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OPTIMAL HARVEST TIME MODEL IN AQUACULTURE TO MAXIMIZE PROFIT

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ABSTRACT

The purpose of this study was to develop the optimal harvest time to generate maximum profits in Aquaculture. This study used a model of von Bertalanffy length growth combined with the length-weight relationship and the mortality rate to estimate of fish biomass. Profit was calculated as total of revenue minus total of cost. Both the harvested biomass of fish and price of fish were determined as factors affected the revenue of aquaculture. The components of costs were cost of seed procurement, cost of feed procurement, cost of harvesting transportation and the daily cost. The daily cost of aquaculture in floating cages are cost of labour, cost of medicines, cost of energy, cost of assets depreciation, cost of supporting equipment and cost of maintenance assets that converted to IDR/day. Profit maximization was performed by derivative the equation of profit to aquaculture periods (first order condition), and its second derivatives was negative (second order condition). The research model was applied to the red *Tilapia* culture in floating cages at the Reservoir of Wadaslintang, Indonesia. The research results demonstrate that the model in this study can be used to estimate aquaculture periods (286 days) which can generates maximum profits.

Key words: Profit Maximization, Von Bertalanffy, Aquaculture, Red *Tilapia*

INTRODUCTION

The purpose of this study was to develop the model of optimal harvest time to generate maximum profits in Aquaculture. In principle, the growth of cultured fish biomass is influenced by several factors which are including the average growth of fish, initial fish populations and mortality rates. Biomass growth affects revenue and cost in aquaculture. Total revenue is multiplication price and biomass of fish. Biomass growth also affects the total cost, especially the cost of feed procurement and cost of transportation of products.

Bjorndal (1988) derived a general rule in the optimization of the harvest time, and Arnason (1992) developed the interdependence of optimal feeding path and harvesting time. Bjorndal (1988) conducted a study to optimize the profit of aquaculture using Beverton-Holt growth model, but Bjorndal ignoring fixed capital in the decision harvest. Arnason (1992) continued the study of Bjorndal (1988), but Arnason model assumed if the profit optimization will be influenced only by feeding and harvest time factors. Heap (1993) continued the study of Bjorndal (1988) and Arnason (1992), but Heap focus on optimizing the feeding process to generate optimal profits. Strand and Mistiaen (1999) also continued the study of Bjorndal (1988) and Arnason (1992) by incorporating a piecewise-continuous price factors in the model, but Strand and Mistiaen assumed that the farmed fish was a single fish with no natural mortality.

Springborn *et al* (1992) conducted a study of optimum harvest time in aquaculture using fish growth model of von Bertalanffy that assumed a length exponent is 3. Springborn *et al* (1992) assumed if the price of fish was a constant, and the costs consisted of start-up costs (fingerling cost, pond lime and preparation cost), the daily cost during treatment (manure cost, cost of manuring labour, and fixed cost) and harvesting cost (cost of harvest labour, transportation cost and interest on operating cost).

In Indonesia, there are some major aquaculture commodities including shrimp, milkfish, cat fish, seaweed, grouper, *gouramy*, common carp and red *Tilapia*. In this study, the model of optimal harvest time was applied to the red *Tilapia* culture in floating cages in the Reservoir of Wadaslintang, Indonesia.

MATERIAL AND METHOD

Research Material

This research used red Tilapia culture using cage in Wadaslintang Reservoir, Indonesia as an object of research. This study used both the primary and secondary data. The primary data were collected by observation and interview with the key informants. The key informant were an aquaculturist, and fish traders in Wadaslintang Subdistrict. The secondary data collected from data owned by aquaculturist. This data were collected in this research including aquaculture cost, fish price, fish growth, fish length, fish weight, FCR (food convertion ratio), initial weight of fish, density, and mortality rate (MR).

Model of Fish Weight Growth and Fish Biomass Growth

In general, fish growth has certain characteristics. In this study, fish growth used the length growth model of von Bertalanffy, by the following equation (Wijayanto *et al*., 2014):

$$L_t = L_{inf}\left[1 - e^{-K(t - t_o)}\right] \quad (1)$$

$$t = t_{ao} + t_a \quad (2)$$

Where L_t is the length of the fish at time t (cm), L_{inf} is the maximum length of fish (cm), e is exponential number, K is the growth coefficient of fish, t is the age of fish (day), t_o is the initial age of fish have length, t_a is the aquculture period (days) and t_{ao} is the age of fingerling at the first time cultured (day). Estimation to L_{inf}, it could be done with Walford growth transformation equation (equation 3). Estimation to K and t_o used equation (4).

