp. bacteria. In addition to the amount of feed, other variables that gave a positive and significant response to the number of *Vibrio* spp. bacteria were the amount of fertilizer and dummy of pond bottom cover. This means that the higher the amount of feed and fertilizer used in whiteleg shrimp cultivation, the production of *Vibrio* spp. bacteria increases. The variables that gave a negative and significant response were the amount of lime, probiotics, and rainfall. Thus, it can be interpreted that the higher the amount of lime and probiotics used and the higher the rainfall, the production of *Vibrio* spp. bacteria decreases. The variables that had no significant effect on the number of *Vibrio* spp. bacteria are the number of aeration points, salinity, temperature, frequency of pond water changes, and mangrove area.

The use of production inputs that generate the highest income, but produce pollutants according to recommendations. The results of the simultaneous equation parameter estimation show that stocking density has a significant effect on the amount of feed. Furthermore, the amount of feed has a significant effect on the production and income of whiteleg shrimp cultivation. The amount of feed also has a positive and significant effect on the number of *Vibrio* spp. bacteria. Probiotics have a negative and significant effect on the number of *Vibrio* spp. bacteria. Based on this, a simulation was carried out on the use of production inputs (fry, aeration points, and probiotics) that can generate the highest income, but the waste or pollutants produced are still at the recommended quality standards.

The stocking density that is often recommended for intensive and semi-intensive whiteleg shrimp farming is 100 ind m^{-2}. With this stocking density, the recommended number of aeration points is 33 units ha^{-1} (Regulation of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia Number 75 of 2016). Engle et al (2017) concluded that the number of aeration points for intensive ponds with a stocking density of 80-100 ind m^{-2} is 28 units ha^{-1}. Suwoyo et al (2018) stated that the number of aeration points of 140 units produced better water quality for DO, nitrite, total nitrogen, phosphate, and higher whiteleg shrimp production compared to the basic aeration points of 70 units.

As recommended, in this study, simulations were carried out, namely I: constant stocking density (33.23 ind m^{-2}), increasing the number of aeration points by 60% and probiotics by 100%; II: increasing stocking density by 201% (100 ind m^{-2}), aeration points by 330% (33 units ha^{-1}) and probiotics by 398% (175 L ha^{-1}); III: increasing stocking density by 526% (208 ind m^{-2}), aeration points by 551% (55 units ha^{-1}) and probiotics by 744% (327 L ha^{-1}). The results of the simulation of increasing the stocking density, the number of aeration points and probiotics in whiteleg shrimp farming are presented in Table 4.

Table 4

Simulation results of increasing stocking density, number of aeration points and probiotics in whiteleg shrimp farming in Kolaka Regency

No	*Variables*	*Actual mean*	*Predicted mean*	*Difference*	*Percentage change (%)*
1	Simulation I: constant stocking density, increase in the number of aeration points by 60% and probiotics by 100%				
	Amount of feed (kg ha^{-1})	11351.2	11351	0.00	0
	Output (yields) (kg ha^{-1})	3772.6	3773	0.00	0
	Variable costs (USD ha^{-1})	8052.15	8268.10	215.95	2.68
	Revenue (USD ha^{-1})	17472.39	17472.39	0.00	0
	Income (USD ha^{-1})	9419.63	9268.03	(215.95)	(2.29)
	TAN (ppm)	0.36	0.1	(0.26)	(72.22)
	Number of *Vibrio* spp. (cell mL^{-1})	863.4	101	(762.90)	(88.36)
2	Simulation II: increasing stocking density by 201%, number of aeration points by 330% and probiotics by 398%				
	Amount of feed (kg ha^{-1})	11351.2	11884.18	532.98	4.7
	Output (yields) (kg ha^{-1})	3772.6	9823	6050.40	160.38
	Variable costs (USD ha^{-1})	8052.15	9104.42	1052.27	13.07
	Revenue (USD ha^{-1})	17472.39	47062.51	29590.11	169.35
	Income (USD ha^{-1})	9419.63	37958.09	28538.46	302.97
	TAN (ppm)	0.36	0.09	(0.27)	(75)
	Vibrio spp. (cell mL^{-1})	863.4	97.21	(766.19)	(88.74)
3	Simulation III: increase in stocking density by 526%, number of aeration points by 551%, and probiotics by 744%				
	Amount of feed (kg ha^{-1})	11351.2	12746.28	1395.08	12.29
	Output (yields) (kg ha^{-1})	3772.6	19479	15706.40	416.33
	Variable costs (USD ha^{-1})	8052.15	12996.61	4944.47	61.41
	Revenue (USD ha^{-1})	17472.39	93324.91	75852.51	434.13
	Income (USD ha^{-1})	9419.63	80328.29	70908.66	752.78
	TAN (ppm)	0.36	0.10	(0.26)	(72.22)
	Vibrio spp. (cell mL^{-1})	863.4	98.06	(765.34)	(88.64)

The simulation results showed that by applying a constant stocking density, but increasing the number of aeration points and probiotics, the values of TAN and *Vibrio* spp. bacteria can be reduced at the wastewater quality standard limit, but also reducing the income (Table 4). Furthermore, simulation by increasing stocking density, number of aeration points and probiotics can increase income and reduce the number of TAN and *Vibrio* spp. bacteria at the wastewater quality standard limit. The simulation that produced the highest income and produced pollutants according to recommendations was by increasing the stocking density by 526% (208 ind m^{-2}), the number of aeration points by 551% (55 units ha^{-1}) and probiotics by 744% (327 L ha^{-1}).

