Profit maximization of whiteleg shrimp (*Litopenaeus vannamei*) intensive culture in Situbondo Regency, Indonesia

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Abstract. Shrimp is one of the major commodities of aquaculture in Indonesia. The culture of whiteleg shrimp (*Litopenaeus vannamei*) in Indonesia has an important role in economic growth, employment and welfare of coastal communities in Indonesia, including Situbondo Regency. This research purpose was to estimate the maximal profit at the intensive culture of whiteleg shrimp in Situbondo Regency, Indonesia. Our research model used polynomial growth model and profit maximization to estimate the optimal time of whiteleg shrimp culture at the maximal profit. This research model was applied to whiteleg shrimp intensive culture at BPBAP Situbondo, especially at IPU (location unit) of Gelung Village. The profit maximization used the first derivative of profit equation to culture time equal to zero. We used single-price and multi-price in the simulation of research. In the case of our research, the intensive culture of whiteleg shrimp can reach the maximum profit in 159 days (single-price model) or 160 days (multi-price model). But, if we calculate the opportunity cost, so the intensive culture of whiteleg shrimp can make the optimal benefit if use three cycle of culture per year.
Key Words: bioeconomy, *Litopenaeus vannamei,* profit maximization, Situbondo, single-price, multi-price.

Introduction. Shrimp is one of the main products of aquaculture culture in Indonesia. While Situbondo regency is one of shrimp culture centers in Indonesia. According to KKP (2015), shrimp culture production in Indonesia reached 380 972 tons per year in 2010 and increased to 639 369 tons in 2014. Shrimp culture production contributed 4.82% of total culture production in Indonesia, and is third rank in aquaculture production (excluding seaweed culture), with first rank is tilapia (7.08%) and second rank is milkfish (5.17%). The export volume of shrimp from Indonesia was 196 623 tons with export value of USD 2 141 million in 2014. USA and Japan are the main export target countries for shrimp commodities from Indonesia. Shrimp exports from Indonesia to the USA was 107 427 tons (USD 1 284 million) in 2014, and exports to Japan was 33 608 tons (USD 429 million). The above description shows that shrimp culture has an important role in economic growth, employment and welfare of coastal communities, including in Situbondo Regency.

The adults of whiteleg shrimp (*Litopenaeus vannamei*) live in the sea, while the juvenile live in brackish waters. Habitat of whiteleg shrimp is at a depth of 0 to 72 m, with a mud substrate (Holthuis 1980). Shrimp is one of the fisheries commodities that have a high economic value and the price is relatively stable. This is evidenced by research of Sumaila et al (2007) used time series data from 1950 to 2004. Modern shrimp culture in the world began in the 1970s and continued to increase significantly until in the 1990s. Currently shrimp culture business continues to grow, despite the complex problems associated with decreased water quality and increased disease attacks. In 1982, shrimp culture contributed only 5% of the world shrimp production. However, in 2008 shrimp culture production has contributed more than 40% of the world shrimp production (Gillett 2008). The research results of Ye & Beddington (1996) on the bioeconomics of capture and aquaculture interactions showed that if capture and aquaculture have the same market, so aquaculture have an impact prices reductions, increased supply, fishing efforts reductions and increased fish and shrimp stocks in the wild.

In the beginning, the major of shrimp production was supplied from tiger shrimp (*Penaeus monodon*) until 2002, but most shrimp farmers shifted to whiteleg shrimp in 2003. According to Flegel (2009), it was caused by the tiger shrimp get many attacks diseases, including White Spot Syndrome Virus (WSSV) and Yellow Head Virus (YHV). Even the research results of Anshary et al (2017) indicate that broodstock of tiger shrimp obtained from coastal waters of Sulawesi contain several pathogenic viruses, including WSSV, Monodon Baculovirus (MBV), Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV) and Hepatopancreatic Parvovirus (HPV).

