Pacific whiteleg shrimp (*Litopenaeus vannamei*) behaviour, oxygen consumption and sediment oxygen demand at different sediment redox potential

[1]Wiyoto Wiyoto, [2]Sukenda Sukenda, [2]Enang Harris, [2]Kukuh Nirmala, [2]Daniel Djokosetiyanto

[1] Production Technology and Management of Aquaculture, College of Vocational Studies, IPB University (Bogor Agricultural University), Bogor, Indonesia; [2] Department of Aquaculture, Faculty of Fisheries and Marine Sciences, IPB University (Bogor Agricultural University), Bogor, Indonesia. Corresponding author: W. Wiyoto, wiyoto@apps.ipb.ac.id

Abstract. Understanding the shrimp behaviour, shrimp oxygen consumption, and sediment oxygen demand in a culture tank could contribute to the improvement of *Litopenaeus vannamei* culture. The objective of the study was to evaluate the influence of sediment redox potential on the white shrimp behaviour. Shrimp with an average body weight of 7.27 ± 1.20 g were distributed in tanks containing substrate at different redox potential (+100, -106, and -210 mV). Subsequently, the vertical distribution of the shrimp was observed directly at 1 h intervals. We found that the sediment redox potential did not affect the behaviour of the shrimp and the percentage of shrimp that stayed on the bottom ranged from 72 to 81%. Shrimp oxygen consumption (OC) rate was 0.33±0.06 g O_2 kg^{-1} h^{-1}. The levels of sediment oxygen demand (SOD) in the treatment tanks were 7.78±1.67 mg O_2 m^{-2} h^{-1}, 12.22±0.96 mg O_2 m^{-2} h^{-1} and 27.22±0.96 mg O_2 m^{-2} h^{-1} for the RP+100 mV, RP-106 mV and RP-210 mV, respectively.
Key Words: culture tank, substrate, vertical distribution.

Introduction. Pacific white leg shrimp *Litopenaeus vannamei* is an economically important aquaculture species which has several advantages such as the availability of specific pathogen-free post larvae, relatively high growth rate (up to 3 g $week^{-1}$), and considerably high survival rate (80-90%) (Briggs et al 2004). Furthermore, this species can be cultured at a wide range of temperature and salinity (Wyban & Sweeny 1991; Briggs et al 2004), at a high density (Wasielesky Jr. et al 2006), with a low feed conversion ratio (Babu et al 2014). With these characteristics, this species has been widely cultured by farmers and its production has been continuously increasing, comprising 77.5% of the global shrimp production (FAO 2018).

The increase in shrimp production needs to be supported by knowledge about the animal behavioural characteristics and the most optimal environmental conditions. Understanding animal behaviour is essential in developing optimum culture conditions that support the growth and production of the cultured species (da Costa et al 2016). There are only a few behavioural studies conducted on shrimp, most of them being related to the daily activity of *L. vannamei* (Soares Pontes et al 2006), the behaviour at different stocking densities (da Costa et al 2016) and feeding behaviour (Soares Pontes et al 2008).

Recently, most study related to shrimp culture only focus on culture practices, particularly the enhancement of culture intensity through the increase of stocking densities in association with mortality and growth performance (Krummenauer et al 2010). The study of *L. vannamei* behaviour at different sediment redox potentials can demonstrate whether or not the bottom conditions affect the shrimp's activities in this environment and, therefore, can contribute to the determination of the proper management of pond bottom. In addition, the behavioural profile of shrimp can also be used as a background knowledge to elucidate the effect of the bottom environments on the shrimp production (da Costa et al 2016). For instance, Avnimelech & Ritvo (2003) suggested that the increase of swimming activity in the attempt to avoid bad environment is one of the factors that cause a slower growth of the shrimp maintained in deficient sediments.

