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Strategies for Water Management in Shrimp Mariculture: A Case Study of Kedongkelor Village, Pemalang Regency

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Abstract

Water quality plays a crucial role in the success of shrimp mariculture. This study aimed to evaluate the relationship between key water quality parameters and the growth performance and survival of shrimp in four mariculture ponds. Environmental variables, including temperature, salinity, dissolved oxygen (DO), and pH. Results showed that temperature fluctuated between 26–31 °C, salinity ranged from 26.5–33 ppt, DO concentrations varied from 4.7 to 8.3 mg/L, and pH levels were stable between 7.3 and 8.2. Optimal evening temperature and DO levels did not show a consistent correlation with improvements in Average Daily Growth (ADG), Average Body Weight (ABW), or Survival Rate (SR). Pond 2, located closer to the water treatment reservoir, exhibited the highest growth performance and survival, highlighting the importance of water quality management. Conversely, Pond 3 showed reduced SR due to high stocking density and improper water management practices. Biosecurity measures, such as chlorine application and pond lining with High-Density Polyethylene (HDPE), were implemented but require further efforts to prevent pathogen intrusion. The study emphasizes the critical need for continuous water quality monitoring, proper water circulation, and enhanced biosecurity strategies to support best shrimp farming production. Maintaining stable environmental conditions within optimal ranges can enhance shrimp growth, and survival, ultimately improving mariculture productivity.

1. Introduction

Although Indonesia's shrimp export volume has fluctuated over time, the commodity remains highly competitive in the mariculture sector, contributing significantly up to 60% to the country's total marine commodity for exports (Agustiyana *et al.*, 2023). The high production rate of *Litopenaeus vannamei* is driven by their rapid growth, short rearing period, and the use of high-density stocking systems (Apresia *et al.*, 2024; Heriyati *et al.*, 2024). As a key national commodity contributing to foreign exchange earnings, shrimp is exported in various forms, including frozen, fresh, and processed products (Yulisti *et al.*, 2021). *L. vannamei* also known as white shrimp, is an introduced species that has become widely cultivated across Indonesia (Gompi *et al.*, 2023). As one of the country's primary export commodities, it is prioritized in the development of aquaculture to support national economic growth (Fatimah *et al.*, 2022) . The shrimp species high production potential is attributed to its fast growth rate, relatively short mariculture cycle, and compatibility with intensive production systems involving high stocking densities (Rosyidah *et al.*, 2020; Sandi *et al.*, 2020). Moreover, vannamei shrimp exhibit strong feeding behavior and notable resistance to various diseases, making them highly favorable for commercial mariculture (Suryadi *et al.*, 2021).

Despite the advantages of intensive *L. vannamei* mariculture, this system is also accompanied by significant production risks (Muliani *et al.*, 2021). These risks often stem from declining water quality during the grow-out phase and the emergence of disease outbreaks, leading to variability in shrimp productivity among farmers (Saraswati *et al.*, 2023). Water quality plays a pivotal role in shrimp aquaculture, as it directly influences both growth performance and susceptibility to disease (Listriyana *et al.*, 2023). Consequently, consistent and systematic water quality monitoring is essential throughout the mariculture period to ensure optimal environmental conditions and improve harvest outcomes (Yunarty *et al*., 2022). Implementing effective water management strategies not only helps maintain pond water quality but also enhances shrimp growth and minimizes the likelihood of disease-induced mass mortality (Suryadi *et al*., 2021).

Water quality is a critical factor in the success of mariculture. It is assessed based on several key parameters, including salinity, temperature, pH, and dissolved oxygen (DO) (Farabi and Latuconsina., 2023). The optimal salinity range for marine species such as shrimp is between 26–32 ppt, as salinity levels directly affect metabolic processes, particularly fluid osmoregulation, which plays a vital role in the growth of shrimp and other marine organisms (Jayanti *et al*., 2022). The ideal temperature range for *L. vannamei* mariculture is 25–30 °C, temperatures beyond this range can induce stress and increase susceptibility to disease (Utami *et al.*, 2023).

