Dissolved oxygen models in intensive culture of whiteleg shrimp, *Litopenaeus vannamei,* in East Java, Indonesia

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Abstract. This study was conducted to determine a model of dissolved oxygen and its relationship with water quality in intensive aquaculture ponds of whiteleg shrimp, *Litopenaeus vannamei* in East Java. This study used a causal design with an ex-post-facto or natural phenomenon-based descriptive method in order to pursue the processes in the shrimp ponds and their existing conditions through observations of the intensive farming activities for about 100 days. Pond management followed a standard operating procedure under Best Aquaculture Practices Certification. Materials and facilities used in the study were eight intensive-patterned ponds of 3,292.50±347.02 m^2, with a stocking density of 119.84±18.52 individuals m^{-2}, production facilities and infrastructures, and water quality measuring equipment. The main water quality measured was dissolved oxygen at 22.00 hrs from the beginning of shrimp farming to the harvest time and daily dissolved oxygen measured every 2 hours to obtain a model of daily dissolved oxygen. Other supporting water quality parameters measured were daily pH, temperature, salinity, and transparency. Ammonium, nitrite, nitrate, phosphate, organic matter, carbonate, bicarbonate, total alkalinity, phytoplankton, and total bacteria were measured weekly. Data were collected and analyzed to assess the diversity of conditions in each pond and model the relationship of daily dissolved oxygen in one culture cycle. Correlation tests were also done between dissolved oxygen and other water quality measures. To determine the relationship between variables, data analysis used version 16 of SPSS. Results showed that mean dissolved oxygen in whiteleg shrimp farms was 4.84±0.41 ppm, and daily relationship model was $Y = -0029\ 0732\ T^2 + T + 2.120$ ($R = 0.83$; $\alpha = 0.01$) with the highest dissolved oxygen recorded at 12:35 hours, whereas the relationship model of dissolved oxygen in one culture cycle was $y = -0011\ t + 5.7164$ ($R^2 = 0.71$; $\alpha = 0.00$). Dissolved oxygen was positively correlated with pH, temperature, transparency, and negatively correlated with salinity, phosphate, total organic matter, Shannon-Wiener index, dominance index and total bacteria.

Key Words: brackish water ponds, aquaculture, water quality, diversity index, dominance index.

Introduction. Dissolved oxygen (DO) is one of the important factors affecting the growth and the health of whiteleg shrimp, *Litopenaeus vannamei,* held in the concrete ponds under an intensive farming system. It is also an important limiting factor for cultivation activities of all aquatic organisms to survive and grow, with some exceptions, such that the amount of DO should meet the living requirements of the aquatic organisms. The solubility of oxygen in nature is dependent upon the physical and chemical properties and biochemical activities of the body of water. Low oxygen solubility can reduce feeding activities and kill the aquatic organisms present. DO regulates various biochemical processes of water quality, such as nitrification cation process, denitrification, and organic compound degradation. Parameters that can control DO in the water are oxygen intake of the sediment, oxygen production from photosynthesis, oxygen consumption by the aquatic organisms, biochemical activities in the water and aeration (Datta 2012; Anongponyoskun et al 2012). Oxygen concentration generally increases in the pond during the daytime, which is caused by the photosynthetic process, and its decline at night results from the predominance of respiration of plants and animals during this period (Chen & Kou 1998).

One of the problems in the intensive shrimp farming system is a high density of whiteleg shrimp in most operations, which needs a large amount of feed and DO. DO is widely acknowledged as one of the most important variables in aquaculture (Lin & Chen 2003; Schuler 2008; Cobo et al 2014). Increasing size of the growing shrimp will also increase the amount of waste so that the oxygen demand for biochemical activities in the intensive pond water will not be enough and therefore, cannot only rely on the DO available in the pond. Moreover, 15% of feed provided will dissolve in the water and 20% will be returned to the environment as feces (Primavera 1994). According to Boyd (1998), about 25-35% of nitrogen and 15-25% of phosphorous are left in the shrimp tissue. To produce a ton of shrimp, approximately 12.6-21.0 kg of nitrogen and 1.8-3.6 kg of phosphorus is lost into the water. In general, about 75% of N and P from shrimp feed will become waste in the pond (Crab et al 2007). Cao (2012) indicated that input of N and P of feed stored in the shrimp body as biomass was only 32% and 15%, respectively, and the rest would be released as waste in the pond. As a result, changes in nutrients will occur in the pond and make the pond water quality change as well (Burford & Lorenzen 2004). Unconsumed feed and shrimp excretion will produce an accumulation of organic matter in the rearing media that needs oxygen to decompose (Boyd 1989). Increased duration of the shrimp culture will also raise the waste load. Consequently, the need for oxygen for biochemical activities in the intensive pond water will not be enough to merely depend upon the natural oxygen in the pond. Therefore, it is necessary to study the models of daily DO during whiteleg shrimp farming and the physicochemical factors influencing the DO changes.

