



Oxygen Consumption of *Litopenaeus vannamei* in Intensive Ponds Based on the Dynamic Modeling System

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Abstract

In intensive shrimp culture, oxygen consumption of shrimp is an important indicator that greatly affects the physiological condition of shrimp as a reared organism. The purpose of this study was to dynamically determine the oxygen consumption of shrimp in intensive culture as well as the variables of water quality and shrimp growth. This research was conducted with the concept of ex-post-facto causal design in intensive aquaculture ponds during the shrimp cultivation period. During the shrimp culture period, the rate of oxygen consumption of shrimp is inversely related to the sigmoidal average increase in shrimp body weight. Meanwhile, based on the simulation analysis with the dynamic modeling concept, it is shown that oxygen consumption was linear to the dynamics of average daily gain and inversely proportional with the increasing rate of shrimp biomass in the ponds. In addition, the oxygen consumption rate of shrimp in intensive ponds had a close relationship with water salinity and total organic matter. In conclusion, dynamically, the fluctuation of oxygen consumption rate and average daily gain of shrimp in intensive culture is closely related to the stability of the water quality conditions on the shrimp habitat.

INTRODUCTION

Dissolved oxygen is the most crucial and dynamic water quality parameter in the culture system because aerobic organisms in the waters need oxygen rates that are sufficient for biochemical processes (Boyd and Tucker, 1998; Oakes, 2011). The oxygen solubility in intensive ponds is mainly influenced by conditions of pH, temperature, salinity, turbulence and air pressure parameters (Effendi, 2003; Supriatna *et al.*, 2017). Dynamically, the dissolved oxygen

concentration will fluctuate due to biological, physical and chemical processes (Egna and Boyd, 1997).

In intensive cultivation, shrimp is an aquatic biota that requires oxygen for the process of bioenergy balance in its metabolic system. The rate of oxygen consumption of shrimp depends on the growth stage and the rate of food consumption (Budiardi *et al.*, 2005). In addition, the rate of oxygen consumption of shrimp is also influenced by abiotic

factors in aquatic habitats (Bett and Vinatea, 2009). So, in other words, it can be explained that the rate of oxygen consumption greatly affects the condition of the shrimp metabolic system when it grows and has activities (Re and Diaz, 2011). This study aims to measure the dynamics of oxygen consumption by shrimp in intensive ponds and its relationship with variables of water quality and shrimp growth.

METHODOLOGY

Place and Time

This research was conducted in April-June 2019 or during the cultivation period of Vannamei shrimp in the intensive aquaculture area of Bayeman Village, Tongas District, Probolinggo Regency (7.7260 "South Latitude and 113.1283" East Longitude) with the concept of ex-post-facto causal research design. Data collection in the form of oxygen consumption, biological growth and water quality were carried out every 10 days from the beginning of stocking to harvest.

Research Material

The cultivation of Vannamei shrimp has been carried out in 2 ponds of 400 m² of HDPE (high-density polyethylene) pond liners with a stocking density of 112 fish/m² and the use of 4 hp waterwheels for each cultivation pond. The data of shrimp oxygen consumption rate were collected by random sampling, after which experimental trials were carried out using a 20 L aquarium and DO meter (AZ 8402, China). Meanwhile, the observation of dissolved oxygen concentration and temperature in pond waters used a DO meter (AZ 8402, China), the measurement of water pH concentration used a pH tester (HANNA HI98107, China), while the measurement of the water salinity used a refractometer (MASTER-S10 ATAGO, Japan). In addition, the measurement of ex-situ parameters such as phosphate, nitrite, nitrate, TAN, and total organic matter (TOM) content was carried out

based on the standard operating procedures of APHA (1990).

Research Design

The data of oxygen consumption rate of shrimp were collected experimentally, by randomly taking 4 shrimp from each pond, and the shrimp taken were the ones with complete body organs, active motion and full intestines.