The world production of whiteleg shrimp reached 8 000 tons in 1980, and increased to 194 000 tons in 1998. However, the production of whiteleg shrimp in the world declined in 1999 and 2000 because of WSSV attacks in Latin America. Then, the production of whiteleg shrimp have aggressive growth after culture of whiteleg shrimp developed in Asia. *L. vannamei* was introduced to Asia in 1978/1979, especially to the Philippines, and in 1988 to the People's Republic of China (Mainland China). In 1996, *L. vannamei* was introduced into Asia on a commercial scale. It started in Mainland China and Taiwan, and then quickly spread to the Philippines, Indonesia, Vietnam, Thailand, Malaysia and India. Whiteleg shrimp production in the world reached 1 386 000 tons in 2004, with major producers being China, Thailand, Indonesia and Vietnam. In 2005, whiteleg shrimp production in the world reached 1 594 039 tons (first rank), while tiger shrimp of 710 806 tons in the second rank. Shrimp production in the world is estimated at 8 061 thousand tons in 2030 (Gillett 2008; Flegel 2009; World Bank 2013).

There have been several reasons for the introduction of *L. vannamei* or *Penaeus vannamei*, including specific pathogen free (SPF) stocks of *L. vannamei*, WSSV from *P. monodon*, slow growth rate of *P. monodon* and international market of shrimp. But, there are also disadvantages relate to the introduction of *L. vannamei*, including potential to transfer serious pathogens (Funge-Smith et al 2003). But at the present, the culture of whiteleg shrimp is also getting attacks from WSSV, TSV (Taura Syndrome Virus), IHHNV, IMNV (Invectious Myo Necrosis Virus), PvNV (*Penaeus vannamei* nodavirus), ASDD, vibrio, and EMS or Early Mortality Syndrome (Flegel 2009; WWF Indonesia 2014).

In Indonesia, shrimp culture has fluctuated progress. Although shrimp culture is profitable, but shrimp disease is still one of the major problems. The whiteleg shrimp was legally first introduced into Indonesia in 2001 based on the Decree of the Minister of Marine and Fisheries Affairs of the Republic of Indonesia No. 41/2001. The whiteleg shrimp's origin is from the eastern Pacific waters (Holthuis 1980). In practice of shrimp culture, shrimp farmers often use their habit and experience, including the harvest time. There are several kind of shrimp prices that are influenced by harvest size. If there is no disease attack, whiteleg shrimp culture (semi-intensive) is usually harvested after 4 months (WWF Indonesia 2014). Therefore, it is necessary to study the optimal harvest time which is estimated to generate maximum profit by using bioeconomic approach.

The whiteleg shrimp culture (especially in super intensive method) has unique characteristics of high growth diversity. Suwoyo et al (2014) stated that only about 85% of harvested shrimp sizes that have relatively uniform weight. This indicates that the right time will greatly affect the acquisition of uniform shrimp harvest which also means will affect the acquisition of the harvest with the best size and price.

The studies of bioeconomic are more conducted in fisheries compared to aquaculture. However, research of bioeconomic to estimate the optimal time of aquaculture has been conducted by several researchers. Bjorndal (1988), Arnason (1992), Heap (1993), and Mistiaen & Strand (1998) developed the model of profit optimization used the Beverton-Holt growth model. Adams et al (1980), Springborn et al (1992) and Wijayanto (2014) developed the bioeconomic model to aquaculture base on von Bertalanffy fish growth model. Dasgupta et al (2007) conducted a study of profit maximization using linear programming method. Griffin et al (1981) and Shamshak & Anderson (2009) used a stochastic dynamic modeling approach in aquaculture bioeconomic modeling, which fish growth was influenced by salinity, water temperature, feeding rate and FCR. Kazmierczak Jr. & Caffey (1996) conducted a bioeconomic research of recirculating aquaculture systems which fish growth was influenced by fish density, initial weight, time of culture, and daily growth rate. This research model used the polynomial growth model and the profit maximization that developed by Wijayanto et al (2016). This research model has been applied to the catfish culture (Wijayanto et al 2016) and the giant gouramy culture (Wijayanto et al 2017). Our research purpose was to estimate the optimal time of culture to generate the maximal profit of whiteleg shrimp (*L. vannamei*) culture in Situbondo Regency, Indonesia.