$$L_{t+1} = L_{inf}(1 - e^{-K}) + L_t.e^{-K}. \quad (3)$$

$$Ln\,(L_{inf} - Lt) = Ln\, L_{inf} + K.to - K.t.$$

If L_{inf}, K, t_o and t are known, then fish length can be estimated using equation (1). The relation of fish weight and length can use this equation:

$$W_t = aL_t^b \quad (4)$$

$$W_{inf} = a\, L_{inf}^{\ b} \quad (5)$$

While the growth in weight of the fish can be estimated by the following equation (Wijayanto, 2014):

$$W_t = W_{inf}\left[1 - e^{-K(t_a + t_{ao} - t_o)}\right]^b \quad (6)$$

Where W_t is the weight of fish at time t (g), a and b are constants, and W_{inf} is the maximum weight of fish (g).

In this study, the biomass of fish (B_{ta}) during a certain aquaculture period (t_a) was the average weight of fish (W_{ta}) multiplied by the number of cultured populations which were still alive at the time t_a. The number of fish populations t_a depends on the initial population size (N_o), the fish mortality rate (MR) and aquaculture period (t_a). Thus the fish biomass equation is as follows (Wijayanto, 2014):

$$B_{ta} = W_{ta}.N_o.(1\text{-}MR.t_a) \quad (7)$$

Maximum fish biomass (B_{max}) is done with the first derivative of the fish biomass equation (7) to t_a equal to zero or $dB_{ta}/d_{ta} = 0$. Mortality rate is reversed to the fish survival rate (SR). In this study, the unit of the fish mortality rate was in % per day.

Revenue, Costs and Profit

The profit of aquaculture at time t_a (Π_{ta}) influenced both the total of revenue (TR_{ta}) and total of cost (TC_{ta}). Total of revenue is influenced by the biomass of harvested fish (B_{ta}) and the price of harvested fish (P_{fi}). While total of costs consist of the cost of procurement of seeds (C_s), the cost of procurement of feed (C_{fe}), the cost of harvesting transportation (C_{tr}) and cost of daily (C_{dy}). The daily cost of aquaculture in floating cages in this model are cost of labor (C_l), cost of medicine (C_m), cost of energy (C_e), cost of assets depreciation (C_{dp}), cost of supporting equipment procurement (C_{st}) and cost of assets maintenance (c_{am}) were converted to units of IDR/day. So, profit can be estimated use this equation (Wijayanto, et al., 2014):

$$\prod_{ta} = TR_{ta} - TC_{ta} \quad (8)$$

$$TR_{ta} = B_{ta}.P_{fi} \quad (9)$$

$$TC_{ta} = C_s + C_{fe} + C_{tr} + C_{dy}.t_a \quad (10)$$

The cost of procurement of seeds is influenced by the price of seeds (P_s), and biomass of seeds in the initial period which influenced by the initial fish population (N_o) and the average weight of the seeds at the initial of the aquaculture period (W_o). The procurement cost of feed is influenced by prices of fish feed (P_{fe}) and the amount of feed given. The amount of feed is estimated by biomass gain (B_{ta}-$N_o.W_o$) and food conversion ratio (FCR). The cost of harvest transportation is influenced by tariff of transportion (P_{tr}) and fish biomass.

$$C_s = P_s.N_o.W_o \quad (11)$$

$$C_{fe} = (B_{ta}\text{-}N_o.W_o)\ FCR.P_{fe} \quad (12)$$

$$C_{tr} = B_{ta}.P_{tr} \quad (13)$$

In intensive aquaculture, the procurement cost of artificial fish feed has a large proportion in the composition of costs. Furthermore, by using equation (7), (8), (9), (10), (11), (12) and (13), then the equation of profit is (Wijayanto *et al*., 2014):

$$\Pi_{ta} = W_{inf}\left(1 - e^{-K(t_a + t_{ao} - t_o)}\right)^b N_o(1 - MR.t_a)P_{fi} - P_s.N_o.W_o - \left(W_{inf}\left(1 - e^{-K(t_a + t_{ao} - t_o)}\right)^b N_o(1 - MR.t_a) - N_o.W_o\right)FCR.P_{fe} - W_{inf}\left(1 - e^{-K(t_a + t_{ao} - t_o)}\right)^b N_o(1 - MR.t_a)P_{tr} - C_{dy}.t_a$$

Subject to: (i) $dB_{ta}/dt_a \geq 0$

(ii) $t_a \geq 0$ (14)

Profit equation above can be used in various types of aquaculture. However, if the method of culture does not using floating cages, it is necessary to adjust the cost, especially the component of daily cost (C_{dy}).