The optimal pH level for shrimp mariculture ranges from 6.9 to 8.7. pH primarily influences the molting process and growth, as lower pH levels may result in softer exoskeletons, making shrimp more vulnerable (Scabra *et al*., 2023).. The optimal DO concentration is between 3.5–6.5 mg/L, as insufficient oxygen levels can compromise shrimp health, increase vulnerability to disease, and lead to physiological stress due to impaired oxygen intake and loss of equilibrium (Kusumaningrum *et al.*, 2022). Given its significant role, water quality is considered a vital determinant in the growth of shrimp. Therefore, this study aims to examine the relationship between water quality parameters and the growth and survival of cultured marine species.

2. Material and methods

2.1 Material

The materials and equipment utilized in this study included vannamei shrimp, chlorine for water sterilization, and lime for pH adjustment. Additional instruments used to support water quality monitoring and sampling included a digital balance for biomass measurements, sampling nets, a DO meter (Lutron DO-5510), a pH meter (Smart Sensor AS218), a refractometer (KENTA Optical Refractometer 05560004) for salinity readings, and a thermometer (Taffware Digital) for temperature control. Distilled water, sample bottles, and pipettes were also employed for laboratory analyses and accurate handling of water and shrimp tissue samples. All tools were calibrated prior to use to ensure data accuracy and consistency throughout the experimental procedures.

2.2 Methods

2.2.1 Research location

The research conducted was an observational study on *L. vannamei* ponds located in Kedongkelor Village, Pemalang Regency. Data collection was carried out in four ponds, each designed as an earthen pond lined with High Density Polyethylene (HDPE), with a surface area of 1,600 m² per pond and a high stocking density of up to 200,000 individuals of *L. vannamei* (Figure 1). Paddlewheel aerators were systematically arranged in a diagonal configuration, with a total of 16 units installed per pond. Each aerator was positioned approximately 5 meters from the pond wall and maintained a distance of 7 to 8 meters from the central drainage outlet. Regular monitoring of environmental parameters such as water temperature, salinity, dissolved oxygen (DO), and pH was performed twice daily in the morning (8 - 10am) and evening (2 - 5 pm). This layout and data collection approach were intended to optimize water circulation and support uniform water quality distribution throughout the pond, which is critical for the growth and health of cultured shrimp. Data were observed from the beginning of the cycle until harvest in DOC 100–110.

2.2.2 Water Management

Water circulation management in shrimp mariculture is carried out through a multi-stage system, beginning with filtration. Filtration is essential as the primary water source for shrimp mariculture is seawater. Seawater is drawn using a 200-meter-long pipeline extending from the shoreline to the reservoir tank. This pipeline is supported by a pump system that facilitates the transfer of seawater into the reservoir. Once the reservoir reaches a depth of 3 meters, water sterilization is performed using 10 ppm of quicklime and 10 ppm of calcium hypochlorite, and the water is left to settle for 24 hours. Sterilization is conducted prior to utilizing the mariculture ponds for the grow-out phase of marine organisms. To further minimize the presence of pathogens and contaminating microorganisms in the pond water, chlorine is applied at a concentration of approximately 15 ppm, followed by a 24-hour holding period (Naban *et al.*, 2023). After all sterilization processes have been completed, the treated water is channeled into the 4 culture ponds to serve as an acclimatization medium for the shrimp post-larvae.