Material and Method. This research was conducted from March to July 2017 in BPBAP Situbondo, especially in IPU (location unit) of Gelung Village. The culture time of whiteleg shrimp in IPU of Gelung Village is 90 days. The weight of whiteleg shrimp was be measured on 30^{th}, 40^{th}, 50^{th}, 60^{th}, 70^{th}, 80^{th} and 90^{th} days to get the growth progress of whiteleg shrimp and to calculate feeding requirements.

Shrimp growth model. In this research, we used the whiteleg shrimp growth model following this polynomial equation:

$$Wt = a\,t^2 + b\,t \qquad (1)$$

where: Wt is the size of the shrimp (g) at the age of t days, 'a' and 'b' is the slope.

Costs, revenue and profit. The profit is revenue minus cost. Total revenue (TR) is affected by shrimp price and shrimp biomass. Shrimp biomass is affected by individual shrimp growth and shrimp mortality. While the component of cost includes the cost of seed procurement, labor costs, feed cost, cost of facilities and equipment, energy costs, probiotic cost and chemical costs (including fertilizer). Artificial feed cost in aquaculture is affected by feed conversion ratio (FCR), shrimp biomass progress and price of artificial feed (modified from Wijayanto et al 2016, 2017).

$$\pi = TR - TC \qquad (2)$$
$$TR = Btb.Ps \qquad (3)$$
$$Btb = Wtb.Ntb \qquad (4)$$
$$Ntb = No\text{-}M.tb \qquad (5)$$
$$TR = Wtb.Ps.(No\text{-}M.tb) \qquad (6)$$
$$TC = Cf+Cs+Cl+Cd+Ce+Cp+Cc \qquad (7)$$
$$Cf = Pf.Qf \qquad (8)$$
$$Qf = (Btb\text{-}Bo).FCR \qquad (9)$$
$$Bo = No.Wtbo \qquad (10)$$
$$Cs = Ps.No \qquad (11)$$
$$Cl = Pl.tb \qquad (12)$$
$$Cd = Pd.tb \qquad (13)$$
$$Ce = Pe.tb \qquad (14)$$
$$Cp = Pp.tb \qquad (15)$$
$$tb = t - tbo \qquad (16)$$

Note:

- Π : profit (IDR per cycle) at time of culture (tb);
- tb : time of culture (days);
- tbo : age of the shrimp seed at the beginning of culture (days). We used PL12 as the shrimp seed;
- TR : total revenue (IDR per cycle) at tb;
- Btb : biomass of shrimp at the time tb (g);
- Wtb: shrimp weight (g) at tb;
- Ps : shrimp price (IDR per g);
- Ntb : shrimp population (individual) at tb;
- No : initial population of shrimp (individual);
- M : average mortality of shrimp per day (individual per day);
- TC : total cost (IDR per cycle) at tb;
- Cf : accumulative procurement costs of artificial feed (IDR) at tb;

Cs : seed procurement costs (IDR per cycle);
Cl : accumulative labor costs (IDR) at tb;
Cd : accumulative cost of equipment and buildings depreciation (IDR) at tb;
Pf : feed price (IDR per g);
Qf : accumulative amount of feed utility (g) at tb;
Bo : initial shrimp biomass (g);
Wtbo: initial weight of shrimp seed (g per individual);
FCR : feed conversion ratio;
Pl : labor cost per day (IDR per day);
Pd : depreciation rate of facilities and equipments (IDR per day);
Ce : accumulative cost of energy (IDR) at tb, both electricity cost and diesel fuel cost;
Cp : accumulative cost of probiotic (IDR) at tb;
Pe : average costs of energy (IDR per day), both electricity cost and diesel fuel cost;
Pp : average cost of probiotic (IDR per day);
Cc : cost of chemical materials, including fertilizer, chlorine and lime for preparation of pond.

