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Performance of An Aerated Wastewater Stabilization Pond for the Treatment of Cultivation Wastewater of Pacific White Shrimp (*Litopenaeus vannamei*) Grow-out Ponds

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Abstract

Pacific white shrimp (Litopenaeus vannamei) is one of major cultivated crustacean species that its production has doubled in the last decade. The aquaculture used for shrimp cultivation employs either closed or intensive pond systems. However, wastewater generated by intensive shrimp farming may cause environmental effects. This study aimed to evaluate the feasibility of an aerated wastewater stabilization pond to treat the cultivation wastewater. The physicochemical parameters monitored were temperature, pH, salinity, ammonia, nitrite, nitrate and phosphate. In this study, almost all physicochemical parameters of the water exiting the aerated wastewater stabilization pond met the quality standard of feed water for integrated multitrophic aquaculture (IMTA). Temperature, pH, salinity, nitrite, nitrate, and phosphate were 27.1°C to 32.2°C, 7.86 to 8.79, 30 ppt to 34 ppt, 0.003 mg/L to 0.068 mg/L, and 0.19 mg/L to 1.31 mg/L, respectively. However, ammonia concentration significantly fluctuated in the range of 0.44 mg/L to 12 mg/L.

Keywords: aerated, stabilization pond, physicochemical parameter, shrimp farming, wastewater treatment, aquaculture.

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INTRODUCTION

Shrimp is one of the most popular Indonesian marine and fishery commodities in the global trade (Habibie, 2022). The Statistics Indonesia (BPS) reported that Indonesian shrimp exports reached 241.201 tons with a total value of US$ 2.16 or approximately 38.34% of Indonesia total export value in 2022. Accordingly, the Indonesian Government, through the Ministry of Maritime Affairs and Fisheries has set a shrimp export growth target of 250% in 2024 with white shrimp (*Litopenaeus vannamei*) being the main species. Indeed, Pacific white shrimp

(*Litopenaeus vannamei*, Boone 1931), is a major cultivated crustacean species whose aquaculture production has doubled in the last decade (The State of World Fisheries and Aquaculture 2022, 2022). Increased shrimp production can be achieved through implementation of intensive, semi-intensive, extensive, and super intensive implementation of potential of pond cultivation, as well as by shrimp plant systems (Dien et al., 2019).

Intensive shrimp farming aims to minimize the use of water by utilizing various microbial treatments that eliminate the risk of pathogen infection, release of exotic species, and wastewater treatment (Hosain et al., 2021; Suantika et al., 2020). Aquaculture wastewater can contain various undesirable constituents including dissolved or particulate organics, nutrients, and certain organic or inorganic compounds that can cause adverse impacts when directly disposed to the environment (Fakhri et al., 2015). Organic wastes can be found in shrimp ponds including shrimp feed residue, feces and excretions that are usually deposited at the bottom of ponds (Zhu et al., 2016). This organic waste potentially declines water quality so that suggests periodic replacement of pond water, and the contaminated water has to be treated in wastewater treatment pond (Alvarado et al., 2013; Wongkiew et al., 2017). In fact, it is the simplest and most widely applied method for processing shrimp pond wastewater (Daskiran et al., 2018).

Aeration is the process of introducing oxygen to water, which facilitates microbial degradation as the microbes actively consume organic content in the wastewater (Daskiran et al., 2018). There are many types of aerators, including vertical pumps, pump sprayers, propeller-aspirator pumps, paddle wheels and diffused air systems (Lim et al., 2021). Among those available aerator types, the paddle wheel type aerator offers the best performance in terms of aeration efficiency and circulation (Kumar et al., 2013). However, to enhance its performance, an additional technology has been incorporated, namely stabilization pond (Goutam Mukherjee et al., 2021; Alvarado et al., 2013). Hitherto, the stabilization pond is commonly used in tropical regions for its low manufacturing and operating cost as well as excellent flexibility to handle fluctuated organic waste load where adequate land is available. (Nameche and Vasel, 1998).

In the aquaculture application, aerated wastewater stabilization ponds have different dimension, especially their size, age and depth, which directly influence the physicochemical quality of pond water (Boyd et al., 2010). The physicochemical quality of the water filling the aerated stabilization ponds affects the growth of phytoplankton and algae, which are the basis of the food chain in ponds (Boyd, n.d.). Therefore, this research intensively observed the dynamics of white shrimp (*Litopenaeus vannamei*) pond wastewater physicochemical quality in aerated stabilization ponds. It is critical to ensure that waste processing is correctly selected and that waste may be disposed of straight way into the sea without damaging aquatic biota.