The purpose of whiteleg shrimp farming is to obtain the highest income and sustainable production. To achieve these goals, farmers must allocate production inputs optimally. The optimum allocation of production inputs is the allocation of inputs that create maximum income or profit and produce pollutants according to recommendations. Thus, when viewed from the financial aspect and the technical aspect (environment), whiteleg shrimp farming is in the sustainable criteria.

The results of structural equation parameter estimation show that fry stocking density has a positive and significant effect on the amount of feed. Furthermore, the amount of feed has a positive and significant effect on production, and production has an effect on costs, revenues and income. On the other hand, the amount of feed has a positive, but not significant effect on the amount of TAN, but the amount of feed has a positive and significant effect to the number of *Vibrio* spp. bacteria. Thus, if the simulation is carried out only by increasing the stocking density, it will not only have an impact on increasing production and income, but will also have an impact on increasing the number of *Vibrio* spp. and TAN (Chevakidagarn & Danteravanich 2017; Hai et al 2018; Mohanty et al 2018; Samadan 2018; Arambul-Muñoz et al 2019; Tantu et al 2020), as well as on the number of *Vibrio* spp. (Supriatna et al 2017; Ariadi et al 2019). This means that financially, increasing stocking density can make whiteleg shrimp farming sustainable, but not environmentally sustainable. Therefore, simulations need to be carried out to reduce the values of TAN and *Vibrio* spp. bacteria.

Based on the results of parameter estimation, the variables that can reduce the number of TAN and *Vibrio* spp. bacteria are aeration points and probiotics. Thus, increasing stocking density accompanied by increasing the number of probiotics can reduce the number of *Vibrio* spp. (Wulandari et al 2013; Devaraja et al 2013; Anjasmara et al 2018; Widigdo et al 2021). Probiotics can reduce ammonia concentrations in pond water (Wulandari et al 2013; Devaraja et al 2013; Yuvaraj & Karthik 2015; Supono 2018; Truong et al 2021). Ammonia can cause the growth of disease-causing microbes such as *Vibrio* spp. bacteria (Cao 2012; Zafar et al 2015; Ariadi et al 2019). Thus, probiotics can prevent the growth of *Vibrio* spp. bacteria in pond water. Husaeni & Sudarmayasa (2018) stated that giving probiotics after the shrimp were 10-15 days old with a frequency of once every three days during maintenance showed stable growth where the average initial stocking weight of 0.004 g increased to 8.41 g at the end of the activity with a bacterial density ranging from 103 to 104 CFU mL^{-1}.

Likewise, the addition of aeration points along with the increase of stocking density can reduce the TAN value and *Vibrio* spp. bacteria. This is because the formation of TAN in ponds is caused by anaerobic conditions at the bottom of the pond. Anaerobic conditions will trigger the formation of TAN due to the decomposition of organic material at the bottom of the pond. Ammonia in ponds can cause the growth of *Vibrio* spp. bacteria. Therefore, efforts can be made to prevent the formation of TAN and the growth of *Vibrio* spp. bacteria, such as the supply of DO using a water wheel. Using a waterwheel will increase the availability of oxygen and help the stirring process, preventing the formation of toxic ammonia in pond water (Supono 2018; Suhendar et al 2020).

The simulation was continued by increasing the stocking density, the number of aeration points and probiotics. The simulation results by increasing the stocking density by 201%, the number of aeration points by 330% and probiotics by 398% (simulation based on recommendations) produced an output of 9.823 kg ha^{-1}, income of 37958.09 USD ha^{-1}, and produced waste or pollutants with values lower than the standard quality threshold. The output generated from this simulation was lower when compared to the research results of Wijayanto et al (2017) with a stocking density of 100 ind m^{-2} producing 10875.6-13586.2 kg ha^{-1}. However, the income from the simulation results is higher, 37958.09 USD ha^{-1} compared to 9955.68-12436.99 USD per ha^{-1}. This is thought to be due to the increase in the price of whiteleg shrimp products. When compared to the research results of Clark et al (2010), the production and income from the simulation results are lower, namely 16667 kg ha^{-1} and income of 314096.89 USD ha^{-1}, with a stocking density of 100 ind m^{-2}.

The simulation was continued by increasing the stocking density by 526% (208 ind m^{-2}: based on the highest stocking density applied by respondents), increasing the number of aeration points by 551% and probiotics by 744%. The simulation results produced water quality (the values of TAN and *Vibrio* spp. bacteria) within the recommended range. From a financial aspect, the simulation produced 19479 kg ha^{-1}, with an income of 70908.66 USD ha^{-1}. This production is higher compared to the results of de Barros et al (2014), where in a stocking density of 208 ind m^{-2} there was a production of 7169 kg ha^{-1}.

Conclusions. Stocking density has a positive and significant effect on the amount of feed used. Furthermore, the amount of feed has a positive and significant effect on output (yields), revenue and income in whiteleg shrimp farming. The amount of feed also had a positive and significant effect on the number of *Vibrio* spp. bacteria, but did not have a significant effect on TAN. The production inputs that generate the highest income and produce TAN and *Vibrio* spp. bacteria in the recommended range or within water quality standard values is obtained by implementing a stocking density of 208 ind m^{-2}, with a probiotic amount of 327 L ha^{-1}, and 55 units ha^{-1} aeration points.

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