Not only the shrimp behaviour, but oxygen consumption (OC) by the cultivated shrimp and sediment oxygen demand (SOD) are also needed to be evaluated, especially for different environmental conditions. In shrimp pond culture, the oxygen supply is not only required for the shrimps, but also for the heterotrophic decomposition of organic matter that occurs in the sediment (Avnimelech & Ritvo 2003). The low concentration of oxygen in the intensive culture medium is the most limiting factor of production. The availability of oxygen near to the bottom surface is more important for shrimp, since shrimp is a benthic organism (Lester & Pante 1992; Briggs et al 2004).

The information on shrimp OC and SOD rates can be used to determine the number of aerators needed per unit of culture area. Vinatea & Carvalho (2007) noted that the number of aerators per unit of area can be calculated according to the water respiration rate by phytoplankton, sediment respiration rate from the decaying organic matter process and the cultured organisms respiration rate. This study observed the behavioural activity of *L. vannamei*, oxygen consumption and sediment oxygen demand concerning sediment redox condition.

Material and Method

Experimental animals. Pacific white leg shrimp was obtained from a commercial shrimp farm in Lampung, Indonesia, and acclimated in a semi-outdoor laboratory for 1 week before experimentation. The experiment was carried out at Laboratory of Aquaculture, College of Vocational Studies, IPB University, Bogor, Indonesia. Intermolt stage shrimp with an average body weight of 7.27±1.2 g were used for the experiment.

Experimental design. A completely randomized experiment was performed with three different substrate sediment redox potentials (no-substrate, +100 mV, -106 mV and -210 mV). The treatments were denoted as no-substrate (NS), sediment redox potential +100 mV (RP+100), sediment redox potential -106 mV (RP-106), and sediment redox potential -210 mV (RP-210). Pond sediment with a redox potential of -210 mV was obtained from a shrimp pond in Lampung, Indonesia, with an operational period of more than 5 years, whereas other sediments were obtained by mixing the pond sediment with garden soil, which has a positive redox potential (+100 mV). The ratio between pond sediment and soil for the -106 mV sediment was 1:2. The method for measuring sediment redox potential was performed based on Braker et al (2001) and Arsana et al (2003), i.e. by taking an average of three oxidation reduction potential (ORP) readings with an interval of 15 min.

Experimental setup. The experiment was conducted in a semi-outdoor laboratory using 12 tanks (for 4 treatments in 3 replication) of 30 cm x 30 cm x 120 cm, each containing 90 L (100 cm water depth) of filtered seawater. At the bottom of each tank, a soil substrate (Braker et al 2001; Arsana et al 2003) with different redox potential was added in a layer of about 5 cm. Shrimp with an average bodyweight of 7.27±1.2 g were randomly distributed into the experimental unit at a stocking density of 130 shrimps m^{-2} (12 shrimp $tank^{-1}$). During the experiment (6 hours), water temperature and salinity in each tank were maintained at 26.59±1.14°C and 25.00±0.00 g L^{-1}, respectively, whereas the initial dissolved oxygen concentration was 5.45±0.05 mg L^{-1}. To maintain the sediment redox potential and its effect on the dissolved oxygen concentration, no aeration was provided during the experiment.

Behaviour. One hour after being transferred to the tank, the shrimp behaviour was observed every one hour for 6 consecutive hours. During this period, no feed was offered to the shrimp. The observations included the vertical position of the shrimp in the tank.

The position of shrimps was categorized into 6 ranges of water depth, i.e. 0-10 cm, 10-50 cm, 50-75 cm, 75-90 cm, 90-95, and 95-100 cm.

Dissolved oxygen. At the end of the experiment (6 hours), dissolved oxygen was measured at a depth of 10 cm, 50 cm, 75 cm, 90 cm, 95 cm and 100 cm using a DO meter (Lutron DO-5510).