Material and Method

Description of the study sites. This study was conducted from May to December 2015, used a causal design with an ex-post-facto design or natural phenomena-based analytical method in order to study the processes in the shrimp ponds under existing conditions through observations on the intensive whiteleg shrimp farming activities for about 100 days. Data were collected from the intensively managed whiteleg shrimp ponds in Bomo village, in the district of Rogojampi Situbondo, East Java, Indonesia (8°22'27.1"S 114°21'02.2"E). Pond management activities followed standard operating procedures under the Best Aquaculture Practices Certification (BAPC, F10488). Eight rearing ponds of 3,292.55±347.02 m^2 were used with a mean stocking density of 119.84±19.68 individuals m^{-2}. Water quality data were taken at the beginning of stocking to the harvest time. These were water pH, temperature, salinity, transparency and dissolved oxygen that was measured in the morning and during the day, except that dissolved oxygen was measured at 22:00 hours and every two hours near the shrimp harvest time. Ammonium, nitrite, nitrate, phosphate, total organic matter, carbonate, bicarbonate, total alkalinity, phytoplankton, and total bacteria were measured two times a week.

Water sampling. Physico-chemical parameters observed were DO, temperature (T), transparency (Trp), salinity (S), pH, ammonium (NH_4-N), nitrite (NO_2-N), nitrate (NO_3-N), phosphate (PO_4^{3}-P), total organic matter (TOM), total alkalinity (Alk), carbonates (CO_3^{2-}), bicarbonates (HCO_3^{-}), total bacteria and phytoplankton. DO, temperature, transparency, salinity, pH were measured in situ every day. DO was measured using a YSI Oxygen Meter (Model 550A) and transparency was obtained using a Secchi disk. Water temperature was recorded using a mercury thermometer, and pH using indicator strips (5.0–10) Merck. Salinity was recorded by using a Salinity Hand Refractometer MASTER-S10ɑ Atago. Water samples were also taken for other water quality parameter measurements. Water samples were taken twice a week using sterile 500 mL-sample bottles from the surface, mid-water, and bottom, and brought back to the laboratory for analysis. Measurements of ammonium, nitrite, nitrate, and phosphate used a colorimeter (Merck) and total organic matter, carbonate, bicarbonate, total alkalinity applied the procedure of APHA (1980).

Sampling bacteria was done when and in the same area as the DO was measured. Bacteria were collected using 50 mL sterile sample vials, fully filled. The aquatic bacteria samples were stored in a cool box previously prepared with ice and analyzed in SWK laboratory of Bomo, Rogojampi district, Banyuwangi Regency, East Java. The water sample was diluted in series (up to 10^{-2}), and spread on Tryptic Soy Agar (TSA) media in a petri dish, and incubated at room temperature for 24–48 hours. The bacterial colonies were morphologically characterized based upon shape, color, elevation, and size of colonies formed and then counted using Total Plate Count (TPC) method (Prescott et al 2002).

Phytoplankton was collected using sample bottles, then preserved in 4% formaldehyde. The phytoplankton (cells L^{-1}) were counted using a Sedgwick-rafter under the microscope and assessed using APHA (1980):

$$N = 100 (P \times V) / (0.25 \times W) \text{ (liters)} \qquad (1)$$

where: N = the amount of phytoplankton per liter, P = number of phytoplankton, V = volume of filtered plankton samples, and W = filtered water volume (liter).

Species diversity was calculated using Shannon-Wiener Diversity Index (Poole 1974):

$$\text{Diversity Index } (H') = -\Sigma p_i \ln p_i, \qquad (2)$$

where: H' = diversity, $p_i = n_i/N$, n_i = number of individuals of all species *i*, and N = total number of individuals.

Dominance index was calculated by:

$$\text{Dominance index Simpson } D = 1/(\Sigma P_i^2). \qquad (3)$$

Statistical analysis. All data were grouped with a time of measurement, i.e., daily, weekly and harvest time. The analyzed variables covered: 1) selection of variables in each culture pond in order to make the pond grouping. It was done by looking at the similarities and differences of several variables in the ponds; 2) ANOVA was used to see if there were any difference in the plots at 95% confidence level, and if any, the least squares difference test (LSD) was applied; 3) analysis of covariance and regression was also used to find the relationship of DO with time of culture and other water quality parameters using SPPS ver.16 and continued with determining the quantitative relationship. Each analysis was tested to determine the level of confidence.

