Dynamic model of dissolved oxygen in intensive concrete pond of white leg shrimp (Litopenaeus vannamei) in Bomo Village, East Java

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Abstract. This study is to understand a simple model of dissolved oxygen (DO) and other water quality factors that affect it in two seasons in intensive white leg shrimp ponds. Water quality parameters in the dry and rainy seasons in several ponds were sampled daily, including temperature, pH, (DO), salinity, twice a week, including ammonium, nitrate, orthophosphate, total alkalinity, and total bacteria. Besides daily, dissolved oxygen is also measured before the harvest every two hours by using dark bottles and light bottles. Pond water quality parameters are still suitable for white shrimp culture. Daily DO shrimp ponds form a polynomial regression model. DO in light bottles constructed a quadratic regression model, DO in dark bottles created a linear regression pattern, with a DO reduction rate of 0.6338 mg$l^{-1}$ per hour. During one of the shrimp cultures, the DO model showed an inverse quadratic equation with the lowest oxygen solubility level on day 57. DO was positively correlated with changes in salinity and transparency and negatively related to ammonium, nitrate, phosphate, total alkalinity, and total bacteria count.

1. Introduction.
Dissolved oxygen (DO) is one of the most critical water quality parameters in white leg shrimp culture. Low levels of DO is a limiting factor in intensive shrimp culture systems [1]. In acute DO conditions, it can cause stress in shrimp [2] and subsequently causes greater susceptibility to disease, reduced appetite, and slower growth. DO regulates various biochemical processes in water, such as nitrification, denitrification, and degradation of organic compounds. The parameters that can control DO in water are the rate of oxygen uptake by sediment, oxygen production by photosynthesis, oxygen consumption by aquatic animals, biochemical activity in the water, and aeration [3] [4] [5]. In ponds, the increase in oxygen levels during the day is due to the effects of photosynthetic organisms. It then decreases at night due to oxygen consumption from plants and animals [6]. Reduced levels of DO in water can affect growth rates, weight gain, oxygen consumption, ammonia toxicity, moulting, stress and can even cause death in white leg shrimp [7].

The dynamics of DO in intensive white leg shrimp ponds are complex and influenced by many physical, chemical, and biological processes. Important factors that influence the dynamics of DO in the...
aquatic environment are the exchange of air from the atmosphere with water, photosynthesis, respiration, mineralization, nitrification, pond properties. As a result, the need for oxygen for biochemical activities in intensive pond water will not be enough to rely on natural oxygen in ponds. Several modelling methods to predict water quality as performed by [28] by establishing a DO prediction model of a water quality monitoring system based on the BP neural network [8] by making water quality prediction models based on Smooth Support Vector Machine (SSVM). [9] applies an actual DO prediction and early warning system in carp cultivation. Therefore it is necessary to study the dynamics of DO with a simpler model with a regression approach and water quality factors that influence the change in DO.

2. Materials and Methods
This study uses a causal design with analytical methods ex-post-facto design or analysis of natural phenomena that intensively study the processes that occur in white leg shrimp ponds from concrete pond (3,292.55 ± 347.02) m², which controlled for ± 100 days. Data are collected on intensive white leg shrimp ponds in Bomo Village, Rogojampi Situbond District, East Java. Data were collected from 6 concrete ponds in the rainy season and ten concrete ponds in the dry season from June 2018 to October 2019, intensive patterned with stocking densities (119.84 ± 18.52) tails / m². Farm management activities under the Best Aquaculture Practices Certification (BAPC, F10488). Water quality data collection begins at the beginning of stocking until harvest. Daily water quality data DO (YSI Oxygen Meter Model 550A), pH (indicator strips 5.0-10 Merck), salinity (Hand Refractometer MASTER-S10α Atago), temperature (Hg thermometer), transparency (Secchi disk) measured in the morning except DO at 10 pm and every 2 hours before the shrimp harvest.