Work Procedures

The shrimp were put into a 20-liter aquarium which had previously been acclimatized to the pond water media so that the water quality conditions in the aquarium did not differ greatly from the water quality conditions in the ponds, and then the aquarium was tightly closed with full aeration treatment without any feeding or input into the aquarium. Afterward, the dissolved oxygen concentration and weight of the shrimp were measured every 2 hours for 6 hours consistently from the time the shrimp was put into the aquarium, so the shrimp metabolic rate could be monitored regularly. Finally, calculations were carried out based on the Pavlovskii (1964) formula:

$$T_n = (([O_2]_0 - [O_2]_1 \times V_0) / (W_1)) / (T_1 - T_0)$$

$$T_1 = (([O_2]_{t_{n-1}} - [O_2]_n \times V_{n-1}) / (W_n)) / (T_n - T_{n-1})$$

Note:

$[O_2]_0$ = oxygen concentration at t_0

$[O_2]_n$ = oxygen concentration at t_n

V_0 = water volume at t_0

V_{n-1} = water volume at t_{n-1}

W_n = shrimp weight at t_n

T_0 = time at 0 hour of observation (initial period)

T_1 = time at the 1st hour of observation (final period)

T_n = time at the -n hour of observation

T_{n-1} = time at the n-1 hour of observation

The observation of water quality parameters such as pH, temperature, dissolved oxygen, and salinity was carried out in situ, while the observation of phosphate, nitrite, nitrate, TAN, and TOM has measured ex-situ at the BBPAP laboratory Situbondo every 10 days.

Water samples were taken during the day, and for each pond, 3 water samples were taken from the edge and middle of the pond. Shrimp biological growth parameters observed in this study were the body weight and the average daily gain (ADG), which was sampled periodically every 10 days according to the schedule for measuring the oxygen consumption of shrimp and water quality. The samples of weight and growth rate were obtained by taking the shrimp for experimental tests on the rate of oxygen consumption of shrimp whose weight had been measured beforehand.

Data Analysis

The analysis of dynamic modeling used Stella ver.10.9 software by making a conceptual simulation model of multi-variable research. Meanwhile, for statistical analysis, SPSS ver.16 software was used.

RESULTS AND DISCUSSION

During the cultivation period, the conditions of water quality parameters are generally still considered good or are in accordance with water quality standards for Vannamei shrimp cultivation according to Edhy *et al.* (2010), except for salinity, phosphate, and organic matter parameters (Table 1). The low salinity value is due to the fact that the research pond uses a water source from a borehole as a culture media, so the salinity level is not as high as that of seawater. The high levels of phosphate and TOM are caused by the accumulation of organic matter from increased cultivation activities. The longer period of cultivation, the more frequent the feeding activity in the ponds, so it will affect the accumulation of organic matter and nutrients and also the condition of pond waters which tends to become entrophic (Sahu *et al.*, 2013; Herbeck *et al.*, 2013).

Table 1. The average value of water quality parameters during the cultivation period.

Parameters	Value	N	Quality standards
pH	8.0 (± 0.25)	14	7.5-8.0
Salinity	10 (± 2.11)	14	15-35 g/L
Dissolved Oxygen	6.99 (± 2.13)	14	>4 mg/L
Temperature	28.38 (± 2.01)	14	28-32°C
Phosphate	0.247 (± 0.25)	7	<0.2 mg/L
Nitrite	0.102 (± 0.16)	7	<1.0 mg/L
Nitrate	0.199 (± 0.30)	7	<10 mg/L
TAN (Total Amonia Nitrogen)	0.591 (± 0.78)	7	<2.0 mg/L
TOM (Total Organic Matter)	96.26 (± 22.82)	7	<90 mg/L

*Source: Edhy *et al.* (2010)

The rate of oxygen consumption by shrimp during the growth period has a downward trend with the regression model $Y = 9.444 - 0.047x$. The highest rate of oxygen consumption is obtained at 0.450 mgO₂/L, and the lowest was at 0.002 mgO₂/L (Figure 1). This means that the heavier the shrimp weight, the lower the rate of oxygen demand needed. This is because small shrimp need a higher energy for their metabolic system. In

addition, the rate of oxygen consumption of shrimp is also influenced by environmental conditions such as temperature and salinity (Bett and Vinatea, 2009). The results of other studies stated that the minimum rate of oxygen consumption for shrimp in the juvenile phase is of 0.65 mg/L with an average weight of juvenile shrimp of 4.1 g (Vinatea *et al.*, 2009).