Results and Discussion. Mean of water quality data during the cultivation of whiteleg shrimp is shown in Table 1, except that biological parameters are presented in Table 2 and DO is presented in Table 3. Daily water quality parameters measured were oxygen (O_2), temperature (T), salinity (S), pH, and water transparency (Trp). Table 1 shows that mean DO was 4.84±0.41 ppm (part per million) with a range of 3.48 ppm to 6.90 ppm. Mean water temperature was 26.3±0.87°C in the early morning and 27.92±1.13°C in the afternoon. Water salinity was on average 27.86±1.32 ppt with a range between 24 ppt (part per thousand) and 30 ppt. Mean pH was 7.93±0.36 in the morning and 8.45±0.37 in the afternoon with the lowest of 7.50 and the highest of 8.80 in morning measurements. Mean water transparency was 36.21±15.41 cm with a range from 20.00 cm to 95.00 cm.

Daily water quality parameters were suitable for whiteleg shrimp aquaculture production. The optimum range for the growth of whiteleg shrimp was from 28 to 32°C (Hirono 1992; Boyd 1998; Gunalan et al 2010; Hernandez et al 2011). The optimal salinity concentrations range from 25 ppt to 30 ppt (Maica et al 2014; Sakas 2016). Water environments with pH of 7.5-8.8 are appropriate for shrimp aquaculture production (Hernández-Ayon et al 2003; Hernández et al 2011; Chen et al 2015). Optimal water transparency ranges from 35 cm to 45 cm depth (Boyd & Tucker 1998). In the present study, mean of transparency was 40.23±29.21 cm. Water transparency in the culture pond depends on the availability of zooplankton or phytoplankton and suspended solid particles. The transparency of the pond waters gradually rose from the stocking day to the harvest day. Low transparency reduces the DO content. The common recommendation is to use enough fertilizer to maintain adequate phytoplankton at a visibility of 30 to 45 cm (Boyd & Tucker 2014).

Table 1

Physical and chemical parameters of the whiteleg shrimp culture media

Water quality parameters		*Ponds*							
		P-1	*P-2*	*P-3*	*P-4*	*P-5*	*P-6*	*P-7*	*P-8*
O_2 (ppm)	Mean	4.82±0.65	5.97±0.44	4.76±0.46	4.74±0.39	4.77±0.43	4.78±0.58	4.76±0.52	4.70±0.36
	Range	3.69-6.90	3.51-4.57	3.59-6.19	3.56-5.62	3.59-6.16	3.48-6.54	3.48-5.61	3.60-6.48
T (^{0}C)[1]	Mean	26.35±0.90	26.38±0.90	26.38±0.92	26.37±0.88	26.37±0.88	26.34±0.96	26.35±0.81	26.37±0.82
	Range	28.0-24.0	28.0-24.0	28.0-24.0	28.0-24.0	28.0-24.0	28.0-24.0	28.0-24.0	28.0-24.0
S (ppt)[1]	Mean	27.57±0.99	27.92±1.35	27.50±1.32	28.21±1.21	28.24±1.25	27.30±1.49	27.95±1.61	27.69±1.22
	Range	30.0-26.0	30.5-25.0	30.0-24.0	30.5-26.0	30.5-26.0	30.0-24.0	30.5-25.0	30.5-26.0
pH[1]	Mean	8.01±0.39	7.86±0.35	7.95±0.35	7.89±0.37	7.93±0.38	7.98±0.36	7.86±0.35	7.95±0.39
	Range	8.8-7.6	8.7-7.5	8.8-7.5	8.8-7.5	8.8-7.5	8.8-7.5	8.7-7.5	8.8-7.4
TRP (cm)[1]	Mean	37.82±13.14	36.04±16.92	33.90±18.17	35.63±15.29	34.77±14.03	35.38±14.61	37.08±13.65	34.52±15.90
	Range	95.0-20.0	95.0-20.0	95.0-20.0	95.0-20.0	120.0-20.0	90.0-20.0	95.0-25.0	90.0-20.0
NH_4-N (ppm)[2]	Mean	1.31±0.45	1.29±1.24	1,12±1.19	1.20±1.04	1.37±0.92	1.20±1.09	1.01±1.06	1.39 ±1.45
	Range	3.9-0.0	5.4-0.0	5.4-0.0	5.0-0.0	3.9-0.0	3.5-0.0	3.5-0.0	3.9-0.0
NO_2-N (ppm)[2]	Mean	0.70±1.66	2.10±3.74	1.50±3.45	2.42±4.34	2.42±4.34	0.50±1.04	1.79±2.79	3.29±4.33
	Range	10.0-0.0	10.0-0.0	7.5-0.0	15.0-0.0	14.0-0.0	15.0-0.0	15.0-0.0	4.0-0.0
NO_3-N (ppm)[2]	Mean	4/39±6.56	9.27±1.05	7.16±10.39	8.76±11.98	8.59±12.09	4.08±7.42	9.14±12.56	14.30±15.25
	Range	45.0-0.0	35.0-0.0	25.0-0.0	35.0-0.0	30.0-0.0	35.0-0.0	35.0-0.0	30.0-0.0
PO_4-P (ppm)[2]	Mean	1.29±1.32	1.22±0.90	1.03±1.04	1.04±1.09	1.04±1.08	0.58±0.57	1.54±1.36	1.37±1.13
	Range	4.0-0.2	3.0-0.2	4.0-0.2	2.8-0.0	4.0-0.2	4.0-0.0	4.0-0.2	1.75.0-0.0
TOM (ppm)[2]	Mean	64.73±9.77	67.78±7.20	68.21±6.57	68.82±7.40	68.30±7.13	66.14±7.86	68.62±6.35	69.96±7.55
	Range	80.9-54.4	80.7-50.6	79.1-46.1	75.2-49.3	77.10-5.1	77.1-52.5	77.1-50.6	77.1-49.9
$C0_3^{2-}$ (ppm)[2]	Mean	17.6±25.1	10.62±23.2	13.2±26.3	11.5±21.7	14.2±21.7	15.17±23.4	10.34±20.9	11.41±21.2
	Range	84.0-0	68.0-0.0	84.0-0.0	84.0-0.0	88.0-0.0	72.0-0.0	72.0-0.0	68.0-0.0
HCO_3^- (ppm)[2]	Mean	167.1±46.9	163.1±44.0	158.6±45.81	170.6±47.3	167.9±45.6	157.5±45.8	177.7±52.5	167.6±46.0
	Range	280.0-88.0	260.5.0	256.0-80.0	240.0-76.0	236.0-60.0	248.0-84.0	248.0-100.0	252.0-76.0
Alk (ppm)[2]	Mean	1.847±34.7	173.7±9.9	172.0±26.7	178.9±37.3	182.1±30.8	172.7±26.9	188.1±41.5	177.3±33.3
	Range	280.0-128.0	260.0-120.0	256.00-136.0	240.0-128.0	236.0-124.0	248.0-110.0	248.0-148.0	252.0-136.0