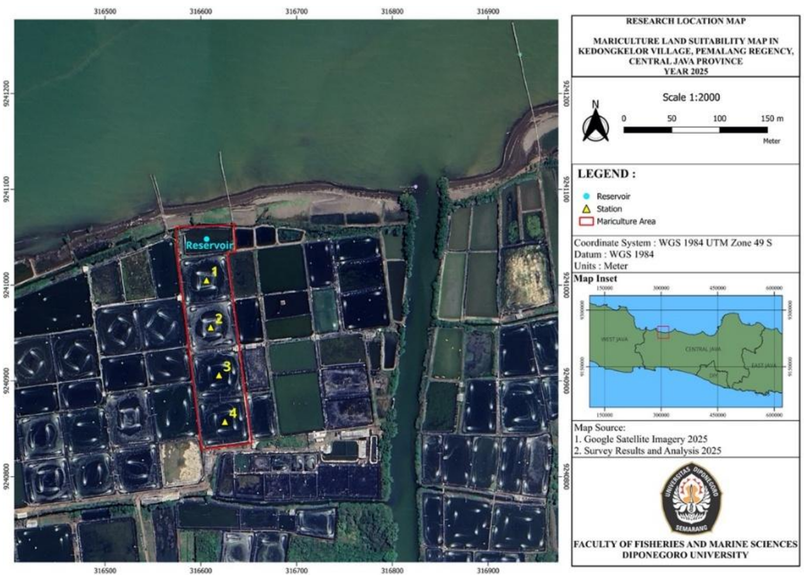

Figure 1. Study Site

The purpose of flushing is to reduce excess feed and debris that settles at the bottom of the pond. The wastewater is then flowed to the settling pond to settle the sediment to produce clean water. In the settling area, several types of mangrove plants are planted which act as biofilters to absorb chemicals such as nitrates, nitrites and ammonia contained in mariculture waste (Anton *et al*., 2020). Clean water from the deposition results will then be channeled back to the sea.

2.3 Shrimp Sampling

Shrimp sampling was carried out using an anco net with a mesh size of 70 x 70 cm. The anco was placed at four different points in each pond. Once the feed was consumed, the shrimp were captured when the anco was retrieved. A total of 30 shrimp were collected and then weighed using a digital balance to allow for data analysis using ABW (Average Body Weight), ADG (Average Daily Gain), and SR (Survival Rate) formulas.

2.2.4 Average Body Weight (ABW)

The Average Body Weight (ABW) is the mean weight value of approximately 30 shrimp collected from a single pond over a specific period. ABW is calculated using 30 shrimp sampled with an anco net, by dividing the total weight of the shrimp by the number of individuals (30) (Pramudia et al., 2022). The ABW is analyzed using the following formula:

$$\text{ABW} = \frac{Weight\ of\ all\ vaname\ shrimp\ (g)}{Number\ of\ vaname\ shrimp\ (shrimp)}$$

2.2.5 Average Daily Growth (ADG)

Average Daily Growth (ADG) is the average daily growth rate of shrimp. ADG is calculated using two different sampling periods: the first sampling is conducted at day 45, and the second sampling is conducted 90 days later. The difference of 45 days between the 2 sampling times is used as the divisor (Pramudia et al., 2022). ADG is analyzed using the following formula :

$$\text{ADG} = \frac{ABW\ II - ABW\ I}{t}$$

2.2.5 Survival Rate (SR)

In this study, survival rate (SR) was estimated indirectly based on the total feed given during the mariculture period. Actual biomass was estimated by dividing the total feed by the target Feed Conversion Ratio (FCR). Theoretical biomass was calculated by multiplying the number of stocked shrimp by the target final average weight (Pramudia et al., 2022). SR is analyzed using the following formula:

$$\text{SR} = \frac{Estimated\ Total\ Feed}{Theoretical\ Biomass} x\ 100\%$$

3. Results

3.1 Water Quality

3.1.1 Temperature

The variation in water temperature throughout the experimental period is shown in Figure 1. Temperature observations conducted in the morning indicated fluctuations across the four main ponds, with the highest readings recorded in Pond 4, ranging from 26.8 to 29.2 °C (Figure 2a), and a stable average of 28 °C. In contrast, during the evening towards evening, temperatures ranged from 28.8 to 31.3 °C (Figure 2b).