2.1. Water quality determination
DO measurements of pond water were using a dark bottle (300 ml) and light bottle (300 ml) each of 12 bottles. Water is filtered with plankton net number 150, put into dark bottles and light bottles, and incubated below the surface of the pond water, as for the other parameters using a sample bottle that is measured twice a week. Water samples are taken on the pond's surface in the middle, top, and bottom using a 500 mL sterile sample bottle. Measurement of PO₄³⁻, NO₃⁻, NO₂⁻, NH₄⁺, with a colorimeter (Merck) and total alkalinity, CO₃²⁻, HCO₃⁻ (10). A sampling of bacteria in water according to the DO measurement point on the pond water body. Samples of bacteria in water were taken using a 50 mL sterile sample bottle and filled to the brim. It is an example of bacteria from pond water in cool boxes. Bacterial samples were analyzed at SWK Laboratory, East Java. Water samples were diluted in series (up to 10⁻²), from each dilution taken 1 ml and spread on Tryptic Soy Agar (TSA) media in Petri dishes, then incubated at room temperature for 24 - 48 hours. Bacterial colonies that grow then grow are the morphologically characterized based on the shape, color, elevation, and size of the bacterial colonies formed and the number of bacteria colonies that grew by calculating the Total Plate Count (TPC) method (11).

2.2. Statistical analysis
The data collected were grouped based on the measurement time and analyzed descriptively to identify the level of DO fluctuations during one shrimp culture cycle. The DO relationship with other quality parameters was determined using a correlation test by the SPSS software Ver. 16.

The collected data is then arranged and grouped daily, weekly, and seasonally and analyzed descriptively. Analysis of variance to determine whether or not there is a mean difference (average) of a variable between plots is used analysis of variance (α = 0.05). The DO covariance analysis and multivariate regression to find the relationship between water quality parameters and DO with the help of SPSS software ver.16 and Excel and continued by establishing quantitative relationships. In each analysis, a test was conducted to determine the level of confidence. The results of the regression analysis to make the dissolved oxygen model.
3. Results
Dissolved oxygen (DO) is one of the most critical water quality parameters in white leg shrimp culture. Low oxygen solubility is a limiting factor in intensive shrimp culture systems (1). It can cause stress in shrimp (2) in a critical DO condition, leading to greater susceptibility to disease, reduced appetite, and slower growth. DO regulates various biochemical processes of water quality, such as the nitrification process, denitrification process, and the degradation process of organic compounds in aquaculture. Parameters that can control DO in water are the rate of oxygen uptake by sediment, oxygen production by photosynthesis, oxygen consumption by aquatic animals, biochemical activity in the water, and aeration (3; 4). In ponds, the increase in oxygen levels during the day is due to the effects of photosynthetic organisms. It then decreases at night due to oxygen consumption from plants and animals (6). The results of daily DO measurements are presented in Table 1.

Table 1. Daily DO (mean±standard error and range) recorded during white leg shrimp culture are ongoing.

| Season  | Ponds | DO (mg⁻³) | Min-max (mg⁻³) |
|---------|-------|-----------|----------------|
| Dry season | A-4   | 4.17 ± 0.32 | 3.75-4.76 |
|         | A-5   | 4.85 ± 0.74 | 3.80-6.30 |
|         | A-6   | 4.28 ± 0.42 | 3.65-4.87 |
|         | B-3   | 4.26 ± 0.31 | 3.53-5.61 |
|         | B-6   | 4.15 ± 0.47 | 3.53-5.61 |
|         | C-2   | 4.78 ± 0.71 | 3.80-6.30 |
|         | Average | (4.73 ± 0.51)* | 3.84 - 6.48 |
| Rainy season | C-11  | 4.78 ± 0.53 | 4.10-6.13 |
|           | C-12  | 4.72 ± 0.34 | 4.29-5.61 |
|           | C-4   | 4.78 ± 0.68 | 4.23-6.36 |
|           | C-5   | 4.61 ± 0.54 | 4.06-5.97 |
|           | C-6   | 4.75 ± 0.59 | 4.00-6.19 |
|           | C-7   | 4.72 ± 0.28 | 4.25-5.51 |
|           | C-8   | 4.82 ± 0.46 | 4.25-6.25 |
|           | C-9   | 4.89 ± 0.59 | 4.15-6.16 |
|           | D-2   | 4.59 ± 0.39 | 3.89-5.64 |
|           | D-3   | 4.64 ± 0.67 | 3.84-6.48 |
|           | Average | (4.45 ±0.61)* | 3.50 - 6.30 |

*Note is significant at the α = 0.01

Table 1 shows that the average DO in the ponds is (4.63 ± 0.56) mg⁻¹ with a range (3.50-6.48) mg⁻¹ and is still in the optimum range for white leg shrimp culture. The level of DO in the dry season is higher than in the rainy season (α <0.01). Clifford (1998) reports that the minimum DO level for shrimp health is 3.0 mg⁻¹. The DO that has the potential to cause death is <2.0 mg⁻¹.