MATERIALS AND METHODS

Aerated Stabilization Pond

The research was carried out in an aerated stabilization pond installed at the Marine Science and Techno Park, Diponegoro University, Teluk Awur, Jepara, Indonesia. The stabilization pond's length, width, and water depth were 110 m, 19 m, and 1.2 m, respectively, and it was equipped with two paddle wheel aerators. An illustration of the top view layout and a photo of the aerated stabilization pond is depicted in Figure 1. The aerated stabilization pond treated all residual culturing water discharged from grow-out shrimp ponds, with an inlet line is positioned at the top of the pond. An overflow channel is a 5 cm-deep open canal that connects the stabilization pond with an equalization pool. The dimensions of the equalization pool were respectively, 20 m × 5 m with a depth of 1.5 m. The aerated stabilization pond is equipped with 2 paddle wheel aerators installed at the surface of the pond. Aerator paddle wheels with a rim diameter of 30 cm rotate at a speed of 1400 rpm and are equipped with a 1 HP motor.

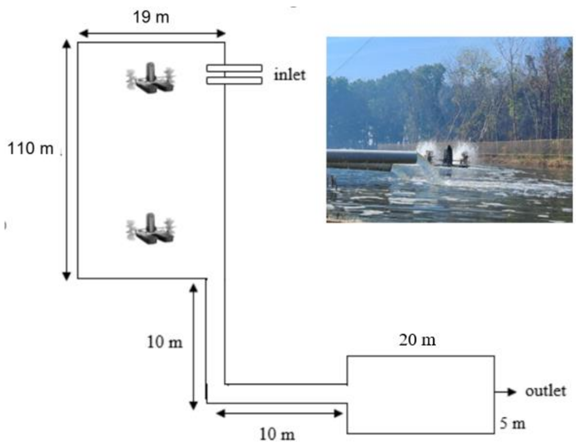

Figure 1. The top view layout and photo of the aerated wastewater stabilization pond

Data, Sample Collection, and Analysis

This research investigated the dynamics of the aerated wastewater stabilization pond used to treat wastewater discharged from white shrimp grow-out ponds. The physicochemical parameters include temperature, pH, salinity, nitrate, nitrite, ammonia and phosphate. The characteristics of the wastewater of white shrimp ponds (*Litopenaeus vannamei*) with intensive cultivation systems are tabulated in Table 1. The temperature, pH, and salinity were measured directly in the field, whereas nitrate, nitrite, and phosphate were examined in the laboratory. Water samples were withdrawn from the stabilization pond outlet. Investigation was carried out for 98 days (14 weeks), in which measurements were taken once a week in the morning.

Table 1. Physicochemical characteristics of Wastewater Content of Pacific White Shrimp (*Litopenaeus vannamei*) Pond in Intensive Cultivation System

Parameters	Value
pH	7.15
Temperature	25.33°C
Nitrite	9.55 mg/L
Nitrate	12.65 mg/L
Phosphate	7.68 mg/L
Total ammonia nitrogen	8.01 mg/L
Total nitrogen	72.05 mg/L

The determination of ammonia, nitrite, nitrate, and phosphate contents were conducted according to the salicylate, the US EPA 44(85) diazotization, the cadmium reduction, and the ascorbic acid methods, respectively, using a portable spectrometer (DR 900, Hach Company, Loveland, USA). Meanwhile, temperature, pH, and salinity were directly measured using an alcohol thermometer, a pH meter (pHTestr20, Eutech Instruments Pte Ltd. Keppel Logistic Building, Singapore), and a refractometer (ATAGO CO., Ltd., Bellevue, Washington, USA), respectively.

RESULTS AND DISCUSSION

Because long-term changes in physicochemical parameters, including temperature, salinity, pH, ammonia, nitrate, nitrate and phosphate, can alter ecosystem communities, they must be extensively studied in relation to a variety of environmental issues stemmed from the increasing intensive shrimp farming. This environmental problem could be affected by algae growth on coastal beaches, which harms the surrounding ecosystem.

