Application of automated paddlewheel aerator in shrimp culture pond; effect on water quality, energy cost and biomass

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Abstract. Aeration plays a pivotal role in an intensive shrimp pond regarding shrimp growth and energy costs. The purpose of this study was to find a way to reduce energy costs while maintaining shrimp performance. The study was carried out in about 0.3 hectares of outdoor ponds for 80 days with stocking density being set to 80 shrimp/m^2 in two types of treatment an Automatic (AP) and a Manual paddlewheel (MP). Parameters observed were dissolved oxygen (DO) concentration, temperature of water and pH, energy cost, and shrimp biomass. Resulting study found that mean DO concentrations in both treatments were not significantly different, which were 4.99 ± 1.45 ppm and 4.94 ± 1.54 ppm for AP and MP respectively. Temperature and pH were also found to be in same range of 26.81-34.08 ^{o}C and 7.8-8.3. Differences in paddlewheels had no effect on final biomass; AP produced 2249.56 ± 300.67 kg, while MP resulted in 1547.43 ± 359.04 kg. However, the treatments reduced total energy costs significantly, from $657.84 ± 6.13 for MP to $409.76 ± 3.52 for AP. Using of an automated paddlewheel based on real-time DO concentration can contribute significantly to lowering production costs and energy consumption without interfering with shrimp performance.

1 Introduction

Aquaculture has become significant source of food and commercial products around the world. Shrimp is the most well-known aquaculture commodity that is nutritious and has high economic value [1]. In culture pond, dissolved oxygen (DO) is an important factor for shrimp growth. More DO is required for high-intensity shrimp aquaculture than is provided naturally by aquatic plants photosynthesis and the atmosphere's transfer of oxygen to the water [2]. Water exchange can be utilized to enhance oxygen until a certain point, but mechanical aeration, like that provided by a paddlewheel aerator, is more effective [3].

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The requirement for electricity to operate a paddlewheel aerator in the shrimp aquaculture industry reaches 80 - 90% of the total energy needed [4]; [5]. It is the third most expensive expenditure after feed and larvae cost. So, to create competitive cost production and sustainability of the culture, various approaches were carried out by aquaculturists and scientists.

M. Jayanthi [6] asserted that a Paddlewheel aerator outperformed Venturi jet, Scorpion jet, and Wavesurge aerators in terms of oxygen transfer and water circulation. The determination of the ideal number and type of aerators can lower shrimp production expenses overall and conserve energy. J. Marappan [4] stated that using the right aerator combination and sizing aerators based on salinity can lower energy and production costs. T. Itano [7] assessed the water flows generated by a self-designed centrifugal water stirrer and a typical commercial Taiwanese paddlewheel aerator in a rectangular reservoir. The primary point of the study is that while comparing aerators for aquaculture, it is important to consider the variation in flow structure as well as the effectiveness of dissolving oxygen. Further, according to A.I Rahmawati [8] nanobubbles could improve the growth environment by raising the DO concentration in the *P. vannamei* shrimp pond. Y.S Lim [9], investigated microbubble aeration with biofloc culture to evaluate the water quality and growth performance of white shrimps, *Litopenaeus vannamei*, for 70 days.

All that researches emphasized the type and design of paddlewheel and its influence on DO production and shrimp growth. Meanwhile, C.E. Boyd [10] affirmed that optimizing aeration management and improving aerator design are the greatest ways to lower energy consumption of shrimp pond paddlewheel aeration in the near term. As a result, it is necessary to investigate methods to reduce energy consumption by optimizing operations with a proportion of installed aeration capacity in use and flexible daily operating hours from stocking to harvest based on real-time DO in the water. Aeration is frequently not supplied at high enough rates to prevent the night-time concentrations of DO from dropping too low and stressing the culture species. On the other hand, during the daytime when dissolved oxygen levels are often adequate, excessive aeration may be used. Therefore, considerable work should go into creating better operational plans for aerators [11]. Regarding aeration management, J. Izel-Silva [12] investigated feasibility of using two aeration strategies in the Tambaqui production. They proposed that an emergency aeration regime (at DO<3 mgL^{-1}) preferable to supplementary aeration in terms of growth performance, economic efficiency, and fish health maintenance.