Profit maximization. First derivative of profit (equation 2) to culture time (tb) equal to zero could be used to estimate the culture time to produce the maximal profit as the first order condition (FOC). Second derivative of profit to culture time equal to negative is the second order condition (SOC). We used this equation to estimate the optimal culture time to generate the maximal profit (modified of Wijayanto et al 2016, 2017):

$$\pi = Btb.Ps - Cf - Cs - Cl - Cd - Ce - Cp - Cc \quad (17)$$

$$\pi = g.tb^3 + h.tb^2 + i.tb + j \quad (18)$$

Note:
g = a.(Pf.FCR.M - Ps.M);
h = Ps.a.No-Ps.b.M+2.Pf.FCR.a.tbo.M-2.Ps.a.tbo.M-Pf.FCR.a.No+Pf.FCR.b.M;
i = 2.Ps.a.tbo.No-Ps.b.tbo.M+Pf.FCR.a.tbo^2.M-Pf.FCR.b.No–Ps.a.tbo^2.M+Ps.b.No-2.Pf.FCR.a.tbo.No+Pf.FCR.b.tbo.M–Pd- Pp–Pl - Pe;
j = Ps.a.tbo^{2}No + Ps.b.tbo.No - Pf.FCR.a.tbo^2.No - Pf.FCR.b.tbo.No + Pf.FCR.Bo-Cb-Cc;

$$\frac{d\pi}{dtb} = 0 = 3.g.tb^2 + 2.h.tb + i \quad (19)$$

Estimation of optimal tb at equation (19) used quadratic equation solution (Rosser 2003).

$$tb_{opt} = \frac{-(2h) - \sqrt{(2h)^2 - 4.(3g).i}}{2.(3.g)} \quad (20)$$

Result and Discussion

Intensive culture of whiteleg shrimp. The intensive culture of whiteleg shrimp in IPU of Gelung Village (BBPAP Situbondo) used a pond made of concrete material covered with high density polyethylene (HDPE) plastic. The source of seawater came from the Madura Strait with a salinity range of 28 to 31 ppt. Sea water was stored in the pond reserve to be precipitated, before being used for the ponds of culture. The source of fresh water came from the well and was stored in the tank tower by using an electric pump. To increase the supply of dissolved oxygen (DO) in the pond, we used a water-wheel. Energy sources used electricity and generators as reserves. Other facilities which were counted as depreciation cost, including buildings, genset, equipments, and transportation facilities. We used 'ancho' to conduct sampling for analysis of shrimp response to feed. Automatic feeder was used at the time of cultivation more than 30 days until the harvest.

In preparation for shrimp culture, the pond was dried to accelerate the oxidation process of toxic materials, such as NH_3, and H_2S. After that, the pond was cleaned using chlorine and then dried for 1 day, then rinsed using fresh water. Once the pond was ready, the seawater was flowed to the ponds reserve, after the reserve ponds were full, then the sea water was sterilized using chlorine. The dose of chlorine was 10 ppm. After sterile seawater, it can be channeled into the pond of culture. Once the water in the pond reaches a height of 150 cm, then water-wheel can be installed.

Liming was done to increase the pH of water, accelerate the decomposition of organic materials and the growth of plankton. We used an agricultural lime. Lime dosage was 5 to 10 ppm. Fertilization was done by using ZA (zwavelzure ammoniak) or ammonium sulfate with a dose of 1 ppm to grow plankton. Cultures of probiotics were made using skim milk, molasses, special lacto and yeasts. Probiotic ingredients were stored in tightly sealed containers and probiotics can be used after 5 days. Probiotics were given in the morning to maintain water quality stability, help shrimp metabolism and minimize harmful pathogenic bacteria and boost beneficial bacteria.