Similarly, if DO is below 3 or 4 mg⁻¹ for a short period, it can cause stress, leading to greater susceptibility to disease, reduced appetite, and slower growth [2]. The critical DO concentration for white leg shrimp is 0.65 mg⁻¹ in super-intensive culture and will die entirely at 34.7 and 31.8 minutes if there is no sunlight. In traditional white leg shrimp culture without aeration, the lowest is 4.1 mg⁻¹ [13]. DO in white leg shrimp ponds will be determined by the oxygen consumption rate of soil sediments, production and consumption of oxygen in the aquifer layer, shrimp oxygen consumption, and aeration rate. DO in white leg shrimp ponds will be determined by the oxygen consumption rate of soil sediments,
production and consumption of oxygen in the aquifer layer, shrimp oxygen consumption, and aeration rate [4]. Furthermore, [14] states that to maintain DO levels above three mg⁻¹. White leg shrimp need to be added aeration by calculating the production target of 400 kg to 500 kg per HP padlocked aeration. The study results [13] showed that the minimum DO requirement of juvenile white leg shrimp was 4.1 mg⁻¹. Ideally, the DO requirement for white leg shrimp is > 4 mg⁻¹ [15]. In contrast, the results of [7] research on white leg juveniles showed optimal growth at a DO level of 5.5 mg⁻¹. The results of [16] showed a correlation between the salinity of the culture media and the size of the white leg shrimp that the larger the size of the white leg shrimp, the smaller the oxygen demand for growth. So also says that with environmental conditions that are hyperosmotic and hypoosmotic, oxygen demand will increase. The cumulative effect of these water parameters will reflect on shrimp production [17].

DO pattern on the surface and bottom of the pond shows a quadratic pattern (Figure 1) with the equation model \( Y_1 = 0.0762x^3 - 1.1448x^2 + 4.5549x + 2.3707 \) (\( R^2 = 0.9259 \)) where \( x \) = observation time; peak \( \tan \theta = 0 \) with the highest oxygen peak obtained at 11.28 '32 " and will decrease until 20 16' 41" and after the DO rises again due to a decrease in pond temperature. While the measurement of DO at the bottom of the pond produces \( Y_2 = 0.0822x^3 - 1.2492x^2 + 5.1795x + 0.9157 \) (\( R^2 = 0.9678 \)) with the highest oxygen peak obtained at 11 48 '54 " until 20 13' 26," and after that, dissolved oxygen at the bottom of the pond rises again in line with a decrease in pond bottom temperature. The highest DO level is not much different from the research results by (18) and (19).

The increase of DO that occurs at night even though there is no photosynthesis is caused by the decrease in pond water temperature at night. The decline in dissolved oxygen in the pond is quite significant, and the lowest peak of DO in the pond water is at 8 15 '2 "PM. After that, DO in the pond water continues to rise until noon. Increased DO at night due to pond water temperature dropped dramatically until the morning after sunrise. If the water temperature decreases continuously, the process of oxygen diffusion from the air into the pond's water body will increase continually to a certain extent. The level of DO in pond water is influenced by the pond water temperature [20]. The DO in pond water bodies and temperature changes are also related to other parameters such as salinity, pH, transparency, and oxidation-reduction processes that occur in pond water. [21] states that changes in DO in ponds water are the same as the addition of oxygen from photosynthesis, aeration supply, natural aeration, and inlet water, as well as reduction of phytoplankton respiration, fish respiration, detritus decomposition, and exit water. The rate of change of DO in each category is modelled as a function of external and internal environmental conditions.