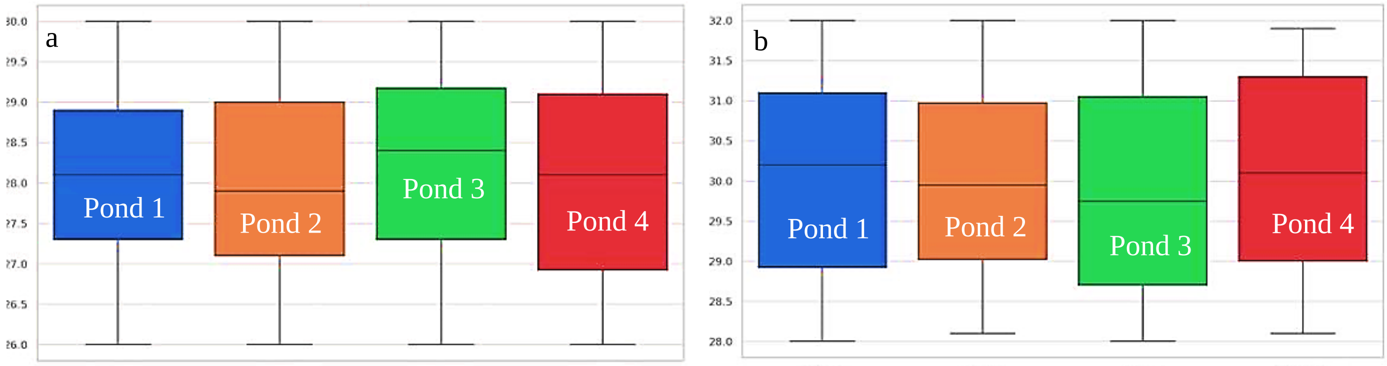

Figure 2. Temperature Dynamics at Ponds in the Morning (a) and Evening (b)

3.1.2 Salinity

Salinity measurements observed in four ponds are illustrated in Figure 3. Salinity is presented in Figure 3. Salinity was measured in the morning, showing fluctuations ranging from 27.3 to 33 ppt. Notably, Pond 2 exhibited considerable variation, with salinity levels ranging between 27.6 and 32.7 ppt (Figure 3a). Similar trends were observed in the evening, where Pond 2 again showed substantial fluctuations between 27.8 and 32.8 ppt (Figure 3b).

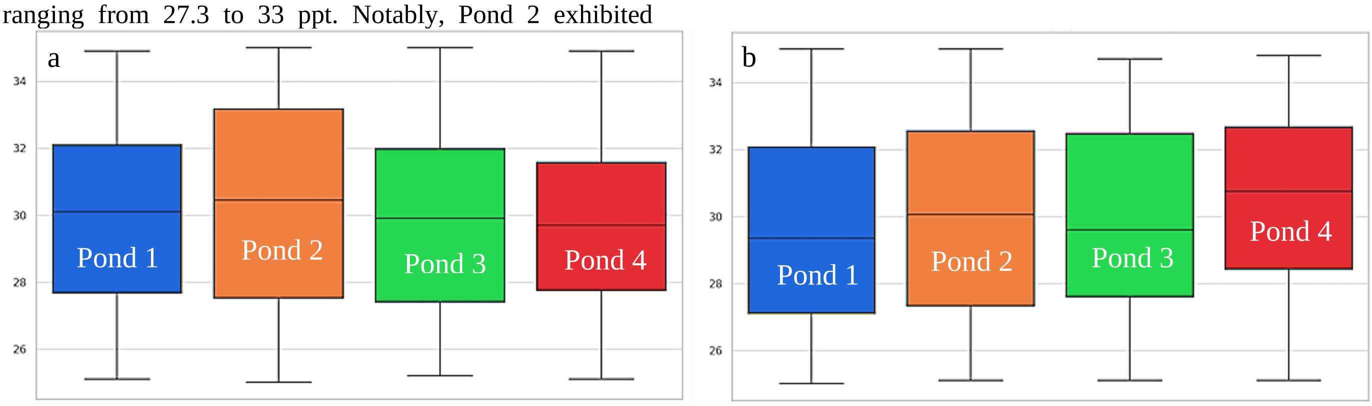

Figure 3. Salinity Dynamics at Ponds in the Morning (a) and Evening (b)

3.1.3 Dissolved Oxygen (DO)

Dissolved oxygen (DO) concentrations based on regular observations and measurements are presented in Figure 4. Dissolved oxygen (DO) levels ranged from 4.7 to 8.3 mg/L in the morning (Figure 4a). The optimal DO levels were recorded during the evening period, ranging between 5.7–7.2 mg/ L (Figure 4b), contributing to improved water quality, as well as the growth and development of cultured biota and plankton communities.