Once the ponds were ready, the shrimp seeds were ready to be stocked in the culture pond. Before the seeds were stocked, it is necessary to acclimatise them for 15 to 30 minutes. The stocked seed had the following requirements: certified, 80% uniformity level, SPR (specific pathogen resistant) or SPF (specific pathogen free), active swim against current, bright colors and had minimum length of 12 mm. We used PL12 as seeds.

The feed used for whiteleg shrimp was adjusted based on the age of the shrimp. For shrimp aged 1 to 10 days, we used powder-shape feed, cremble for shrimp age of 11 to 40 days and then pellet after 40 days. The dosage of feed was calculated based on the sampling rate of 3.5% of the shrimp biomass. Water quality control was routine conducted to monitor the water quality. Pond bottom cleaning (siphon) was done after the shrimp past the blind feeding period (day of culture or DOC 13). After that, pond bottom cleaning was done twice a week. Partial replacement of water was done when the water in pond looks concentrated. Water quality during shrimp culture showed salinity of 15 to 22 ppt, brightness of 50 to 80 cm, pH of 7.5 to 8.5, temperature of 28.5 to 31.5^{o}C, DO of 3.0 to 7.5 ppm, alkalinity of 120 to 160 ppm, nitrite of 0.01 to 0.05 ppm, NH_3 of 01 to 0.05 ppm, H_2S of 0.01 to 0.05, TOM (total organic matter) < 55 ppm and phosphate of 0.1 to 0.25 ppm.

The growth of whiteleg shrimp. We used PL 12 as the seed as many as 170 000 ind for 1 700 m^2. On 30th day, the weight of whiteleg shrimp reached 5 g and continued to grow up to 20 g on 90th day (Figure 1). The specific growth rate (SGR) of whiteleg shrimp was 2.31%. The research results of Khademzadeh & Haghi (2017) show that *L. vannamei* had a specific growth rate of 4.90% per day and the length-weight relationship follows the equation $W = 0.0108\ L^{2.6935}$ (R^2 = 0.8895). According to Holthuis (1980), the maximum total length of whiteleg shrimp is 230 mm and the maximum carapace length is 90 mm. That is, the maximum weight of whiteleg shrimp is estimated to reach 83 g.

In this research, the survival rate (SR) during 90 days of whiteleg shrimp culture was 66% with a initial stock density of 100 ind per m^2. The achieved FCR was 1.4. While the research results of Balakrishnan et al (2011) showed that whiteleg shrimp culture in India (west Godavari district) produced SR at 110 days of 80% to 92% with stock density of 50 to 61 per m^2, and FCR of 1.34 to 1.4. The research results of Mude & Ravuru (2015) on the culture of whiteleg shrimp in winter season with locations in India (Prakasakm district) and a density of 50 ind per m^2 showed that an average weight of 16.5 to 17.5 g reached in 90 to 94 days, and FCR of 1.43 to 1.51. Based on the above description, the growth of whiteleg shrimp is influenced by a combination of several factors, i.e. water quality (including temperature), seed quality, feed quality, feed quantity, and stocking density.

The polynomial shrimp growth model of whiteleg shrimp follow the equation:

$$Wt = 0.0013\ t^2 + 0.0599\ t \qquad (21)$$

$R^2 = 99\%$

Subject to:

$W_t,\ t \geq 0$

$Wt \leq W_{inf}$

In general, fish and shrimp growth have several stages, namely slow growth phase, fast growth phase and decreased growth phase until fish and shrimp reach the infinity weight (Hernandez-Llamas & Ratkowsky 2004). The culture of whiteleg shrimp tends to be done in the rapid growth phase. However, longer culture time have risk of shrimp death is also greater.