RESULT AND DISCUSSION

Profit Maximization

Profit maximization is done with the first derivative of the profit equation (14) to t_a equal to zero or $d\Pi_{ta}/d_{ta} = 0$. The first derivative of the profit equation can be defined if the value of b is equal to 2 or 3. In this study, the assumption of b value is 3. The first derivative of profit equation to t_a equal to zero using software Maxima-5.31.2 (open source) is as follows:

$$\frac{d\Pi_{ta}}{d_{ta}} = 3W_{inf}\left(1 - e^{-K(t_a + t_{ao} - t_o)}\right)^2 N_o(1 - MRt_a)P_{fi}.K.e^{-K(t_a + t_{ao} - t_o)} - W_{inf}\left(1 - e^{-K(t_a + t_{ao} - t_o)}\right)^3 N_o.MRP_{fi} - \left(3.W_{inf}\left(1 - e^{-K(t_a + t_{ao} - t_o)}\right)^2 N_o(1 - MR.t_a)K.e^{-K(t_a + t_{ao} - t_o)} - W_{inf}\left(1 - e^{-K(t_b + t_{bo} - t_o)}\right)^3 N_o.MR\right)FCR.P_{fe} - 3W_{inf}\left(1 - e^{-K(t_a + t_{ao} - t_o)}\right)^2 N_o(1 - MR.t_a)P_{tr}.K.e^{-K(t_a + t_{ao} - t_o)} + W_{inf}\left(1 - e^{-K(t_a + t_{ao} - t_o)}\right)^3 N_o.MR.P_{tr} - C_{dy} = 0 \quad (15)$$

The equation above is the first order condition to produce maximum profits in aquaculture. While the second order condition is a second derivative of the profit equation to t_a which is negative. If the values W_{inf}, K, t_{ao}, t_o, N_o, MR, P_{fi}, FCR, P_{fe}, P_{tr}, and C_{dy} are known, then t_a which generates maximum profit can be calculated.

Case Study: Aquaculture of Red Tilapia

Equation (15) was applied to the case of red *Tilapia* culture in floating cages in the Reservoir of Wadaslintang, Indonesia. Wadaslintang is located in Wonosobo Regency, Central Java. Based on the analysis, the length-weight *relationship* of red *Tilapia* cultured in floating cages in the Reservoir of Wadaslintang were (Wijayanto, et al., 2014):

$$W = 0{,}0163971050600781\ L_t^{\ 3{,}00497458998844}$$

In this study, infinity length (L_{inf}) of red *Tilapia* estimated at 50.04 cm, infinity weight (W_{inf}) estimated at 2.095 kg, the K value estimated at 0.00294133586234927 and value t_0 estimated at 2.21945945860328. From several studies in various locations, red *Tilapia* has a diverse both infinity length and infinity weight (Dache, 1990; Asila and Okemwa, 1999; Ahmed et al, 2003; El-Bokhty, 2010; and Gretchen et al, 2012). By using equations (1) and (6), the equation length and weight of red *Tilapia* cultured in floating cages in the Reservoir of Wadaslintang was as the following equation (Wijayanto, et al., 2014):

$$L_t = 50{,}0441444\ 730955\left[1 - e^{-0{,}00294133\ 586234927\ (t - 2{,}21945945\ 860328)}\right]$$

$$W_t = 2.095{,}4657\ 7834264\left[1 - e^{-0{,}00294133\ 586234927\ (t - 2{,}21945945\ 860328)}\right]^{3{,}00497458\ 998844}$$

The red *Tilapia* have rapid growth in the early period, but later the acceleration of growth decreased with the increasing of age. The red *Tilapia* growth began to slow at around 780 days of age and increasingly accelerated growth slowed at the age of 1153 days to achieve a infinity length and infinity weight.

Based on the survey results, the component of the costs and the price of fish in the cultivation of red *Tilapia* in floating cages in the Reservoir of Wadaslintang are as in Table 1.

By using the assumptions above, it can be estimated using the equation profit equation (14) and the maximum profit condition with equation (15) as in Table 2.