An alternative method in optimizing aeration management is controlling ON/OFF its motor drive. Such an approach is based on DO level in the pond, which fluctuates over time. Many factors influenced DO fluctuation, notably the oxygen production of microalgae during the day [13]. Thus, as DO is sufficient for the shrimp, the paddlewheel can be turned off. The longer time off the paddlewheel, the more energy consumption will decrease.

However, due to the numerous influencing factors that cause DO to change rapidly, regime cannot be based solely on manual scheduling. As a result, to obtain the actual value of DO in the pond culture, data from the DO sensor, which is continuous and real-time, must be input. The numerical values obtained from reading the data of the DO sensor are translated into algorithm numbers, which are then employed as the command language for the paddlewheel's motor drive.

According to the explanation given above, research into the automated regime paddlewheel is required to reduce its energy cost in shrimp pond culture. Therefore, the objective of the study was to find out influences of automated paddlewheel based on actual DO concentration in the pond and its effect on water quality, energy cost, and shrimp biomass.

2 Materials and Method

2.1 Automated paddlewheel

This study used commercial paddlewheel aerator (1 Hp, 380 volt). The paddlewheel equipped by optical DO sensor (Aqualabo OPTOD), data processor, servo motor, access point, local server, and LCD display. Detail schematic presented at Fig. 1. The automated paddlewheel's primary function was to read real-time DO concentration in the pond, convert it in a data processor, and transfer the resulting data to a server. The result was used to manage the motor drive of the paddlewheel automatically. Data about DO concentration and the paddlewheel's ON/OFF status could be shown on the LCD display. It served as a tool for system-wide control as well. Data was recorded at 5-minute intervals.

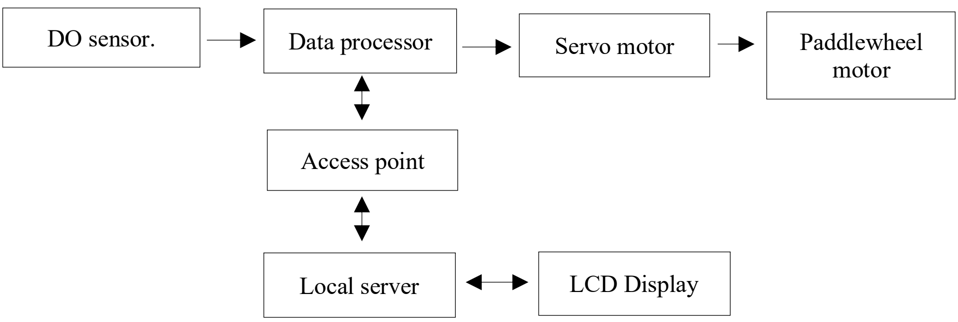

Fig. 1. Schematic diagram of automated paddlewheel.

2.2 Experimental set up

This study was conducted at shrimp pond, which is owned by PT Perindo, Pekalongan, in Central Java, Indonesia. Four rectangular ponds, each measuring about 0.3 hectares, were covered with silver plastic mulch film. Water levels were adjusted so that pond depths averaged 80 cm. Pond preparation entails drying and applying agricultural lime. The pond was filled to a depth of 80-90 cm, then lime dolomite, chlorine, urea, and SP-36 were applied, plankton was allowed to grow for two weeks, and probiotics were added. After a week of probiotic application, the pond was ready to be used for culture.