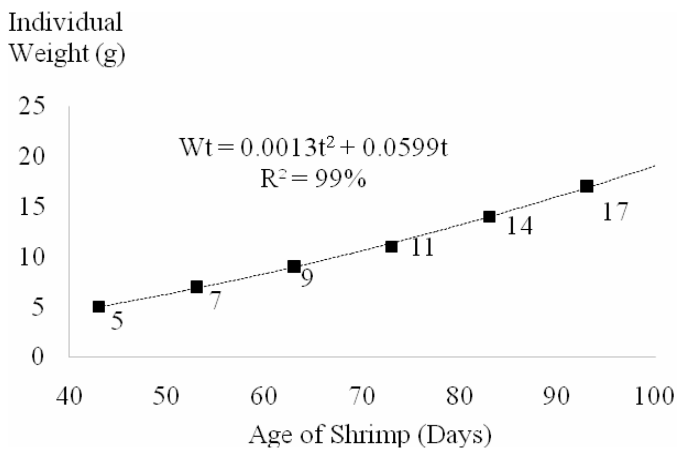


Figure 1. The shrimp growth progress (g). Note: the first age of seed is 12 days.

The profit*.* The profit of whiteleg shrimp culture is the main goal of shrimp farmers. Profits are affected by the price of shrimp, size of the harvested shrimp, total weight of the harvest, and costs, both investment costs, equipments, feeds, seeds, and energy. In estimating the optimal time that generate maximum profit, we use the following data (Table 1).

Table 1

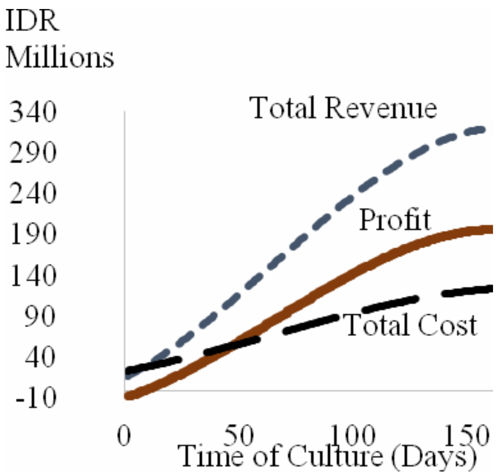
Research assumptions

Assumptions	*Values*
a	0.0013
b	0.0599
Initial age of seed (tbo)	12 days (PL 12)
Number of seed (No) for pond of 1700 m^2	170 000 ind
Average fish mortality (M)	642 ind per day (SR at 90 days of 66%)
Shrimp price (Ps) – single price	IDR. 83 per g[a]
Shrimp price (Ps) – multi price	
Size < 11 g	IDR. 25 per g
20 g > Size ≥ 11 g	IDR. 65 per g
Size ≥ 20 g	IDR. 95 per g
FCR	1.4
Artificial feed price (Pp)	IDR. 15 per g
Seed price (Ps)	IDR. 45 per ind
Facilities and equipment depreciation cost (Pd)	IDR. 57 506 per day per unit of pond [b]
Labor cost (Pl)	IDR 96 617 per day per unit of pond [b]
Average costs of energy (Pe)	IDR 21 301 per day per unit of pond [b]
Average cost of probiotic (Pp)	IDR 38 611 per day per unit of pond [b]
Costs of chemical materials (Cc)	IDR 6 900 000 per cycle per unit of pond [b]