Oxygen consumption rate (OC) and sediment oxygen demand (SOD). Oxygen consumption rate was calculated without taking into account the air diffusion to the system by using the modified formula of Vinatea et al (2011):

$$OC = (IO-EO_{WS})/(B \times t)$$

Where: OC is shrimp oxygen consumption rate (g O_2 kg^{-1} h^{-1}), IO is the initial oxygen (g), EO is the end oxygen without substrate (g), B is biomass (kg), and t is the time (h). Sediment oxygen demand was calculated without taking into account the air diffusion to the system by using the formula modified from Vinatea et al (2011):

$$SOD = ((IO-EO)-(IO-EO_{WS}))/(A \times t)= (EO_{WS}-EO)/(A \times t)$$

Where: SOD is sediment oxygen demand (g O_2 kg^{-1} h^{-1}), IO is the initial oxygen (g), EO is the end oxygen (g), EO_{WS} is the end oxygen at treatment without substrate (g), A is the area of substrate (m^2), and t is the time (h).

Data analysis. Analysis of variance (ANOVA) was used to evaluate the differences between treatments at a significance level of 0.05. Significant differences between treatments were determined using a post-hoc Duncan test. Data normality and homogeneity of the variance were determined using Kolmogorov-Smirnov and Levene tests, respectively. The dynamic of dissolved oxygen concentration throughout the experimental period was analysed using repeated measures ANOVA. Statistical analyses were carried out using SPSS Statistics version 20 for Windows (SPSS Inc.).

Results and Discussion

Shrimp behaviour. The percentage of shrimp found at different water depths was not significantly different amongst the sediment redox potentials. However, the number of shrimps found on the sediment was higher compared to those found in the water column at any water depth ($p<0.05$). The percentage of shrimp that stayed on the sediment or in the water column at the depth of 95-100 cm was between 72-81% (Figure 1). Shrimps appeared to swim in the water column only for a limited time and not more than 11 seconds. This study discerns shrimp individual behaviours, which are complementary to the animal interactions with the environment.

Dissolved oxygen. There were no significant differences in the dissolved oxygen among sediment redox potentials (Figure 2). However, dissolved oxygen decreased with increasing depth and the range of oxygen between the surface and bottom sediment was 3.37-3.94 mg L^{-1}. The dissolved oxygen concentrations were significantly influenced by the water depth ($p<0.01$). The lowest dissolved oxygen concentration was observed at the bottom of the tank in treatment RP-210, which was 3.37±0.01 mg L^{-1}. In this particular treatment, the DO concentrations were consistently low, although the differences were not significant at different water depths.

Oxygen consumption. OC by shrimps was 0.33±0.06 g O_2 kg^{-1} h^{-1}. On the other hand, SOD was affected by different sediment, with the highest SOD observed in treatment RP-210, i.e. 27.77±0.96 mg O_2 m^{-2} h^{-1} (Table 1). Oxygen consumed by sediment seemed to be different between the sediment with positive and negative redox potentials, i.e. 0.008, 0.012 and 0.027 g m^{-2} h^{-1} at sediment redox potentials of +100 mV, -106 mV and -200 mV, respectively. This outcome showed that SOD in more negative ORP was 3.5 times higher than in the positive one.