SPF (Specific pathogen-free) *Litopenaeus vannamei* PL (PL10) were obtained from a local producer. The mean initial weight of the PLs was estimated at 0.10 ± 0.01 g and the mean initial length was 0.90 ± 0.01 cm. The stocking density was 240.000 PLs per pond based on the calculation of 80 larvae/m^2. In addition, two ponds were equipped with eight Automatic paddlewheels (AP). The paddlewheel was managed using four schemas that were based on actual DO concentration. When the DO value increases, the number of paddlewheels "ON" reduces. DO sensor were placed at a depth of 0.4 m from the water bottom and at 10 m from the side of the pond. This method was performed until harvest. Detail the schemes showed at Table 1.

Table 1. Arrangement of paddlewheels

DO concentration (mg/L)	Number of paddlewheels (Unit)	
	ON	**OFF**
0.0 – 5.0	8	0
5.1 – 6.0	6	2
6.1 – 7.0	4	4
7.1 – 12.0	2	6

As a comparison, Manual scheduling of paddlewheel (MP) operation was applied to the two other ponds. But, in those ponds, monitoring of DO concentration also used an optical DO sensor and automatically recorded the DO every 5 minutes. The schedule follows the company's Standard Operating Procedure (SOP). In an early culture (0–20 days), there were four units of paddlewheels during the day and eight units at night. Then, the operation of paddlewheels was multiplied to eight units per 24 hours until harvest.

Other treatments, such as feeding regimen, water exchange, probiotic addition, and harvest time, were carried out in the same way, in accordance with the company's SOP. Ponds were stocked on 7 November 2021 and harvested on 27 January 2022 (DOC 80). Shrimp were sampled on a weekly basis during the culture period.

2.3 Monitoring of water quality

The data of DO and temperature of the water pond were recorded automatically by the DO sensor, which was embedded in paddlewheels and stored in the system. pH of the ponds was recorded in-situ on the farm every ten days using a pH meter (Smart Sensor AS218).

2.4 Calculation of number of paddlewheel and energy cost

Determination of the number of paddlewheels, according to the government regulator (Kemen-KP, 2017), in intensive shrimp culture (*Litopenaeus vannamei*), is 28 units per ha, which means 8 units of paddlewheels were needed in this study. The calculation of energy needed for the paddlewheels was based on an equation developed by [6]. As follow:

$$Energy\ cost\ (\$) = electric\ power\ required \times days\ of\ culture \times hours\ of\ operation \times electricity\ cost\ per\ kW \quad (1)$$

The electric power of the paddlewheels was recorded by a kWh meter installed at each pond. The hours of operation of the automated paddlewheels were recorded by the system installed, while the manual paddlewheel was based on a schedule during cultivation. The cost of electricity per kWh is based on the Indonesian electricity price. And the cost of aeration is the energy cost (in USD) per kilogram of final biomass.

2.5 Shrimp weight and productivity

Individual shrimp weight is collected every week after DOC 30 for the duration of the culture, with 30 shrimp samples used in each collection. Productivity is measured as difference between final total biomass and initial total biomass, divided by volume of culture pond. The parameters in experiment were calculated according to [13] as follows:

$$Productivity\ \left(\frac{kg}{m^3}\right) = \left(\frac{final\ total\ biomass - initial\ total\ biomass}{volume\ pond}\right) \quad (2)$$

2.6 Data analysis

To analyse significant differences between treatments, a t-test with equal variances was used. Differences were considered significant at the 0.05 level.

3 Result and Discussion

3.1 Dissolved oxygen profile

Fig. 2. shows details of the DO profiles for both treatments. For Automatic paddlewheels (AP), values of mean, maximum, and minimum DO of the water pond were 4.99 ± 1.45, 9.78, and 1.59 ppm, respectively. In comparation, the values for Manual paddlewheels (MP) were 4.94 ± 1.54, 10.54, and 0.65 ppm. Except for the minimums, there was no significant difference between the average and maximum value. The mean DO concentration for the growth of *Litopenaeus vannamei* in intensive culture were consistent with [8]; [14] and a Standard Operational Procedure of The Ministry of Marine and Fisheries Indonesia [15].