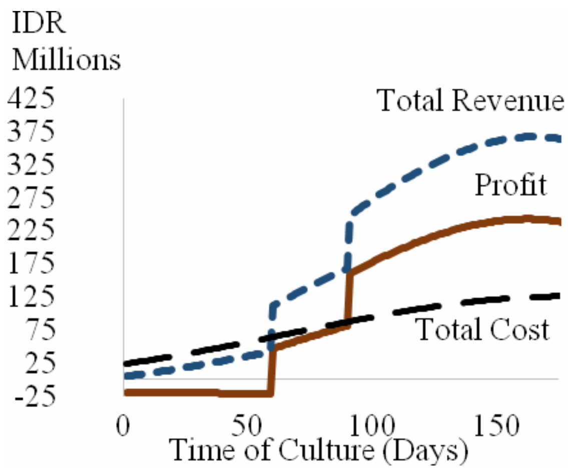
Note: a - single price base proportional price (65% harvest on size ≥ 20.0 g, 33% on size 11.0 to 19.9 g and 3% on size < 11 g); b - proportional price from 6 unit ponds; USD 1 = IDR 13 351.

We used two assumtion of price, i.e. single price and multi price. In the reality, there are multi price of whiteleg shrimp base on size. In the single price model, we used proportional price (IDR 83 per g) and the optimal time of culture to generate the maximal profit is 159 days. That is mean the shrimp farmers need more time to generate maximum profits than their habit of culture time which is about 90 days. However, the increase in culture time has consequences of increased capital and an increased risk of shrimp mortality. The simulation results show that profit at 159 days is IDR 157 761 808 per cycle per pond, and capital requirement is IDR 114 142 255 per cycle per pond. Meanwhile, when using 90 days culture period, the profit of IDR 106 010 124 per cycle per pond with capital requirement of IDR 76 842 777 per cycle per pond (Figure 2a).

If using a multi price model (three categories of prices), then the simulation results of revenue and profit curve showed there are twice of spike. In case of disease attack and whiteleg shrimp must be harvested before 60 days, then shrimp farmer will be loss. Shrimp farmers will take profits after 60th days and those profits increase significantly on the 91st day when the size of the whiteleg shrimp reaches 20 g. Optimum culture time is 160 days and profit will decrease after more than 160 days. Between 160 days to 166 days, there is still an increase in revenue, but the amount of revenue increase is smaller than the increase in cost, so the profit actually decreases (Figure 2b).



a. Single-Price Model



b. Multi-Price Model

Figure 2. Progress of TR, TC and Profit (IDR Millions).

In the two models (Table 2), the culture time of 159 days (single price) and 160 (multi price) are considered most profitable. That is, shrimp culture use two cycles of culture. However, the maximum profit per cycle is not the only factor used in the time determination of whiteleg shrimp culture. When taking into account the opportunity cost, the culture period of three cycles of culture per year will be more profitable than 2 times per year (Table 3).

Table 2

The maximal profit per cycle

	Single price	*Multi price*
Optimal time of culture (days)	159	160
Harvest biomass p (g)	3 859 452	3 859 452
Harvest size (g)	49.8	49.8
Total revenue (IDR per cycle)	271 904 063	311 502 492
Total cost (IDR per cycle)	114 142 255	114 419 732
Profit (IDR per cycle)	157 761 808	197 082 760

Table 3

Time culture and profit scenario

Cycle per year	*Time of culture (days)*	*Single price*		*Multiple price*	
		Profit (IDR per cycle)	*Profit (IDR per year)*	*Profit (IDR per cycle)*	*Profit (IDR per year)*
2	159[a] or 160[b]	157 761 808	315 523 616	197 082 760	394 165 519
3	112	131 415 348	394 246 043	163 680 429	491 041 288
4	81	94 340 832	377 363 326	58 633 099	234 532 397
5	63	70 011 994	350 058 972	42 485 840	212 429 199

Note: a - for single price, and b - for multi price.

Whiteleg shrimp culture with 3 cycles per year is more profitable and feasible than others. It is because 3 cycles per year can generate high prices (as the size target), the highest aggregate profit per year, and the risk of shrimp mortality is also lower than the time culture of 159 days or 160 days.

Conclusions. This research results showed that optimal culture time of whiteleg shrimp to produce maximum profit per cycle is 159 days in single price or 160 days in multi price. However, the number of cycles per year that generate maximum profit is three cycles per year or 112 days per cycle.

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