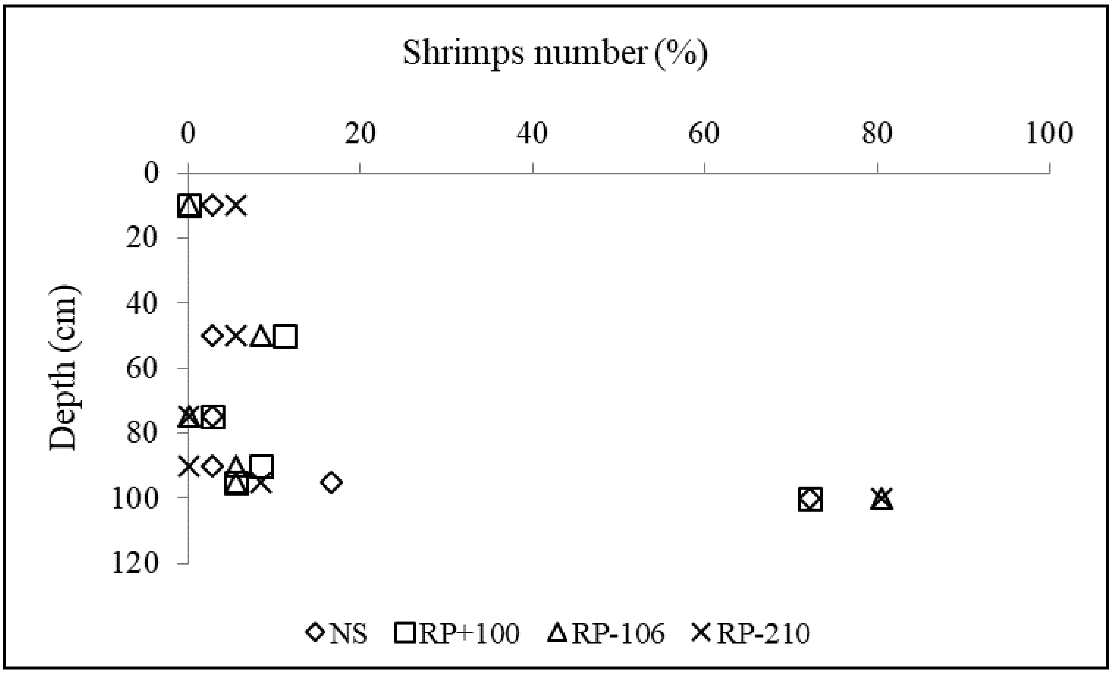

Figure 1. Percentage of pacific white leg shrimps *Litopenaeus vannamei* in different depths in three different sediment redox potentials with density of 130 shrimp m^{-2}; NS - no-substrate; RP+100 - sediment redox potential +100 mV; RP-106 - sediment redox potential -106 mV; RP-210 - sediment redox potential -210 mV.

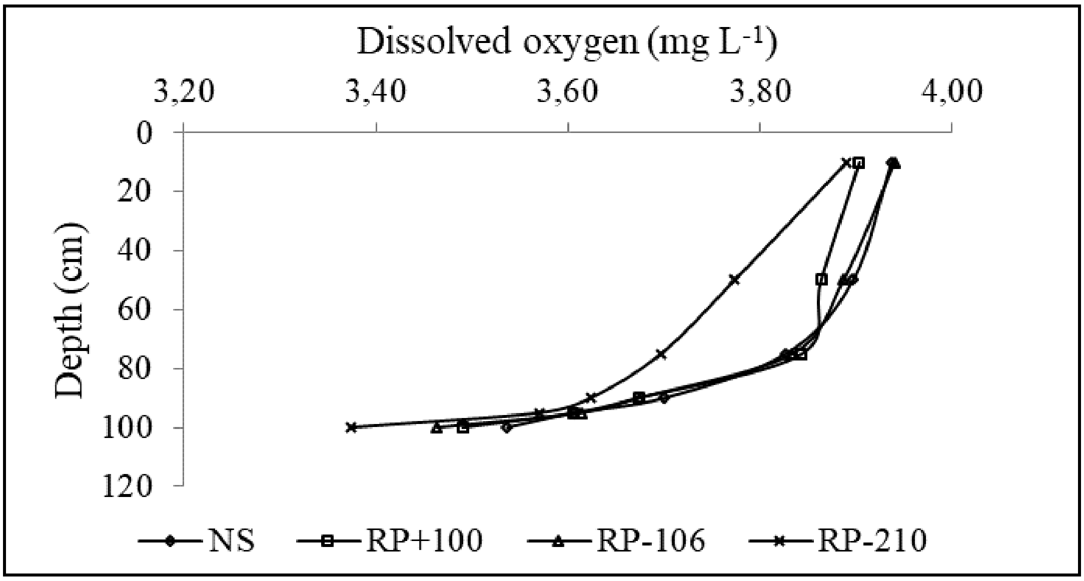

Figure 2. Dissolved oxygen at different water depth in the culture of *Litopenaeus vannamei* in three different sediment redox potentials; NS - no-substrate; RP+100 - sediment redox potential +100 mV; RP-106 - sediment redox potential -106 mV; RP-210 - sediment redox potential -210 mV.