In the beginning, fish biomass has asignificant growth, but at any given time they decreasing caused by the mortality rate. The growth pattern of fish biomass affected the pattern of both cost and revenue. The largest proportion of costs in floating cages of red *Tilapia* culture was the cost of feed. On the red *Tilapia* culture in floating cages, artificial feeding was intensified because fish density was relatively high and the availability of natural feed was insufficient to meet the nutritional needs of fish cultured. For comparison, the study of Rahayu (2011) proved that the cost proportion of feed procurement in the red *Tilapia* culture in running water pond in Klaten-Indonesia could reach 65.55 % of the total of cost.

The results of the simulation profit equations showed that maximum culture profit of red *Tilapia* in floating cages in the Reservoir of Wadaslintang reached in 286 days (approximately). In the 286 days it was estimated that weight average of fish was 622 g and produced profit of IDR. 34,095,810 in a single cycle of culture.

Findings of aquaculture period that generate maximum profits in the simulation has fulfilled rules of profit maximization, which the first derivative of profit function was equal to zero and the second derivative of profit function was negative. At the time of the culture period was 286 days, the first derivative of profit function was not equal to zero (value 866), but the culture period of 286,46996 days proved if the first derivative a profit of function was 0.00314.

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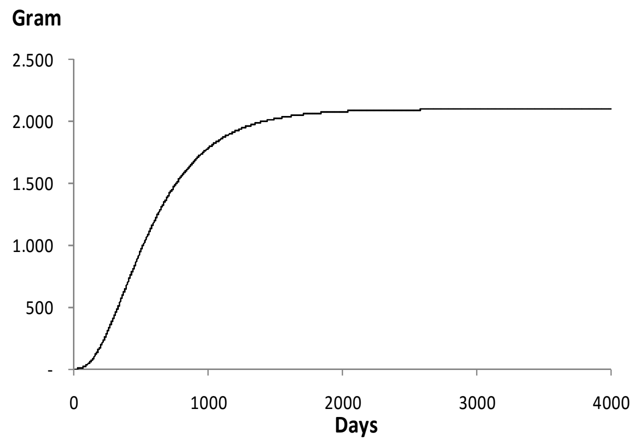

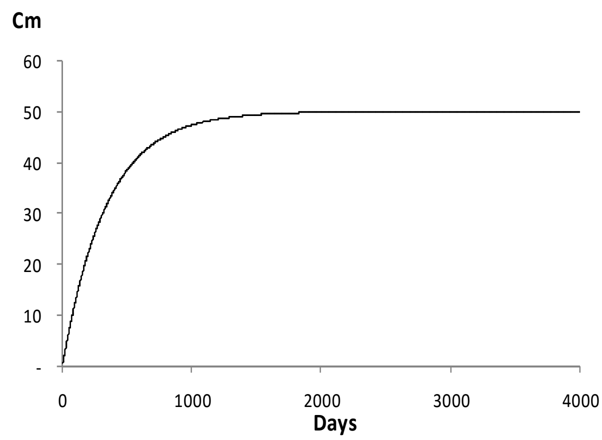

Figure 1. Simulation of Length (cm) and Weight (g) red *Tilapia* Growth
Source: Wijayanto, et al (2014)

Table 1. Assumption of Costs, Prices and Biology Factors

	Value
Cost of Daily (C_{dy})	IDR. 81,164/day
Cost of Labour (C_l)	IDR. 29,384/day
Cost of Medicine (C_m)	IDR. 8,219/day
Cost of Energy (C_e)	IDR. 9,863/day
Cost of Depreciation Asset (C_{dp})	IDR. 29,590/day
Floating Cages	IDR. 24,110/day
Boat	IDR. 2,740/day
Machine	IDR. 2,740/day
Cost of Supporting Equipment (C_{st})	IDR. 822/day
Cost of Asset Maintenance (C_{am})	IDR. 3,288/day
Cost of Seed Procurement (C_s)	IDR. 23,702.833
Price of Seed (P_s)	IDR. 20,000/kg
Initial Seed Weight (W_o)	0.0246 kg
Initial of Seeds Populations (N_o)	48,000
Price of Fish Feed (P_{fe})	IDR. 9,000/kg
FCR (Food Convertion Ratio)	1.3
Price of Transportation Harvest (P_{tr})	IDR 1,000/kg
Prices of Fish Harvest (P_{fi})	IDR. 17,000/kg
Mortality Rate (MR)	0.1667%/day
Fish Growth Coefficient (K)	0.00294133586234927
Estimation of t_0	2.21945945860328
Estimation of Initial Age of Seeds (t_{ao})	90 day
Assumption of b value	3