Daily fluctuations of DO occur during the day and night. The DO during the day was higher than the oxygen at night. This was since during the day, oxygen was produced by both the paddlewheel and microalgae, whereas at night, DO was produced by the paddlewheel solely. The DO concentration in both ponds also tend to decline as DOC increases because shrimp require more oxygen as their biomass rises. Total oxygen demand and aeration requirements in *Litopenaeus vannamei* culture ponds both increase with time [16]. Meanwhile, the lowest DO concentration at DOC 31 in both treatments might be caused by debris that sticks to the DO sensor. It was revealed that DO concentration returned after the sensor was cleaned.

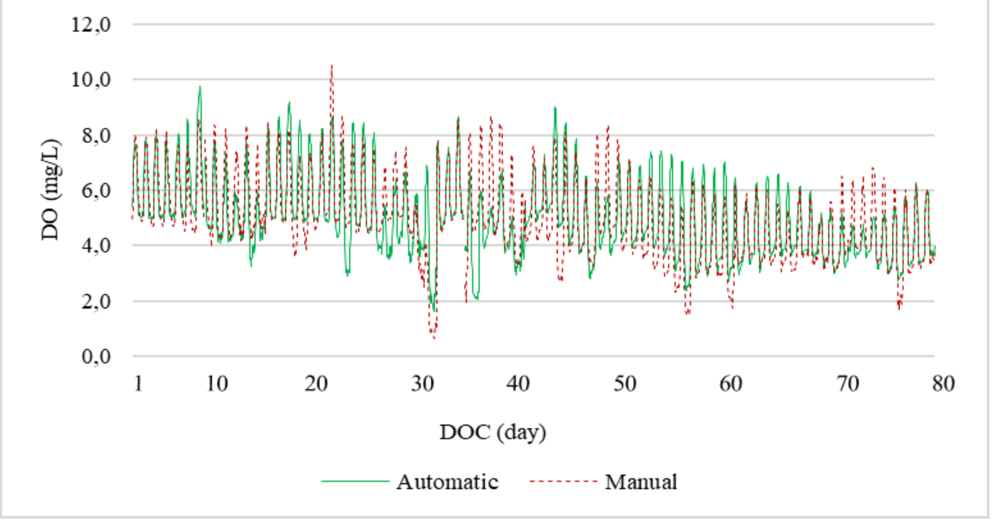

Fig. 2. DO concentration of the water shrimp ponds during cultivation.

The automatic regime of the paddlewheel had not influenced DO concentration in the pond throughout the 80 days of cultivation. The DO concentration is also within the range of optimal conditions for shrimp growth.

3.2 Water Pond temperatures

The paddlewheel also prevents thermal stratification in ponds, which occurs when the bottom water temperature is lower than the surface water temperature. Then mechanical mixing from the paddlewheel would reduce pond stratification. Fig. 3 shows the daily fluctuation of water temperature in both ponds. Automatic pond treatment achieved a maximum temperature of 34.07 ºC and a minimum temperature of 26.93 ºC, whereas manual pond treatment achieved a maximum temperature of 34.08 ºC and a minimum temperature of 26.81 ºC. The data exhibited that different methods of setting the paddlewheel had no significant effect on water temperatures.

Larvae of *Litopenaeus vannamei* have a wide range of thermal tolerance, from 12 to 34 ºC (Kumlu et al., 2010). But native habitat of the larvae is in temperature of 20 ºC [17]. Therefore, the water temperatures in both ponds during cultivation in this study were within the range of tolerance.