Temperature

Figure 2 shows the temperature dynamics in the aerated wastewater stabilization pond during 14 weeks. It is seen in the figure that the temperature fluctuates, with the highest temperature (32.2°C) occurred in the 2nd week, and the lowest (27.1°C) in the 7th week. It could be related to the daily fluctuation of sunshine intensity. This research was conducted during the dry season (June-October 2023), at which the ambient temperature is high enough due to the high UV irradiation form the sunlight (Rao et al., 2015).

Basically, temperature affects metabolic processes of marine organisms, the growth of aquatic biota, and the denitrification process (Bardera et al., 2019; Ponce-Palafox et al., 2019; Singh et al., 2022). Temperature is one of the parameters that influences the denitrification process (Rajta et al., 2020). Furthermore, temperature also affects algae growth and nutrient absorption in wastewater treatment (Abdel-Raouf et al., 2012). In fact, ambient temperature in the tropical countries suits well the biological wastewater treatment (Holan et al., 2020), because it is appropriate for the growth of mesophilic bacteria that mostly play dominant roles in wastewater treatment (Rajta et al., 2020).

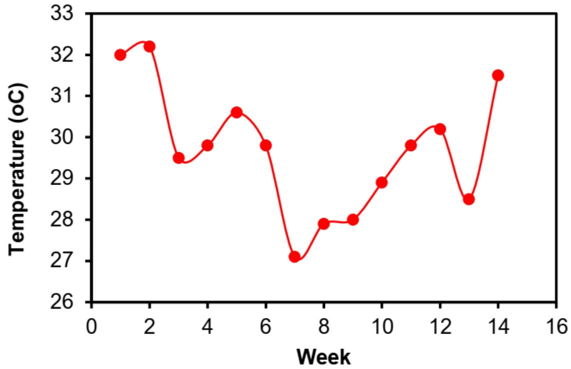

Figure 2. Temperature Dynamics of the Aerated Wastewater Stabilization Pond

However, high temperatures will reduce the solubility of CO_2 in water (Holan et al., 2020). A significant increase in temperature can also worsen the toxicity of organic compounds in water because of the increased ionization of ammonia fraction in water (Lin et al., 2023). Based on the results obtained in this study, the temperature range was 25 C to 37°C, which is appropriate for the shrimp pond wastewater treatment (Li et al., 2018).

pH

pH is one of chemical factors that fluctuates quickly in ponds due to the dissolution of CO_2 in water. The increase in CO_2 concentration is directly proportional to the increase in the concentration of hydrogen and bicarbonate ions and the decrease in the concentration of hydroxyl and carbonate ions (Raven et al., 2020). Carbon dioxide concentration in the atmosphere and surface water might simultaneously increase by more than 25% due to the presence of dissolved inorganic compounds contained in the wastewater, which can result in the fixation of inorganic carbon by phytoplankton (Raven et al., 2017). Besides, the climate and seasonal changes in the nearby coastal areas also influenced pH dynamics.

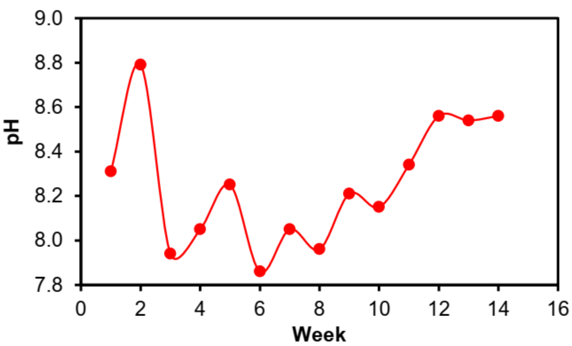

Figure 3. pH Dynamics of the Aerated Wastewater Stabilization Pond

Figure 3 displays the pH dynamics of the aerated wastewater stabilization pond. There were fluctuations in the pH of the water, which could be related to the net conversion of dissolved inorganic carbon involving changes in H^+/OH^-, thus affecting the pH of the wastewater. In addition, the changes in pH could also be the result of biological activity and changes in dissolved inorganic carbon compounds (Raven et al., 2020). The highest pH (8.79) was observed in the 2nd week, while the lowest (7.86) was achieved in the 6th week. A low pH value is most likely caused by the large quantity of organic compounds entering the aerated wastewater stabilization pond that trigger the nitrification process in wastewater resulting in more acidic condition. Meanwhile, in the last 3 weeks of data collection, the pH in the aerated wastewater stabilization pond tended to be constant at around 8.56 (weak basic). Under this condition, waste processing was maximal because the denitrification process is effective in the pH range of 6.75 to 8.75 (Guo et al., 2016). Changes in the pH of the aerated wastewater stabilization pond can affect the rate of photosynthesis and algae growth directly through the effect of the acid-base balance (Raven et al., 2020).