Table 1

Oxygen consumption (OC) by *Litopenaeus vannamei* and sediment oxygen demand (SOD) in three different sediment redox potential

Treatments	*OC (g O_2 kg^{-1} h^{-1})*	*SOD (mg O_2 m^{-2} h^{-1})*
NS	0.33±0.06	-
RP+100	-	7.78±1.67[c]
RP-115	-	12.22±0.96[b]
RP-210	-	27.77±0.96[a]

Note: NS - no-substrate; RP+100 - sediment redox potential +100 mV; RP-106 - sediment redox potential -106 mV; RP-210 - sediment redox potential -210 mV.

This study showed that Pacific whiteleg shrimp spent most of their time on the bottom, and swam to the column or near to the water surface for short periods of time, between 0-11 seconds. This is in line with the results of Avnimelech et al (2004), who suggested that shrimp normally live on or near the bottom, and in contrast to Briggs et al (2004), who noted that the same species spend more time in the water column. This underlines the particular importance of the bottom sediment conditions that can affect the shrimp behaviour, subsequently affecting the growth and the health of the shrimp (Krummenauer et al 2010; Lin et al 2010). It has been reported that shrimp pond sediment is of particular importance, because, as a benthic organism, shrimp spend most of their time in the soil-water interface environment. Moving, by swimming or crawling, might be related to searching for food. Silva et al (2012) demonstrated that *Farfantepenaeus subtilis* more commonly moved after feeding.

DO concentrations in all treatments decreased with the increase of water depth. This condition might be caused by the sediment condition and the fact that most of the shrimp stay at the bottom and, therefore, resulted in the depletion of DO concentration. Shrimp oxygen consumption has been reported to be affected by size, temperature, and stocking density. According to Vinatea et al (2011), bigger shrimp size, higher temperature and higher stocking density incur higher oxygen consumption. The present study also found that the rate of DO reduction at the water surface ranged from 0.25 to 0.26 mg L^{-1} h^{-1}, while at the bottom (water-sediment interface), the decreasing rate of DO was higher, i.e. 0.32-0.35 mg L^{-1} h^{-1}. On the other hand, the treatment without sediment showed a lower rate of DO reduction compared to other treatments, indicating the absence of the sediment effect. Spanopoulos-Hernández et al (2005) and Bett & Vinatea (2009) stated that the oxygen consumption rate is influenced by salinity, temperature and wet body weight. In this study, we assume that the oxygen diffusion from the air to the culture system was similar amongst treatments, and the rate of oxygen consumption by shrimp biomass could be estimated at 0.33 g O_2 kg^{-1} h^{-1}. This result is similar to the research conducted by Bett & Vinatea (2009), who reported that for shrimp with an average body weight of 5-10 g, shrimp oxygen consumption rate at a temperature of 25-30°C was 0.24-0.33 g O_2 kg^{-1} h^{-1}.

At a negative sediment redox potential, the reduction rate was noticeably higher, indicating that the sediment oxygen demand in this particular environment was higher as compared to other sediments in this study. According to Yee et al (2011), the sediment oxygen demand can vary between sediment and was found to be higher at the area near the waste from aquaculture activity. Ling et al (2009) reported that sediment oxygen demand at the station with shrimp farm discharge was 32-890 mg O_2 m^{-2} h^{-1}. Avnimelech et al (2004) noted that in intensive organic matter degradation at the pond bottom, high sediment oxygen demand could exceed the oxygen regeneration rate and could cause the development of anoxic conditions in the sediments and at the sediment-water interface.