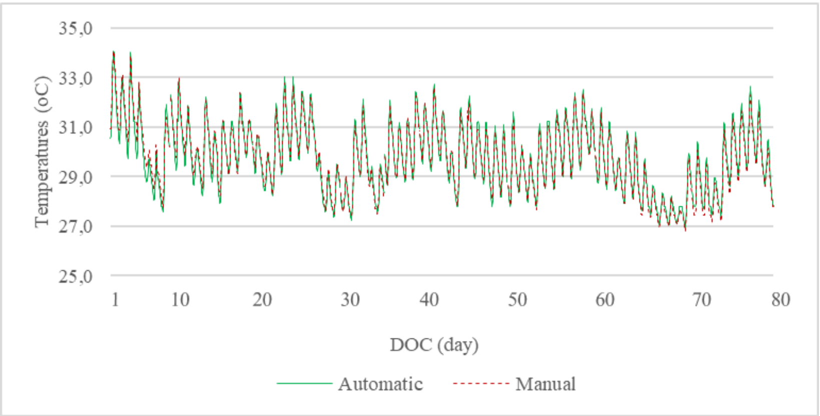

Fig. 3. Temperatures of the water shrimp ponds during cultivation.

3.3 pH of water ponds

The pH of the water fluctuated during cultivation (Fig. 4). Despite these fluctuations, both treatments had similar results ($p > 0.05$). The pH range was 7.8–8.3 for AP ponds and 7.7–8.3 for MP ponds. Those values are favourable for supporting shrimp growth [18]; [14].

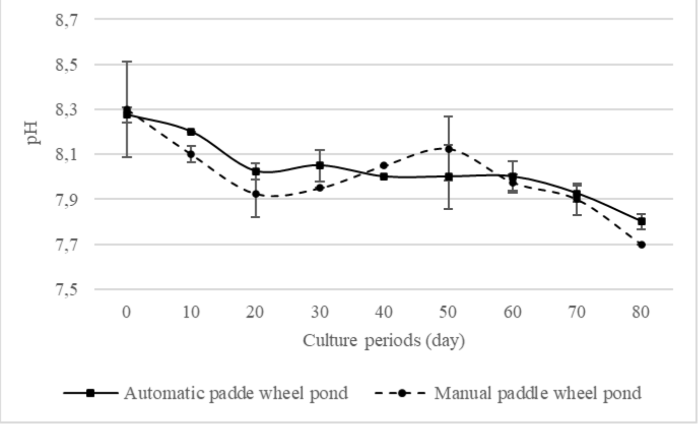

Fig. 4. Water pH in pond.

3.4 Energy cost

The energy requirements of various paddlewheel regimes are determined by the number of paddlewheels to be used, wire power, hours of operation, number of days of operation, and energy price in the location. Except for the number of paddlewheels that were ON or active throughout cultivation, all the variables in this study were same. Fig. 5. depicts data from paddlewheels that were active in the two treatments.

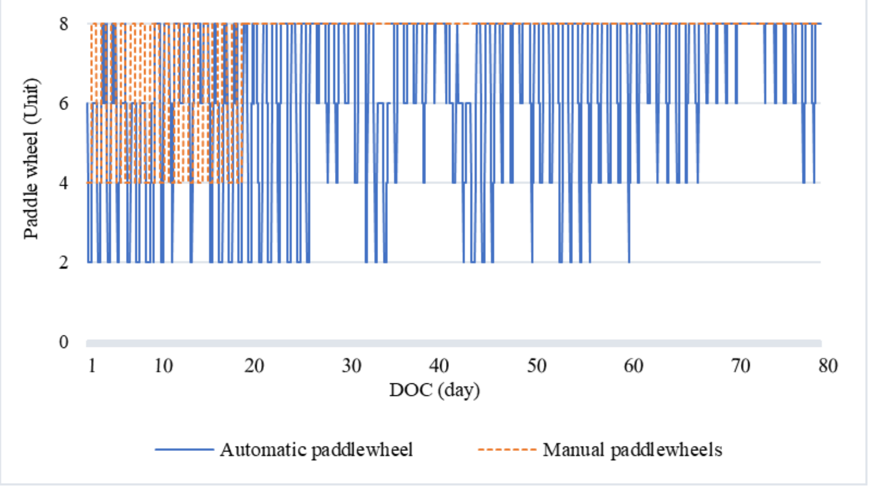

Fig. 5. Number of active paddlewheels during cultivation.