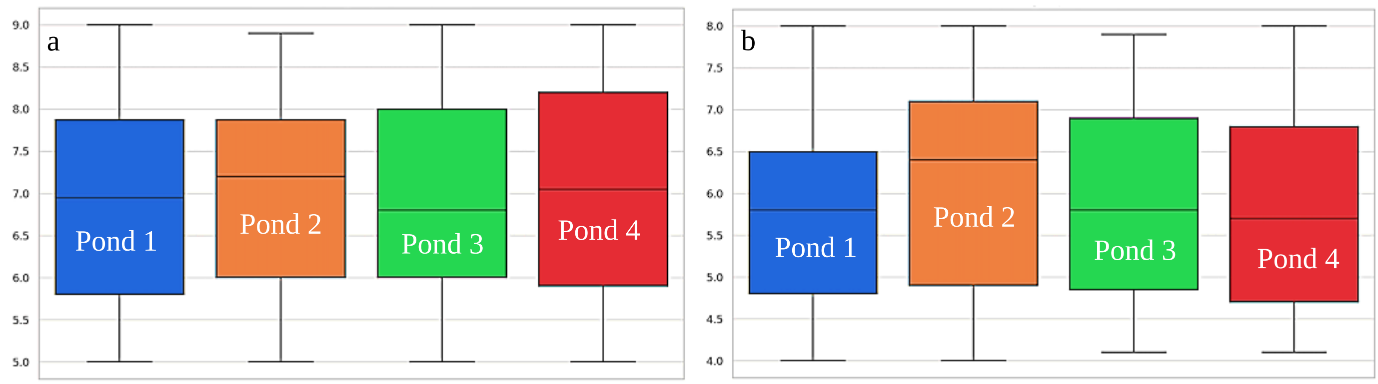

Figure 4. DO Dynamics at Ponds in the Morning (a) and Evening (b)

3.1.4 pH

The measurement of pH were taken twice daily (Figure 5), at 07:00 in the morning and 16:00 in the evening, using a calibrated pH meter to ensure accuracy. Morning measurements showed pH values ranging from 7.3 to 8.0, with an average of 7.6 (Figure 8). In contrast, evening measurements recorded pH values between 7.5 and 8.2, with an average of 8.0 (Figure 9).

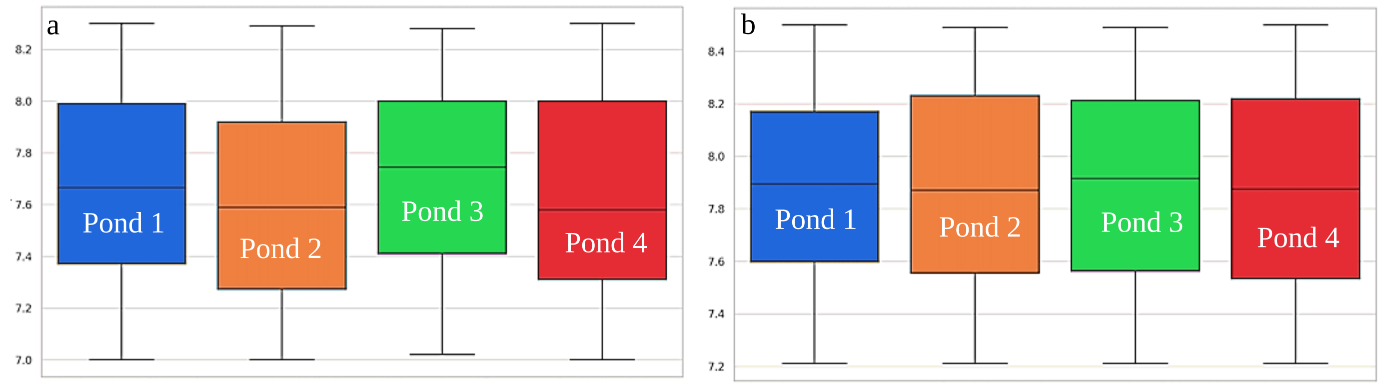

Figure 5. pH Dynamics at Ponds in the Morning (a) and Evening (b)

3.2 Average Daily Growth (ADG), Average Body Weight (ABW), Survival Rate (SR)

Average Daily Gain (ADG) was calculated individually for each pond (Figure 6). The ADG ranged from 0.139 to 0.149 g/day, with Pond 2 exhibiting the highest ADG, while the lowest values were recorded in Ponds 1 and 3 (Figure 6a). The ABW values ranged between 3.16 and 3.41 g per individual, with Pond 2 showing the highest ABW and Pond 3 the lowest (Figure 6b). Survival Rate (SR) was estimated based on the total feed input during the mariculture period. The SR values ranged between 89.97% and 93.74%, with the highest SR observed in Pond 2 and the lowest in Pond 3 (Figure 6c). Overall, variations in growth performance and survival among ponds were likely influenced by differences in pond management practices and environmental conditions.