Conclusions. Sediment redox potential did not influence *L. vannamei* behavioural profile. The shrimp stayed on the tank bottom for most of the time for all treatments. DO decreased with the increase in water depth, indicating that DO on the bottom was consumed by both the shrimp and the sediment. A more negative sediment redox potential increases the sediment oxygen demand.

Conflict of Interest. The authors declare that there is no conflict of interest.

References

Arsana I. G. K., Yahya S., Lontoh A. P., Pane H., 2003 [The relationship between early submerging and redox potential, ethylene production, and its effects on growth and yield of rice (*Oryza sativa*) on direct seeding system]. Buletin Agronomi 31(2):37-41. [In Indonesian].

Avnimelech Y., Ritvo G., 2003 Shrimp and fish pond soils: Processes and management. Aquaculture 220(1-4):549-567.

Avnimelech Y., Ritvo G., Kochva M., 2004 Evaluating the active redox and organic fractions in pond bottom soils: EOM, easily oxidized material. Aquaculture 233(1-4):283-292.

Babu P. P. S., Razvi S. S. H., Venugopal G., Ramireddy P., Mohan K. M., Rao P. S., Patnaik R. R. S., Narasimhacharyulu V., Ananthan P. S., 2014 Growth and production performance of Pacific white leg shrimp *Litopenaeus vannamei* (Boone, 1931) in low stocking short term farming in earthen pond conditions. Indian Journal of Fisheries 61(4):68-72.

Bett C., Vinatea L., 2009 Combined effect of body weight, temperature and salinity on shrimp *Litopenaeus vannamei* oxygen consumption rate. Brazilian Journal of Oceanography 57(4):305-314.

Braker G., Ayala-Del-Río H. L., Devol A. H., Fesefeldt A., Tiedje J. M., 2001 Community structure of denitrifiers, *Bacteria*, and *Archaea* along redox gradients in Pacific northwest marine sediments by terminal restriction fragment length polymorphism analysis of amplified nitrite reductase (nirS) and 16S rRNA genes. Applied and Environmental Microbiology 67(4):1893-1901.

Briggs M., Funge-Smith S., Subasinghe R., Phillips M., 2004 Introductions and movement of *Penaeus vannamei* and *Penaeus stylirostris* in Asia and the Pacific. RAP Publ. 10, 92 p.

da Costa F. P., de Farias Gomes B. S. F., Pereira S. D. do N. A., de Fátima Arruda M., 2016 Influence of stocking density on the behaviour of juvenile *Litopenaeus vannamei* (Boone, 1931). Aquaculture Research 47(3):912-924.

Krummenauer D., Cavalli R. O., Ballester E. L. C., Wasielesky Jr. W., 2010 Feasibility of pacific white shrimp *Litopenaeus vannamei* culture in southern Brazil: effects of stocking density and a single or a double CROP management strategy in earthen ponds. Aquaculture Research 41(2):240-248.

Lester L. J., Pante M. J. R., 1992 Penaeid temperature and salinity responses. In: Marine shrimp culture: Principles and practices. Fast A. W., Lester L. J. (eds), Elsevier, Amsterdam, pp. 515-534.

Lin Y. F., Jing S. R., Lee D. Y., Chang Y. F., Sui H. Y., 2010 Constructed wetlands for water pollution management of aquaculture farms conducting earthen pond culture. Water Environment Research 82(8):759-768.

Ling T. Y., Ng C. S., Nyanti L., Buda D., 2009 Oxygen demand of the sediment from the Semariang Batu River, Malaysia. World Applied Sciences Journal 7(4):440-447.

Silva P. F., de Souza Medeiros M., Silva H. P. A., de Fatima Arruda M., 2012 A study of feeding in the shrimp *Farfantepenaeus subtilis* indicates the value of species level behavioral data for optimizing culture management. Marine and Freshwater Behaviour and Physiology 45(2):121-134.