Note: [1] (daily monitored); O_2 (Oxygen); pH (power of hydrogen); S (salinity); T (temperature); TRP (transparency); [2] (monitored two times a week); NH_4-N (ammonium), NO_2-N (nitrite), NO_3-N (nitrate), PO_4-P (phosphate), TOM (total organic matter), $C0_3^{2-}$ (carbonate); HCO_3^- (bicarbonate), Alk (Alkalinity).

Table 2

Mean of biological parameters (phytoplankton and bacteria) water quality of the white eg shrimp

		Ponds							
		P-1	*P-2*	*P-3*	*P-4*	*P-5*	*P-6*	*P-7*	*P-8*
Phyto-plankton	N (x10^6)	10.76±13.34	12.37±11.53	18.87±25.92	20.01±29.96	9.13±8.55	10.72±12.16	8.75±9.49	20..81±9.75
	H	2.33±1.04	2.79±1.35	2.49±0.98	2.46±1.07	2.42±1.04	2.16±0.99	2.52±0.20	2.41±1.05
	D	0.53±0.26	0.44±0.22	0.47±0.20	0.49±0.22	0.51±0.26	0.56±0.25	0.50±0.25	0.49±0.24
Total bacteria (x 10^6)		21.21±23.30	20.95±23.39	22.80±33.47	24.10±18.20	23.60±20.40	24.25±26.22	17.95±19.67	30.56±21.07

Note: N (sum of phytoplankton); H (diversity index of phytoplankton); D (dominance index of phytoplankton).

Mean ammonium concentration of each pond was 1.85±1.99 ppm with the highest reading of 4.38 ppm and the lowest of 0 ppm, for a fairly high variability. Mean nitrite was 3.38±1.77 ppm with a highest of 10.95 ppm and lowest of 0 ppm. Mean nitrate was 8.09±11.21 ppm with the highest reading of 33 ppm and lowest of 0 ppm. Mean phosphate was 1.14±1.05 ppm with a highest of 3.33 ppm and a lowest of 0.14 ppm. Mean TOM was 67.97±8.23 ppm with a highest of 77.56 ppm and a lowest of 51.44 ppm. Mean carbonate was 12.21±21.76 ppm with a highest of 88 ppm and a lowest of 0 ppm. Mean bicarbonate was 169.69±47.00 ppm with a highest of 280.00 ppm and a lowest of 54.35 ppm. Mean total alkalinity was 181.39±34.29 ppm with a highest of 280 ppm and a lowest of 110 ppm.