DO rates in light bottles and dark bottles form the quadratic regression equation presented in Figure 2. DO rates in the light bottle \( (Y_3) \) produce the equation \( Y_3 = -0.6208x^2 + 6.0811x - 0.4511 \) (\( R^2 = 0.9221 \);
x = observation time, peak are tan \( \theta = 0 \) with DO peak obtained at 16 47'44, "and after that, it decreases again. DO rate on dark bottles \( (Y_4) \) produces linear regression equation, which is \( Y_4 = -0.3168x + 3.0243 \) \( (R^2 = 0.9783; x = \text{observation time}) \) or the rate of DO is \(-0.6338 \) mg l\(^{-1}\) per hour, the peak increase in oxygen on the surface of the pond with the bottom of the pond about one hour. Difference in DO rate in light bottles and dark bottles shows the equation \( Y_5 = 0.0792x^3 - 1.197x^2 + 4.8672x + 1.6432 \) \( (R^2 = 0.9475; x = \text{observation time}, \text{peak are tan} \theta = 0) \) which reaches the peak point of adding oxygen at 11 39'2" then decreases again until 20 15' 2" and after that the DO in the shrimp ponds rises again.

**Figure 2.** DO model on light bottles \( (Y_3) \), dark bottles \( (Y_4) \), the productivity of DO \( (Y_5) \) of white leg shrimp ponds

Daily DO models during one shrimp culture cycle (Figure 3) produce a quadratic regression, which is \( Y_6 = -0.0004x^2 + 0.0458x + 5.6435 \) \( (R^2 = 0.4597; \alpha 0.00) \). The lowest DO was 57 \( (\text{tan} \theta = 0) \) based on the above equation. [22] have observed that low DO when high stocking densities and long periods in shrimp culture. The accumulation of organic matter in ponds can increase oxygen consumption higher [23].

**Figure 3.** DO from the spread of white leg shrimp seeds until harvest.

DO in pond water is closely related to the physical chemistry of water. DO in white leg shrimp ponds is a function of salinity, temperature, density, and size of shrimp [24]. Relationship between the level of DO in ponds with physical, chemical, and bacterial parameters, a correlation test is presented in Tables
2, 3, and 4. Table 2 shows that DO is positively correlated with salinity and transparency but not with temperature and pH.

**Table 2. DO Correlation with pond water physics parameters.**

|          | pH     | Salinity | Temperature | Transparency |
|----------|--------|----------|-------------|--------------|
| DO       | Pearson Correlation | -0.039  | -0.150*    | 0.028        | 0.513**      |
| Sig. (2-tailed) | .511  | .012     | .643        | .000         |
| N        | 281    | 281      | 281         | 276          |

*Note is Correlation is significant at the 0.05 level  
** Correlation is significant at the 0.01 level

Table 3 shows that DO is negatively correlated with NH$_4^+$, NO$_2^-$, NO$_3^-$, PO$_4^{3-}$, total oxygen matter (TOM), alkalinity and does not correlate with NO$_2^-$. Likewise, in Table 4, it is shown that DO negatively correlated with vibrio bacteria and the total number of bacteria. (25) has found a positive correlation between water temperature and salinity, salinity with primary productivity, primary productivity with DO, DO with nitrate, nitrate with phosphate at all-white leg shrimp pond stations in Patelwadi Village, Diu (Union Territory) and also states that the overall average value of nutrients in water indicates pond water fertility which leads to shrimp farming operations.

**Table 4. Correlation of dissolved oxygen with vibrio bacteria and total pond water bacteria**

|          | Vibrio bacteria | Total bacteria |
|----------|-----------------|----------------|
| DO       | Pearson Correlation | -0.137* | -0.126 |
| Sig. (2-tailed) | .024  | .041        |
| N        | 271              | 263          |

*Note is Correlation is significant at the 0.05 level  
** Correlation is significant at the 0.01 level