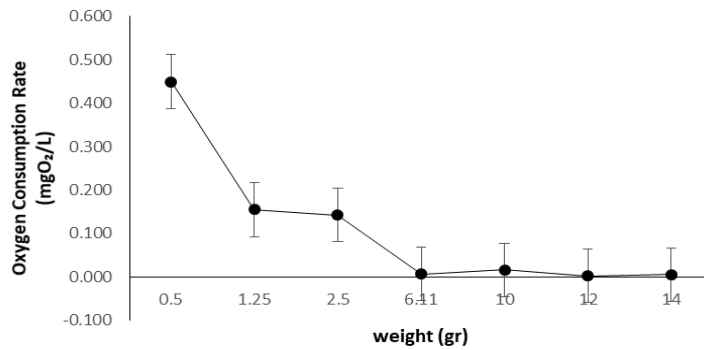


Figure 1. Graph of oxygen consumption rate of shrimp based on weight gain of shrimp.

The rate of body weight and average gain of shrimp per 10 sampling days can be seen in Figure 2. In the graph of the weight and average daily gain of shrimp (Figure 2.), it can be seen that the body weight of shrimp continues to increase from the initial period of cultivation to the harvesting. However, the average daily gain of shrimp appears to experience a decrease at the age of 50 days of cultivation, and after that it remains stagnant. The growth stagnation at the age of 50 days is due to the high stocking density and biomass of shrimp in the ponds and the low levels of water salinity, which affect the biological growth conditions and the balance of osmoregulation system of the shrimp (Bray *et al.*, 1994; Sookying *et al.*, 2011; Chand *et al.*, 2015). These conditions genetically will also affect the level of molt-inhibiting hormone (MIH)

expression at each phase of shrimp growth (Gao *et al.*, 2016).

The rate of shrimp growth is exponential at the age of 30-50 days. The rate of exponential growth of each aquatic organism varies depending on the species and habitat conditions. Biologically, Vannamei shrimp is a type of shrimp that grows faster per period of growth than other crustacean species do (Edhy *et al.*, 2010). In addition, the growth rate of organisms is also influenced by the availability of food nutrients and genetic factors (Guillaume *et al.*, 1989). By knowing the period of exponential growth rate of shrimp, it is expected that certain strategies or manipulation can be carried out to spur shrimp growth in that period. Engineering that might be done is to manipulate feeding habits and add supplements to the feed (Jayesh *et al.*, 2015).

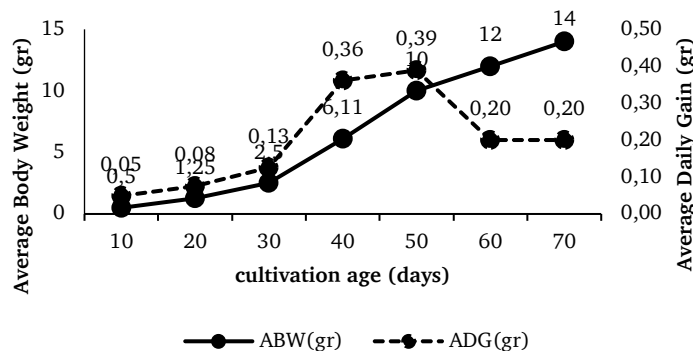


Figure 2. Graph of Average Body Weight dan Average Daily Gain of Shrimp during Cultivation. (—●—) Average body weight, (---●---) Average Daily Gain of Shrimp.

The relationship between the rate of oxygen consumption with the biological variables of shrimp and the conditions of

water quality parameters can be predicted through a simulation of the dynamic modeling concept in Figure 3.

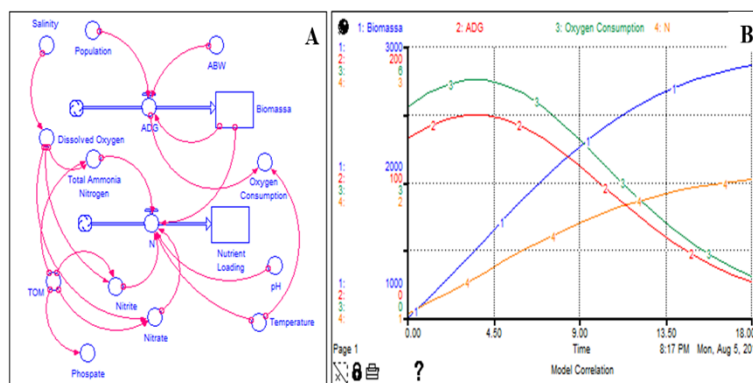


Figure 3. Simulation results of dynamic modeling using Stella ver. 10.9 software. (A) A conceptual of the dynamic model of an intensive pond; (B) Results of the analysis of dynamic modeling of the shrimp consumption rate of shrimp in intensive shrimp culture systems.