Moreover, a mean abundance of phytoplankton of (137.91±182.26)x10^5 cells L^{-1} was found, with a highest of 1,737.50 x 10^5 cells L^{-1} and a lowest of 6.25x10^5 cells L^{-1}; a diversity index (H) of 2.41±1.00 with a highest of 5.46 and a lowest of 1.00; and a dominance index (D) of 0.51±0.24 with a highest of 1.00 and the lowest of 0.19. This is in accord with Stirn (1981), where if H' < 1, then the community is declared unstable if H is around 1-3 then the stability of the biota community is moderate and if H' > 3, the stability of biota community is good. The greater the H-index, the higher the phytoplankton diversity. A high H' index reflects also a better place to live. The H-index of conditions observed in the ponds was easily changed by relatively small environmental influences. Dominance index (D) of the phytoplankton in the ponds was 0.51±0.24 (ɑ = 0.177), a moderate dominance index (Legendre & Legendre 1998).

Water quality parameters monitored two times a week were suitable for whiteleg shrimp culture. Ammonium range remained good for whiteleg shrimp growth. Lazur (2007) recommended that ammonium is less than 5.0 ppm. LC50 of ammonium for juvenile whiteleg shrimp is 42.92 ppm under salinity of 18 ppt (Schuler 2008). Nitrite concentration should be < 5 ppm (Lin & Chen 2003; Timmons & Ebeling 2007). Similarly, Furtado et al (2015) recommended nitrate concentrations < 177 ppm, but Kuhn et al (2010) recommended nitrate < 200 ppm, and alkalinity of 80-200 ppm (Ching 2007). The bacterial abundance of 10^{6}-10^{8} CFU g^{-1} indicates that the sediment and water quality conditions will support the shrimp's growth, particularly the health status of cultured penaeids (Gopal et al 2005). Mean total bacteria in the shrimp ponds was within 10^{3}-10^{4} CFU mL^{-1} (Tookwinas 2000).

Table 3

Dissolved oxygen (DO) measurements during the shrimp farming

Ponds	*Mean (ppm)*	*Min (ppm)*	*Max (ppm)*
P-1	4.82 ±0.65^{a}	3.69	6.90
P-2	5.97 ± 0.44^{a}	3.51	4.57
P-3	4.76 ± 0.46^{a}	3.59	6.19
P-4	4.74 ± 0.39^{a}	3.56	5.62
P-5	4.77 ± 0.43^{a}	3.56	6.25
P-6	4.78 ± 0.58^{a}	3.59	6.16
P-7	4.76 ± 0.52^{a}	3.48	6.54
P-8	4.70 ± 0.36^{a}	3.48	5.61

Note: ɑ (0.486) > 0.5; a = not significant.

Table 3 shows that mean DO was 4.84±0.41 ppm with a range of 3.48 ppm to 6.90 ppm. DO in each pond was not significantly different (ɑ <.05), such that each pond could be used as replication in this study. Clifford (1998) reported that minimum DO level for healthy shrimp was 3.0 ppm, and DO of < 2.0 ppm could potentially kill aquatic organisms. Similarly, DO below 3 or 4 ppm for a short period of time could cause stress and would lead to greater susceptibility to disease, low appetite and slow shrimp growth (Boyd & Tucker 1998). Furthermore, Boyd (2016) stated that to maintain the DO levels above 3.0 ppm in the intensive pond aquaculture of whiteleg shrimp, the pond should be aerated by calculating the production target of 400 kg to 500 kg/HP (horsepower) of the paddlewheel. Suprapto (2005) argued that the optimum DO for whiteleg shrimp culture was > 3 ppm with a tolerance of 2 ppm. Adiwijaya et al (2003) suggested that the optimal range of DO during shrimp farming was 3.5 ppm to 7.5 ppm. Sugama (2002) also added that DO level during cultivation of whiteleg shrimp should be > 3.5 ppm. According to Vinatea et al (2009), the minimum need of juvenile whiteleg shrimp for DO was 4.1 ppm. DO in shrimp ponds is a function of salinity, temperature, density and size of shrimp (Vinatea et al 2011). Ideally, DO requirement of whiteleg shrimp is > 4 ppm (Xincai & Yongquan 2001). Re & Díaz (2011) who studied juvenile whiteleg shrimp showed that the optimum growth would be obtained at DO level of 5.5 ppm. Moreover, Walker et al (2009) found a correlation between water salinity and shrimp size of whiteleg shrimp, in which the greater the size of whiteleg shrimp was, then the lower the oxygen requirement for growth was. Similarly, hyperosmotic and hypoosmotic environmental conditions could increase the oxygen need. The cumulative effect of the water quality parameters would reflect the shrimp production (Chakravarty et al 2016). Although the statistical analysis on daily DO in each pond did not show significant differences (Table 3) when plotted to the production of whiteleg shrimp and the amount of feed consumed in each shrimp pond (Figure 1), the survival rate (SR) decreased with decreasing DO. Similarly, feed conversion ratio (FCR) of shrimp also decreased with increased DO concentration in the pond. In other words, increased mean DO in water ponds can improve the efficiency of shrimp feed.