Water quality white leg shrimp culture shows that the results are suitable for white leg shrimp life. The average pH of pond water is 7.80 ± 0.25, with the lowest at pH 7.40 and the highest at pond water at pH 8.70. The average temperature of pond water is (26.15±0.93) °C, ranging between 24.00 °C to 28.00 °C. The average salinity of pond water is 27.09±1.91 g l$^{-1}$, where the highest salinity is 30 g l$^{-1}$, and the lowest is 24 g l$^{-1}$. The moderate transparency of pond water is (33.34±11.60) cm, with a transparency range of 20 cm to 80.00 cm. DO ranges 3.84-6.48 mg l$^{-1}$ with a mean (4.71±0.51) mg l$^{-1}$. The degree of acidity (pH) during white leg shrimp culture is still within the tolerance range for the life of white leg shrimp, which is 7.60-8.80. The pH range can be said to support the continuation of shrimp farming. According to [26], the optimal pH values for white leg shrimp farming range from 7.0 to 8.5 with a tolerance of 6.5-9.0. While according to Poernomo [27], a suitable pH range for shrimp culture is 8 to 8.5 because shrimp can experience optimal growth in that range.

The concentration of water pH affects the shrimp's appetite and chemical reactions in the water. In addition, pH below the tolerance range causes difficulty changing the skin where the skin becomes soft and survival is low (29). The salinity range in each pond is still within the tolerance limits for white leg
shrimp culture (27.30-28.24) g l⁻¹. This salinity is consistent with the opinion of (29), that white leg shrimp can live in the range of 0-45 g l⁻¹ salinity but grow well at 15-25 g l⁻¹. Meanwhile, according to (30), white leg shrimp have a wide optimal tolerance of saltiness of 15-35 mg l⁻¹. During the cultivation of white leg shrimp in each pond ranged (26.34-26.38) °C. The temperature range is still within the tolerance range of white leg shrimp. According to (31), the optimal water temperature for the growth of white leg shrimp ranges between 26-32°C. This temperature is consistent with the results of research (32) that the lowest temperature is 23°C and the maximum is 32°C in pond one (dry season) and pond 2 (rainy season), the lowest temperature is 22°C, and the maximum is 32°C. If the shrimp's body temperature is higher than the optimum value, the metabolism in the shrimp's body takes place quickly.

Similarly, the chemical parameters of water in the form, NH₄⁺, NO₂⁻, NO₃⁻, PO₄³⁻, TOM and total alkalinity. The average NH₄⁺ of each pond plot had a reasonably high diversity (1.41±1.39) mg l⁻¹ with a range of values 0-5.40 mg l⁻¹, NO₂⁻ (2.15±3.73) mg l⁻¹ with a range of values 0-15.00 mg l⁻¹, NO₃⁻ (9.63±11.71) mg l⁻¹ with a range of values 0-45.00 mg l⁻¹, PO₄³⁻ (1.39±1.11) mg l⁻¹ with a range of values 0.20-4.00 mg l⁻¹, TOM (71.27±4.44) mg l⁻¹ in the range 47.99-80.89 mg l⁻¹ and total alkalinity (186.25±30.78) mg l⁻¹ in the field 124.00-276.00 mg l⁻¹. Ammonia value in the study was a minimum of 0.057 mg l⁻¹ and a maximum of 0.1 mg l⁻¹. Ammonia range is still in a decent condition for the growth of white leg shrimp. According to (33) that the relatively safe ammonia concentration is below 0.1 mg l⁻¹. If the ammonia concentration value exceeds will be toxic and endanger the life of shrimp. According to (34), the ammonia content for juvenile white leg shrimp ranges between 0.4-2.31 mg l⁻¹.

4. Conclusions
DO levels in the dry season are higher than DO levels in the rainy season by following a polynomial regression pattern. The highest DO level was reached at 11 39” 2 and then decreased again to 20 15’ 2 and after that DO rose again along with the decrease in water temperature of white leg shrimp ponds. The DO in a light bottle is a quadratic regression model, and the DO model is a linear regression, with a rate of DO decrease is 0.6338 mg l⁻¹ hour for dark bottles. During one of the shrimp cultures, the DO model showed an inverse quadratic equation with the lowest oxygen solubility level on day 57. DO was positively correlated with changes in salinity and transparency and negatively related to ammonium, nitrate, phosphate, total alkalinity, and total bacteria count.

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