Pond with MP activated more unit than pond with AP. In the earlier cultivation (until DOC 20), MP were operated either 4 or 8 units, afterward were operated 8 units paddlewheel until harvest day. The company stated that the method used took electricity into account and would sufficiently supply DO for shrimp. On the other hand, active paddlewheels in the automatic regime changed continuously in response to DO concentration. So, 2 active unit paddlewheels were still present in the pond up to DOC 60 and 4 paddlewheels were discovered to be operational even during the most recent 20 days of culture. This means that DO concentration were still under control and indicates that even though the paddlewheel unit was used less, it still provided enough oxygen. A natural oxygen producer named microalgae was most likely to have an impact on the level of DO sufficiency. Microalgae increase dissolved oxygen levels in cultured water during the day due to photosynthesis but decrease dissolved oxygen levels at night due to respiratory metabolism [13].

Fig. 6. presents an assessment of the electric power of the paddlewheels during shrimp culture per 10 days in comparison to DO concentration. Electric power for AP ranges from 393.63 to 751.40 kW, while for MP it ranges from 641.63 to 1316.70 kW. The differences electric power increased along with increasing days culture. Initially, manual ponds used either 4 or 8 units, resulting in differences in the electric power of the narrow. After that, the difference gradually widened because the manual pond used 8-unit paddlewheels continuously, while paddlewheels ranging from 2 to 8 units were still used in automatic ponds. This is in line with [6] finding that proper number of aerators system for shrimp culture can reduce the overall costs of shrimp production and save energy use.

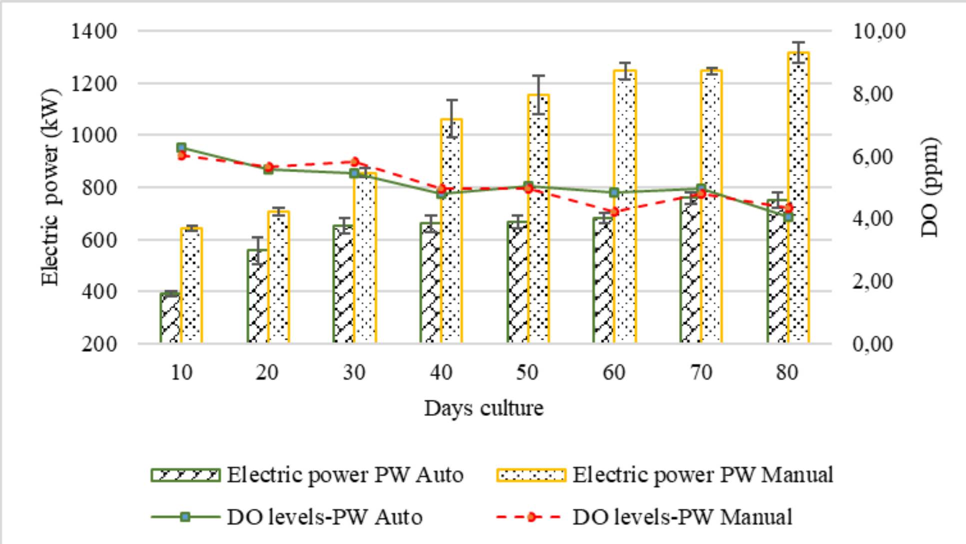

Fig. 6. Comparation of electric power paddlewheels and DO concentration.

The electric power of both treatments tends to rise along with the increase in shrimp DOC. The rising was caused by declining of DO concentration in the water pond because of increased shrimp biomass. Differences in electric power led to a significant difference in energy costs between the two ponds. Table 2 shows the detailed calculation of those energy cost.