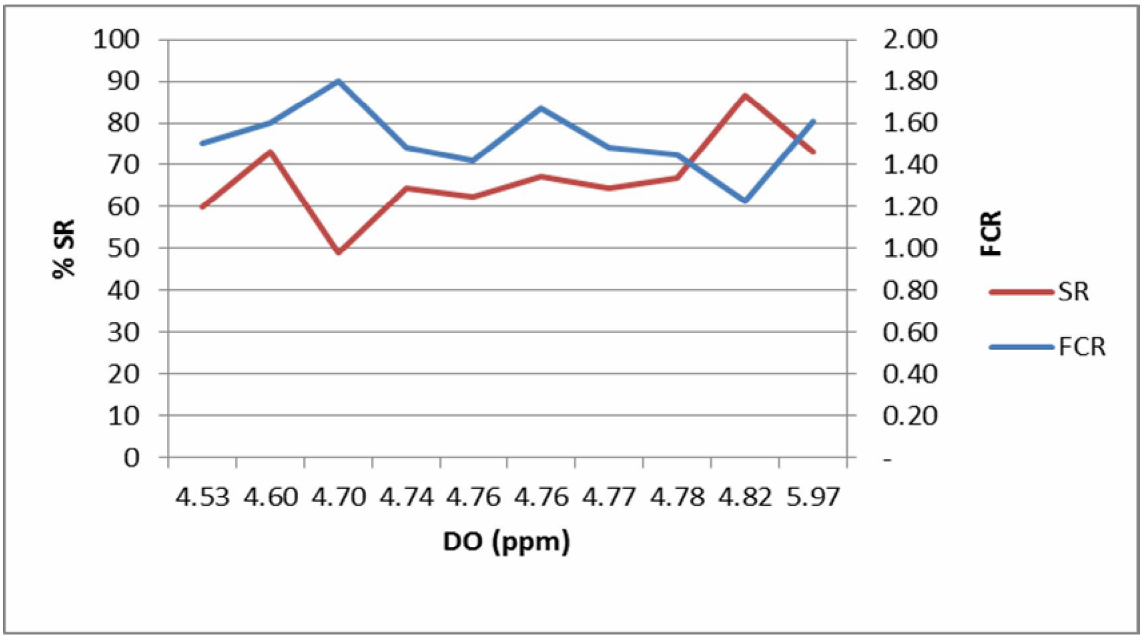

Figure 1. Dissolved oxygen relationship with the survival rate (SR) and feed conversion ratio (FCR) for whiteleg shrimp.

The distribution pattern of DO during the cultivation was obtained by plotting the DO against culture time (Figure 2). Figure 2 shows that mean DO of each pond decreases with a number of culture days. The regression of DO and number of culture days is y = -0.011(T) + 5.72 (R^2 = 0.71; α =0.00). Increased number of culture days makes the DO decrease linearly reaching 0.011 ppm per day. Ruiz-Velazco et al (2013) found that low DO occurred at high stocking densities and over long periods of shrimp farming. The accumulation of organic matter in ponds could increase the oxygen consumption as well (Milstein et al 2005).