Soares Pontes C., de Fatima Arruda M., de Lara Menezes A. A., Pereira de Lima P., 2006 Daily activity pattern of the marine shrimp *Litopenaeus vannamei* (Boone 1931) juveniles under laboratory conditions. Aquaculture Research 37(10):1001-1006.

Soares Pontes C., De Lima P. P., de Fatima Arruda M., 2008 Feeding responses of juvenile shrimp *Litopenaeus vannamei* (Boone) fed at different frequencies under laboratory conditions. Aquaculture Research 39(13):1416-1422.

Spanopoulos-Hernández M., Martínez-Palacios C. A., Vanegas-Pérez R. C., Rosas C., Ross L. G., 2005 The combined effects of salinity and temperature on the oxygen consumption of juvenile shrimps *Litopenaeus stylirostris* (Stimpson, 1874).

Aquaculture 244(1-4):341-348.
Vinatea L., Carvalho J. W., 2007 Influence of water salinity on the SOTR of paddlewheel and propeller-aspirator-pump aerators, its relation to the number of aerators per hectare and electricity costs. Aquacultural Engineering 37(2):73-78. d
Vinatea L., Muedas W., Arantes R., 2011 The impact of oxygen consumption by the shrimp Litopenaeus vannamei according to body weight, temperature, salinity and stocking density on pond aeration: a simulation. Acta Scientarium Biological Sciences 33(2):125-132.
Wasielesky Jr. W., Atwood H., Stokes A., Browdy C. L., 2006 Effect of natural production in a zero exchange suspended microbial floc based super-intensive culture system for white shrimp *Litopenaeus vannamei*. Aquaculture 258(1-4):396-403.
Wyban J. A., Sweeny J. N., 1991 Shrimp health maintenance. Intensive Shrimp Production Technology: the Oceanic Institute Shrimp Manual. Oceanic Institute Honolulu, Hawaii, pp. 103-112.
Yee L. T., Pusin H. N. M. F., Nyanti L., Miod M. C., 2011 Sediment oxygen demand of the Santubong River and their contributing factors. International Journal of Applied Science and Technology 1(6):162-168.
*** FAO 2018 The state of world fisheries and aquaculture (Sofia). Meeting the sustainable development goals. FAO, Rome, 227 p.

Received: 17 February 2021. Accepted: 25 May 2021. Published online: 11 December 2021.
Authors:
Wiyoto Wiyoto, Production Technology and Management of Aquaculture, College of Vocational Studies, IPB University (Bogor Agricultural University), Campus IPB Cilibende, 14 Kumbang St., 16151 Bogor, Indonesia, e-mail: wiyoto@apps.ipb.ac.id
Sukenda Sukenda, Department of Aquaculture, Faculty of Fisheries and Marine Sciences, IPB University (Bogor Agricultural University), Lingkar Kampus IPB Darmaga, 16680 Bogor, Indonesia, e-mail: sukenda67@gmail.com
Enang Harris, Department of Aquaculture, Faculty of Fisheries and Marine Sciences, IPB University (Bogor Agricultural University), Lingkar Kampus IPB Darmaga, 16680 Bogor, Indonesia, e-mail: enang_harris@yahoo.com
Kukuh Nirmala, Department of Aquaculture, Faculty of Fisheries and Marine Sciences, IPB University (Bogor Agricultural University), Lingkar Kampus IPB Darmaga, 16680 Bogor, Indonesia, e-mail: kukuhni25@gmail.com
Daniel Djokosetiyanto, Department of Aquaculture, Faculty of Fisheries and Marine Sciences, IPB University (Bogor Agricultural University), Lingkar Kampus IPB Darmaga, 16680 Bogor, Indonesia, e-mail: djokosetiyanto@yahoo.com

How to cite this article:
Wiyoto W., Sukenda S., Harris E., Nirmala K., Djokosetiyanto D., 2021 Pacific whiteleg shrimp (*Litopenaeus vannamei*) behaviour, oxygen consumption and sediment oxygen demand at different sediment redox potential. AACL Bioflux 14(6):3510-3516.