Salinity

Salinity is an important parameter in coastal waters because it influences the life of marine biota (Sahu et al., 2016). In fact, high salinity can increase the survival rate of aquatic organisms (Lin et al., 2023). During dry season, the salinity level tends to be higher due to high evaporation rate. Salinity is inversely proportional to the concentration of unionized ammonia in water, which increases the tolerance of aquatic biota to total ammonia nitrogen (Rajta et al., 2020). Such adjustment is required in wastewater treatment to ensure that the effluent is suitable for disposal to the coast without seriously harming the marine environment.

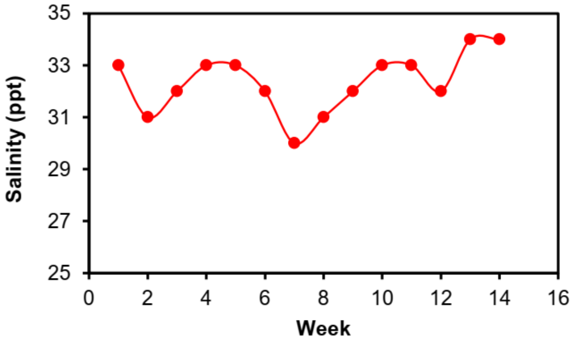

Figure 4. Salinity Dynamics of the Aerated Wastewater Stabilization Pond

Figure 4 proves that the salinity of wastewater in the aerated wastewater stabilization pond is nearly constant. Its value only fluctuated from 30 to 34 ppt. The lowest salinity (30 ppt) was observed in the 7th, while the highest salinity (34 ppt) was recorded in the 13th and 14th weeks. Previous research suggested that the salinity in the stabilized aeration pond is in a good range for marine ecosystem life (25-35 ppt), which allows the survival of aquatic biota (Jaffer et al., 2020;Ji et al., 2022). Besides, salinity also affects the stress levels and growth of aquatic biota that can be related to denitrification process (Gao et al., 2016). Maximum nitrogen removal or denitrification from shrimp cultivation waste occurs at salinity of 28 ppt to 40 ppt by bacteria suspended in water (Sudarno et al., 2011). The salinity profile recorded in this research confirms that the concentration in the aerated wastewater stabilization pond is sufficient and within a good range for wastewater treatment and pond ecosystems.

Total Ammonia

Ammonia is dangerous for aquatic biota (Ou et al., 2022). In the shrimp cultivation ponds, ammonia comes from leftover feed, feces and shrimp excretions (Irani et al., 2023). Ammonia accumulation can result in detrimental physiological and biochemical changes in aquatic biota, especially characterized by a decrease in blood oxygen (Baldisserotto et al., 2014).

In water, ammonia can present in two forms, namely ammonium ionized and unionized ammonia. However, both forms of ammonia are measured as total ammonia nitrogen. Ammonia can interfere with crustacean immunity, resulting in physiological disorders, including molting failure, slower growth, and increased mortality (Lin et al., 2023). To prevent oxygen depletion and eutrophication, removing carbon and nitrogen pollutants before discharging wastewater into water bodies is very important (Sudarno et al., 2011).

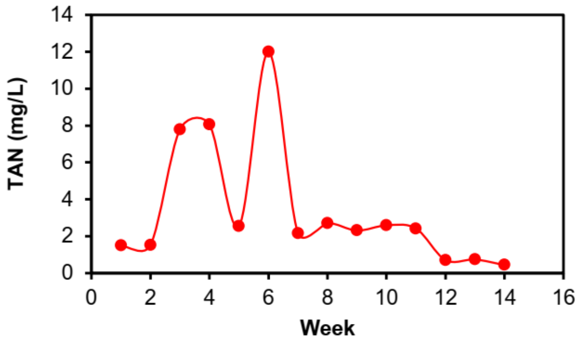

Figure 5. Dynamics of Total Ammonia Nitrogen in the Aerated Wastewater Stabilization Pond