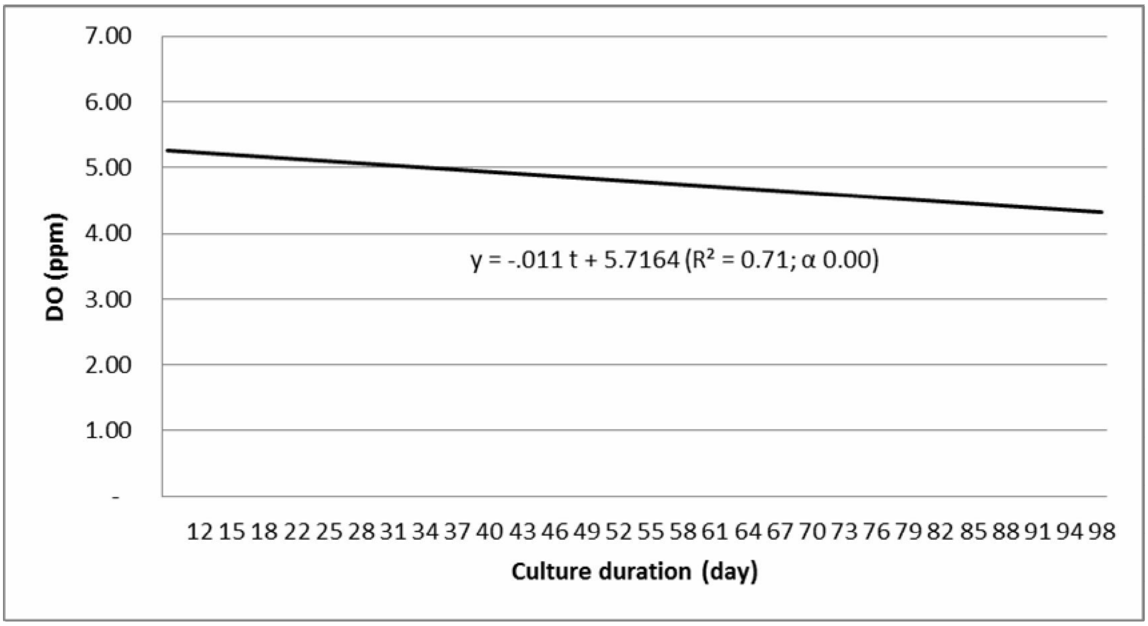

Figure 2. The relationship between oxygen solubility and culture duration of whiteleg shrimp.

The pattern of daily DO in the culture pond can be modeled by a quadratic equation. It was obtained through oxygen measurements every 2 hours. Oxygen measurement was done at the harvest time. The DO measurements were then plotted against the observation time and showed a quadratic regression equation $Y = -0.029(T^2) + 0.73(T) + 2.12$ ($R = 0.83$; $\alpha = 0.02$). The highest DO of whiteleg shrimp ponds in Bomo Village, Rogojampi District, Banyuwangi Regency, East Java, was recorded at 12:35 hrs. It is almost the same as that found by Kurniawan et al (2014) in Situbondo, at 13:00 hrs. The highest DO of the shrimp ponds occurred at noon when the phytoplankton produced oxygen through photosynthesis (Conte & Cubbage 2001).

DO began to decline after 12:37' hours and reached the lowest point before 22:00 hours (Figure 3). Nevertheless, DO concentration of the shrimp pond rose from 22:00 hourss to sunrise and reached its peak at noon (Figure 3). Figure 3 shows that the increase in DO occurs at night, in spite of the lack of photosynthesis. This could result from decreased water temperature at night up to the morning after sunrise, and it would increase oxygen diffusion from the atmosphere up to certain level. The decline in DO in the pond is high enough and the lowest point was recorded at 21:07 hours. The DO, then, rose steadily until 12:00 hrs. This condition is in agreement with Boyd (2010) that DO of the pond water is affected by water temperature. The oxygen solubility in the pond water is influenced by temperature changes and other parameters, such as salinity, pH, transparency, and oxidation-reduction occurring in the pond water. Allen et al (1984) stated that changes in oxygen solubility were same as oxygen input from photosynthesis, aeration, natural agitation, water input, and reduction from respiration of phytoplankton and fish, decomposition of detritus, and water outflow. The change rate of each category is modeled as a function of external and internal environmental conditions (in the pond).