Based on the model simulation results, it can be explained that the rate of oxygen consumption of shrimp will experience depletion and is linearly proportional to average daily growth. However, the rate of oxygen consumption of shrimp is shown to have an inverse relationship to the increase in the variable of shrimp biomass and nutrient abundance in the pond. It means that the rate of shrimp consumption will experience a fluctuation in accordance with the growth rate of shrimp because during the process of shrimp growth, physiologically it is necessary to have sufficient oxygen levels to fulfill their metabolic activity. The dissolved oxygen rate required for the metabolic process of adult shrimp at a stable temperature of 280-33°C is 1.49 mg/L (Niu *et al.*, 2003).

The increase in shrimp biomass, which is described as having a sigmoidal growth curve, during the cultivation period, will have an impact on the increasing level of nutrient accumulation. The increase in nutrient accumulation will create over-enrichment of excess in the pond water environment (Wu *et al.*, 2014). The waters that are rich in excess nutrients will cause plankton blooms in the ponds and an imbalance of the habitat ecosystem (Muendo *et al.*, 2014). In addition, plankton blooms will also affect

the grazing activities of plankton in the food chain in the ponds.

The relationship between the rate of oxygen consumption of shrimp (per one shrimp) and the water quality variable can be seen in Table 2. Meanwhile, the relationship between the rate of oxygen consumption of shrimp (per one shrimp) and the average daily gain can be seen in Table 3. Based on data on the water quality variable, the rate of oxygen consumption has a negative correlation to salinity and TOM parameters. Also, it does not correlate with other water quality parameters. The negative relationship to the water salinity parameter indicates that the fluctuation of mineral ions in the ponds greatly affects the rate of oxygen consumption by shrimp metabolism for the osmoregulation mechanism (Re and Diaz, 2011). The increased rate of oxygen consumption is a physiological response of shrimp to maintain their body condition to remain in a homeostatic condition due to fluctuations in water salinity levels (Hernandez *et al.*, 2005). Meanwhile, the increasing levels of organic matter due to the increase in shrimp biomass will affect the level of increased oxygen demand in the sediment and water column for the respiration process of organisms (Luong *et al.*, 2016; Leduc and Pilditch, 2017).

Table 2. The results of the correlation test of the rate of oxygen consumption to water quality parameters.

	OCR	pH	Sal	T	DO	NO ₃ ⁻	PO ₄ ⁻	NO ₂ ⁻	TAN	TOM
Pearson correlation	1	.298	-.859'	.698	-.350	-.460	-.503	-.447	-.423	-.941''
Sig. (2-tailed)	-	.517	.013	.081	.400	.299	.250	.315	.344	.002
N	7	7	7	7	7	7	7	7	7	7

Note : OCR (Oxygen Consumption Rate); pH (Power of Hydrogen); Sal (Salinity); T (Temperature); DO (Dissolved Oxygen); NO₃⁻(Nitrate); PO₄⁻(Phosphate); NO₂⁻(Nitrite); TAN (Total Ammonia Nitrogen); TOM (Total Organic Matter).

Table 3. The results of the correlation test of oxygen consumption rate to the biological growth of shrimp.

	OCR	ABW	ADG
Pearson correlation	1	-.761'	-.722
Sig. (2-tailed)	-	.047	.067
N	7	7	7

Note : OCR (Oxygen Consumption Rate); ABW (Average Body Weight); ADG (Average Daily Gain).

For the variable of the biological growth of shrimp, the rate of oxygen consumption has a close relationship to the average body weight of shrimp but does not have a close relationship with the average daily gain (Table 3). This is because, during their life, the rate of oxygen consumption of shrimp at each growth phase or each body weight has different oxygen demand ratios (Budiardi *et al.*, 2005). Small shrimp have a higher probability of oxygen consumption for their metabolic activity (Djawad and Jompa, 2002). Different rates of oxygen consumption in the metabolic system at each stage of organisms' growth are also predicted as a form of physiological and behavioral adaptation responses (Kieffer and Wakefield, 2009; Bouyoucos *et al.*, 2018).

CONCLUSION

Based on the results of this study, it can be concluded that dynamically fluctuations in oxygen consumption and average daily gain of shrimp in intensive culture are closely influenced by the stability of water quality conditions in the shrimp habitat.

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