Figure 5 shows that the ammonia concentration strongly fluctuated from the second to sixth week. It can be seen that ammonia increases from 7.79 mg/L in the third week to 8 mg/L in the fourth week. The ammonia concentration at this level could harm the aquatic ecosystem. However, in the 7th week, the concentration decreased to 2.55 mg/L and remained stable until the 11th week, due to the reduced volume of shrimp pond waste being disposed of so that the aerator in the aerated wastewater stabilization pond could work optimally. Then, in the12th to 14th week, the concentration of ammonia dropped to 0.44 mg/L and remained nearly constant. Ammonia concentrations below 2 mg/L are safe levels for aquatic ecosystems.

Nitrite

Nitrite is an intermediate product of the oxidation of ammonia to nitrate, which is toxic. A concentration of more than 0.2 mg/L, nitrite results in eutrophication of the water (Eddiwan et al., 2020). Nitrite is unstable and it can undergo oxidation to become nitrate by aerobic nitrifying bacteria (Dauda et al., 2019). Aerobic bacteria in nitrification will decompose nitrite originating from food waste, feces and shrimp excretions which will then be absorbed by algae or oxidized (Nguyen et al., 2019). Figure 6 shows the dynamics of the nitrite content in the aerated wastewater stabilization pond. Overall, the nitrite levels were lower than 0.1 mg/L, a safe value for aquatic ecosystems if it is discharged into the sea. Nitrite dynamics can happen as the results of several factors, including the speed of oxidation of nitrifying aerobic bacteria, the concentration of ammonia in the pond, temperature, and pH (Bardera et al., 2019; Dauda et al., 2019; Jendia et al., 2020; Singh et al., 2022). Nitrite concentration is influenced by nitrate reductase which is an enzyme to converts nitrate compounds into nitrite (Rajta et al., 2020). In an aerobic denitrification, the biological activities of NH_4^+ and NO_2^- decrease when the pH is below 6.4 and above 9.0 (Wongkiew et al., 2017). Meanwhile, the influence of temperature is be optimal in the range of 28°C to 32°C (Esparza-Leal et al., 2019).

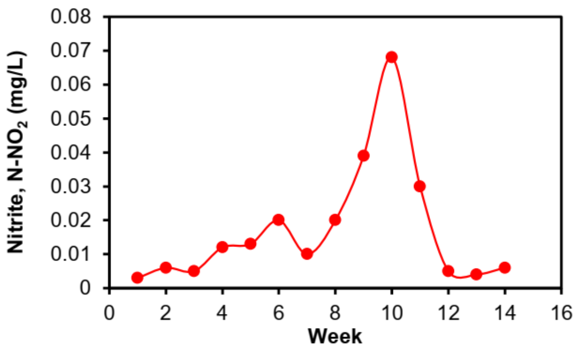

Figure 6. Nitrite Dynamics of the Aerated Wastewater Stabilization Pond

Nitrate

Figure 7 shows the dynamics of the concentration of nitrate in the aerated wastewater stabilization pond. The concentration is low, which ranged between 0.002 to 0.07 mg/L. Nitrate concentrations above 10 mg/L can cause eutrophication and are dangerous for aquatic biota (Rajta et al., 2020). The dynamics of nitrate level depend on the nitrification and denitrification processes. Nitrification is the process of converting ammonia compounds into NO_3^- in the presence of oxygen (Hu et al., 2015). Nitrification is a two-step process, the first step is that ammonia is oxidized to nitrite by ammonia-oxidizing bacteria (AOB), followed by the oxidation of nitrite to nitrate by nitrite-oxidizing bacteria (NOB). Denitrification is a process that occurs in a wastewater stabilization pond system because it can contribute to nitrogen removal by 25-60%. Denitrifiers convert NO_3^- to NO_2^-, nitric oxide (NO), nitrous oxide (N_2O) and finally to nitrogen gas (N_2) under anoxic or low dissolved oxygen conditions (Wongkiew et al., 2017). Dinitrogen compounds are not dangerous for aquatic ecosystems. Denitrification is carried out by archaea and heterotrophic bacteria. These microbes utilize NO_3^- as an electron acceptor and utilize dissolved organic carbon in circulating water as an electron donor (Lu et al., 2014). Heterotrophic bacteria grow by consuming dissolved organic carbon from rotting biomass and shrimp feces as a carbon source under aerobic conditions (Wongkiew et al., 2017).