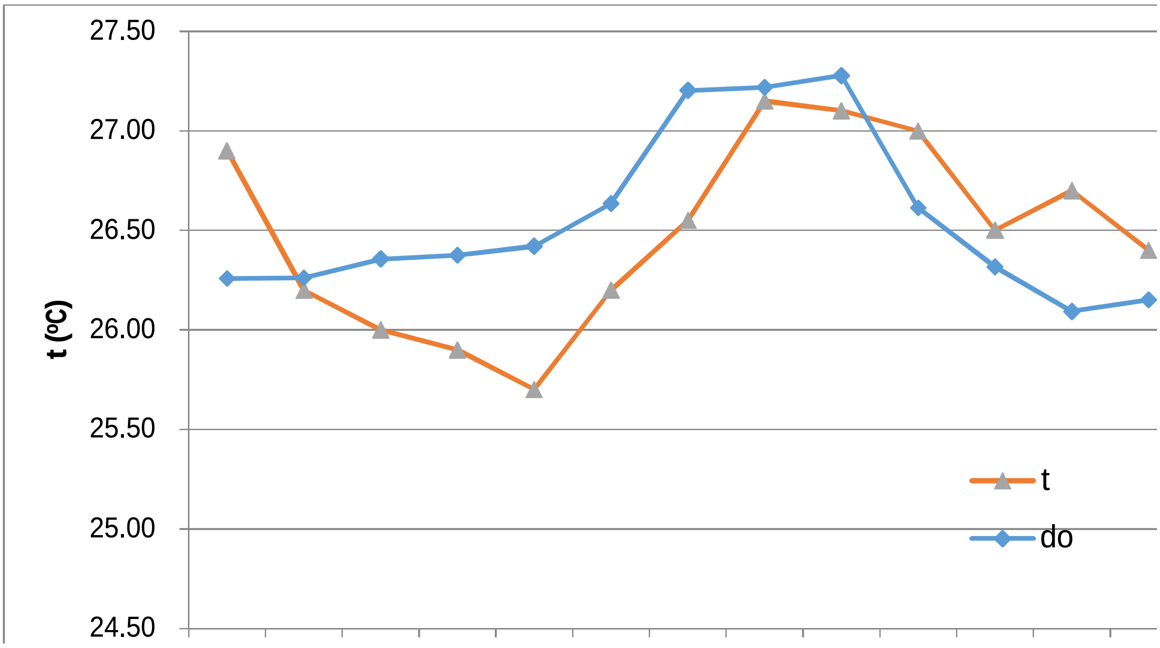

Figure 3. Relationships between the oxygen solubility and temperature of the water and observation time.

DO of the pond water is closely related to physicochemical factors. Correlation values between DO concentration and physical factors are presented in Tables 4 and 5. Table 4 shows that DO concentration of the pond water was positively correlated with pH, transparency and negatively correlated with salinity. There were correlations between DO and chemical factors, such as PO_4-P, TOM, but not with NH_4-N, NO_2-N, NO_3-N, HCO_3^- and total alkalinity. Similarly, Table 5 demonstrates that DO was correlated with the Shannon-Wiener index, dominance index, and total bacteria, but it was not correlated with the number of phytoplankton (N). Li et al (2007) observed interactions between abiotic factors and oxygen consumption in a closed system without aeration.

Table 4

Correlation of dissolved oxygen with physical and chemical parameters

		DO	pH	S	T	Trp	NH_4-N	NO_2-N	NO_3-N	PO_4-P	TOM	HCO_3^-	Alk
DO	Pearson correlation	1	.57**	-.40**	.54**	.44**	-0.19	-0.14	-0.2	-.39**	-.26*	0.22	-0.22
	Sig. (2-tailed)		0	0	0	0	0.084	0.23	0.074	0	0.021	0.052	0.051
	N	79	79	79	79	79	79	79	79	79	79	79	79

Note: * (Correlation is significant at the 0.05 level); ** (Correlation is significant at the 0.01); DO (dissolved oxygen); pH (power of hydrogen); S (salinity); T (temperature); Trp (transparency), NH_4-N (ammonium), NO_2-N (nitrite), NO_3-N (nitrate), PO_4-P (phosphate), TOM (total organic matter), HCO_3^- (bicarbonate), Alk (Alkalinity).

Table 5

Correlation of dissolved oxygen with biological parameters

		DO	*N*	*H*	*D*	*Total of bacteria*
DO	Pearson correlation	1	-0.036	-.288*	-0.268*	-.289**
	Sig. (2-tailed)		0.751	0.011	0.012	0.01
	N	79	79	79	79	79

Note: * (Correlation is significant at the 0.05 level); ** (Correlation is significant at the 0.01); DO (dissolved oxygen); N (sum of phytoplankton); H (Shannon-Wiener index); D (Dominance index).

Kumar et al (2012) found a positive correlation between water temperature and salinity, salinity and primary productivity, primary productivity and DO, DO and nitrate, and nitrate and amount of phosphorus available in all four ponds of whiteleg shrimp farms in Patelwadi village, Diu (Union Territory) and also stated that overall mean value of nutrients in the water reflected pond water fertility for shrimp farming operations. Zafar et al (2015) also found the interaction of DO with nitrate, ammonium in wet season and temperature in dry season at shrimp and prawn farming in the southwest region of Bangladesh.

Conclusions. Dissolved oxygen model in intensive the whiteleg shrimp, *L. vannamei* ponds had a linear regression pattern during the shrimp farming following the equation: y = -0.011(T) + 5.72 and quadratic pattern on daily basis: $Y = -0.029(T^2) + 0.73(T) + 2.12$. Dissolved oxygen was also positively correlated with temperature, salinity, pH, and negatively correlated with salinity, phosphate, organic matter, carbonates, bicarbonates, Shannon-Wiener index, dominance index and total bacteria.

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