Table 2. Total energy cost

Paddlewheels	Total electric power (kW)	Electricity cost per kW (US$)	Energy cost (US$)	Different (%)
Automatic	$5121.96^{b} \pm 43.96$	0.08	$409.76^{b} \pm 3.52$	37.71
Manual	$8222.97^{a} \pm 76.65$	0.08	$657.84^{a} \pm 6.13$	

Table 2. demonstrates total electric power during 80 days of cultivation using different paddlewheels. According to Regulator State of Energy, the electric cost per kW in Indonesia in 2022 is $0.08, so the total energy cost was $409.76 for AP and $657.84 for MP, representing a 37.71% cost reduction. It revealed that the automatic activation of paddlewheels based on real-time DO concentration could reduce energy consumption during shrimp cultivation.

Aquaculture used automatic aerator systems that monitored DO level fluctuations, resulting in lower energy costs [12]; [19]. The method restricted the excessive supply of DO, which is provided by mechanical aerators. Aeration costs were reduced by approximately 17%, according to the reduction of aerator energy cost reported by [20] as a result of the optimization of the dissolved oxygen controller.

3.5 Shrimp biomass

The main indicator of good performance in shrimp growth is weight gain. Fig. 7. depicts the effect of the applied paddle wheel on shrimp weight throughout cultivation. In terms of shrimp weight, there were no significant differences (P > 0.05) between the two aeration methods. Every week, shrimp weight was measured, and it was discovered that shrimp in both administrations grew normally. The average shrimp weight in the automatic pond at the end of the culture was 18.03 ± 0.69 g, while the average shrimp weight in the manual pond was 19.14 ± 2.40 g. This result is higher than that of [8], who found that *P. vannamei* cultured at the pond using nanobubble generators had the highest rate, with a weight average of 15.10 g, while the control obtained a weight average of 12.70 g in 80 days culture.

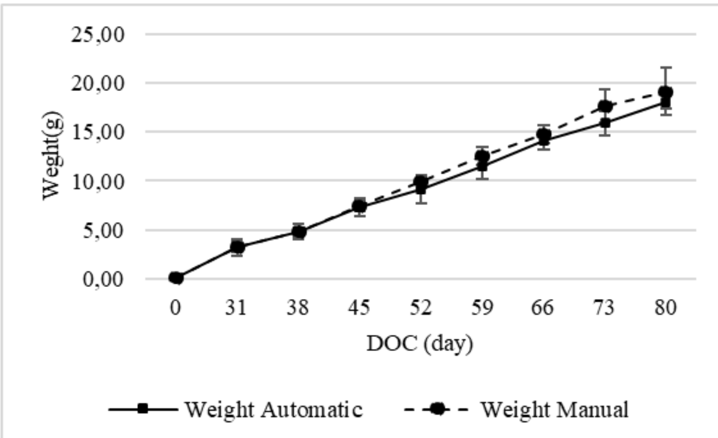

Fig. 7. The effect of the paddle wheel on shrimp weight.

The data on mean shrimp body weight revealed that the use of an AP had no negative effect on shrimp performance. This is due to the paddle wheel not causing a significant change in DO level sufficiency. [21] suggest that the influence of environmental conditions affects penaeids' ability to gather energy and distribute it properly for growth. One of the elements that affects an organism's metabolism is the level of DO.

Table 3 presents comparison values for shrimp biomass, productivity, and aeration costs. Differences in the administration of paddle wheels had no effect on either final biomass or productivity. The final biomass in a pond with an AP was 2249.56 kg, with a productivity of 1.22 kg/m3, whereas a pond with a MP had a biomass of 1547.43 kg and a productivity of 1.15 kg/m3. The fact that there is no significant difference in average individual shrimp weight during cultivation is one of the main reasons for these results.

The use of automatic in comparison with manual paddle wheels, on the other hand, resulted in significantly different aeration costs. The AP cost 0.18 USD per kg to aerate, whereas the MP cost 0.32 USD per kg. The reduction of aeration cost was influenced by the different numbers of units active of paddle wheels during cultivation. The cost figures were equivalent at 8.31 and 14.23 gigajoules per tonne (GJ/t), indicating that both remained within the recommended energy range. According to [10] energy use for aeration in shrimp ponds should not exceed 10-15 GJ/t shrimp.