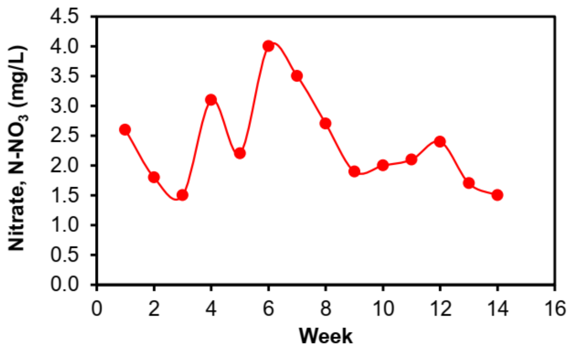

Figure 7. Nitrate Dynamics of the Aerated Wastewater Stabilization Pond

Phosphate

Phosphates are found in wastewater because they are contained in feed residues and feces with high protein concentrations, reaching 60%, while only 10-13% can be assimilated (Zhu et al., 2016). Therefore, a process to reduce excess phosphorus needs to be conducted to prevent pollution of the environment. A good concentration that does not cause pollution is 1 mg/L (Iber and Kasan, 2021).

Figure 8 shows the phosphate concentration in the aerated wastewater stabilization pond for 14 weeks. The concentration in weeks 1 to 3 was still below 1 mg/L, while in weeks 4 to 8 the content of phosphate compounds reached 1 mg/L. The highest phosphate concentration (1.31 mg/L) was recorded in the 8th week, while the lowest (0.19 mg/L) was observed in the 13th week. The phosphate content in the aerated wastewater stabilization pond is beneficial for the nutrition of phytoplankton and algae, so it can reduce other organic compounds. However, if the phosphate concentration exceeds 1 mg/L, there is a risk of increasing algae blooming and blocking sunlight from entering the water body (Motlagh and Goel, 2014). Because phosphorus is an important limiting nutrient, stricter environmental regulations are being implemented to reduce phosphorus input to water bodies and to control eutrophication. The process of biological removal of phosphorus can be carried out using periodic anaerobic-aerobic cycles by certain groups of bacteria called polyphosphate-accumulating organisms (PAOs) (Motlagh and Goel, 2014). The phosphate degradation process in the stabilization ponds varied broadly, with an average of 15% to 50% (Gopolang and Letshwenyo, 2018). Meanwhile, at low phosphate concentrations, it can be removed by a sedimentation process which can occur in aerated wastewater stabilization ponds, so that levels can decrease. In addition, phosphate dynamics are influenced by the pH because it affects phosphate solubility in water (Wongkiew et al., 2017).

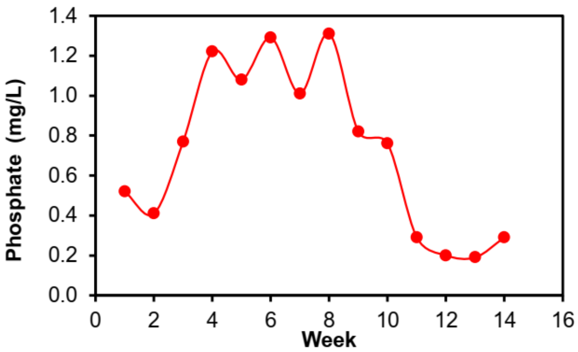

Figure 8. Phosphate Dynamics of the Aerated Wastewater Stabilization Pond

CONCLUSION

The performance of an aerated stabilization pond for treatment of cultivation water discharged from grow-out ponds of pacific white shrimps (*Litopenaeus vannamei*) has been successfully examined through a comprehensive investigation of the physicochemical parameters such as temperature, pH, salinity, ammonia, nitrite, nitrate and phosphate. This case study shows that the aerated wastewater stabilization pond was quite effective for treating cultivation wastewater from grow-out ponds of pacific white shrimp, and may be used as input water for integrated multitrophic aquaculture (IMTA). Based on the results of this study, it can be concluded that the integration of an aerated stabilization pond into intensive or superintensive shrimp farming allows for productive and sustainable cultivation, creating harmony between economic, environmental and social aspects.

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