Note: U.S. $ 1 equal to IDR. 11,783 on February 17, 2014 (Source: Wijayanto, et al., (2014))

Table 2. Maximum Profit

	Value
Aquaculture period that generate maximum profit	286 day
Fish age	376 day
Estimated size of fish (when t_a = 286 day)	622 g
Profit (when t_a = 286 day)	IDR 34,095,810
First Derivatives Value of Profit Functions When ta = 286,46996 day	0,00314
Second Derivative Value of Profit Functions When ta = 286,46996 day	-1887.485840

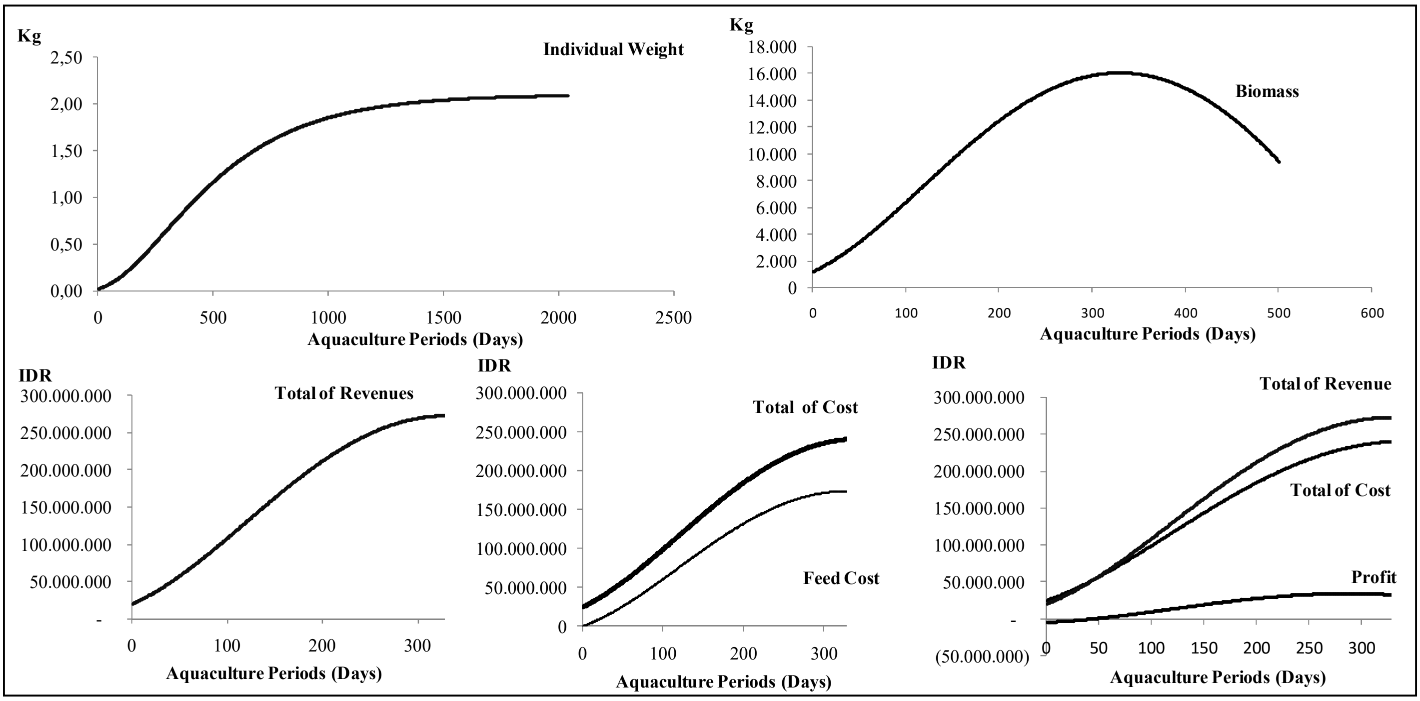

Figure 2. Simulation of Weight Individual Fish, Fish Biomass, Revenue, Cost and Profit

CONCLUSION

Profit maximization model in this study can be applied to estimate the optimal time in the aquaculture. As a note, the aquaculture which can be estimated with this model have suggested the value of b approaches the value of 2 or 3. It getting away from the b value 2 or 3, then biased estimates of growth and biomass of fish will be even greater. In cased of red *Tilapia* culture using cage in Wadaslintang Reservoir, maximal profit was 286 days, what be estimated weight average of fish was 622 g and produced profit of IDR. 34,095,810 in a single cycle of culture.

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