Data Table 3. showed that implementation of AP based on real-time DO concentration would reduce energy cost in shrimp production.

Table 3. Biomass, productivity, and aeration cost of the shrimp culture

Paddle wheel in Ponds	**Initial Biomass (kg)**	**Final biomass (kg)**	**Productivity (kg/m^3)**	**Aeration cost (USD/kg)**	**Gigajoule* / ton**
Automatic	24.00	$2249.56^a \pm 300.67$	$1.22^a \pm 0.25$	$0.18^b \pm 0.03$	$8.31^b \pm 1.13$
Manual	24.00	$1547.43^a \pm 359.04$	$1.15^a \pm 0.28$	$0.32^a \pm 0.05$	$14.23^a \pm 2.36$

*1 kW = 0.0036 GJ

4 Conclusion

The use of an AP based on real-time DO concentration had no negative impact on water quality and shrimp biomass in shrimp-intensive culture, but it could reduce aeration energy costs by up to 37.71%. Aeration costs 0.32 ± 0.05 USD/kg for ponds with MP and 0.18 ± 0.03 USD/kg for ponds with AP. The decrease in energy is due to less paddlewheel Active during cultivation as opposed to the MP. As a result, in terms of aeration costs, the use of an AP may be more profitable for intensive shrimp culture.

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References

1. FAO, *The State of World Fisheries and Aquaculture 2022*, Towards Blue Transformation, FAO, Rome (2022)
2. K. Mahmudov, A. Mahmoud, S. Sur, F. C. Cruz, A. M. Bilton, Energy for Sustainable Development **51** (2019)
3. A. Kumar, S. Moulick, B. Chandra, Aquac Eng **56** (2013)
4. J. Marappan *et al*, Aquac Res **51** (2020)
5. N. N. Tien, R. Matsuhashi, V. T. T. B. Chau, Energy Procedia 157 (2019)
6. M. Jayanthi, A. A. K. Balasubramaniam, S. Suryaprakash, N. Veerapandian, T. Ravisankar, K. K. Vijayan, Aquac Eng **92** (2020)
7. T. Itano *et al*, Aquac Eng **85** (2019)
8. A. I. Rahmawati *et al*, Aquaculture and Fisheries **6** (2021)
9. Y. S. Lim, P. Ganesan, M. Varman, F. A. Hamad, S. Krishnasamy, Aquac Eng **93** (2021)
10. C. E. Boyd, A. A. McNevin, J. World Aquac Soc **52** (2021)
11. C. E. Boyd *et al*, J. the World Aquaculture Society **51** (2020)
12. J. Izel-Silva, E. A. Ono, M. N. de Queiroz, R. B. dos Santos, E. G. Affonso, Aquaculture **529** (2020)
13. C. Huang *et al,* Aquac Rep **22** (2022)
14. Supriatna, Marsoedi, A. M. Hariati, M. Mahmudi, AACL Bioflux **10** (2017)

15. Kemen-KP, *Pedoman Umum Pembesaran Udang Windu (Penaeus modon) dan Udang Vaname* (*Litopenaeus vannamei*), Peraturan Menteri Kelautan Dan Perikanan Republik Indonesia Nomor 75/Permen-Kp/2016, Jakarta (2017)
16. K. D. Santa, L. Vinatea, Aquac Eng **36** (2007)
17. S. A. Ulaje *et al*, J. Therm Biol **92** (2020)
18. V. T. Okomoda *et al*, J King Saud Univ Sci **34** (2022)
19. C. E. Boyd, Aquac Eng **18** (1998)
20. F. J. Fernández, M. C. Castro, M. A. Rodrigo, P. Cañizares, Control Eng Pract **19** (2011)
21. R. Ana Denisse, Open Zool J **4** (2011)