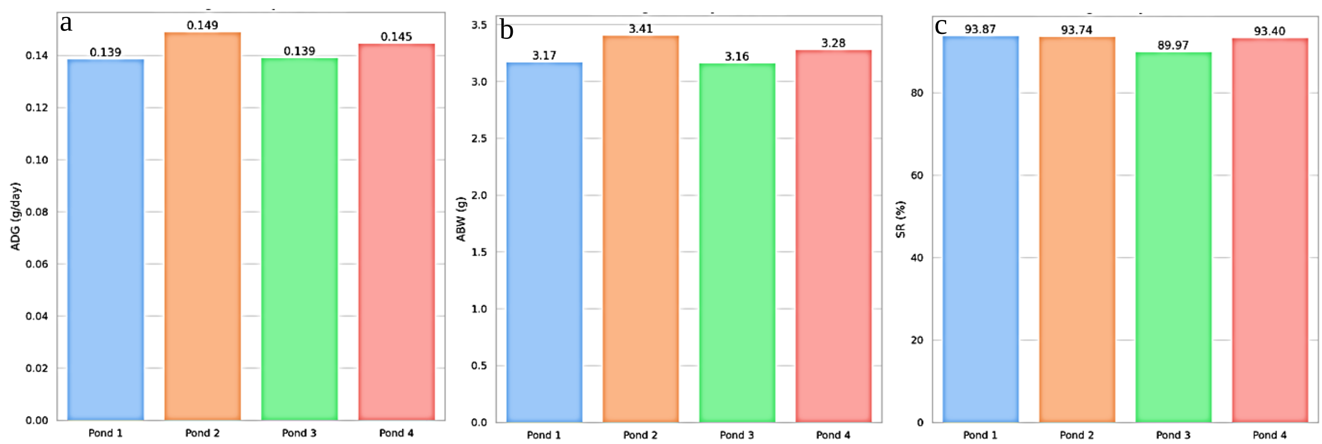

Figure 6. Comparison Chart of ADG (a), ABW (b) and SR (c)

4. Discussion

4.1 Water Quality Dynamics in Mariculture

Salinity was measured based on the specific requirements of mariculture biota to adapt to prevailing environmental conditions, facilitating optimal growth and development. Salinity levels that are either too low or excessively high can lead to increased mortality rates and minimal growth performance (Apresia *et al*., 2024). A salinity range of 26.5–33 ppt was identified as the optimal maximum, attributed to effective water exchange practices through siphoning and the balanced method of water inflow equating water outflow (Listriyana *et al*., 2023). Maintaining this balance is crucial to stabilizing environmental conditions within the pond ecosystem. Conversely, when salinity exceeds 33–36 ppt, it is typically due to elevated solar radiation intensities over the adjacent seawater, leading to significant evaporation. This phenomenon increases both the salinity and water temperature, ultimately causing the exoskeleton of shrimp to become harder and potentially impacting their growth dynamics (Juniarti *et al,* 2017). These results fall within the optimal salinity range for mariculture, particularly for supporting healthy growth, which according to Se *et al* (2023), is between 25–35 ppt. Maintaining salinity within this range is crucial for the physiological performance and survival rate of cultured species. Variations outside the optimal range can lead to increased stress levels and reduced growth rates. Therefore, consistent monitoring and management of salinity are essential to ensure optimal culture conditions in shrimp mariculture systems.

Phytoplankton utilize sunlight to perform photosynthesis, supported by the availability of carbon dioxide (CO_2), producing glucose and oxygen as end products. The oxygen generated through this process significantly contributes to the increase in dissolved oxygen (DO) levels within the ponds, which in turn supports the metabolism and growth of mariculture biota (Farabi and Latuconsina, 2023). Adequate oxygen availability is a key factor in maintaining the health and optimal development of organisms, including shrimp and microbial communities. The optimal temperature varied among the ponds, with the minimum recorded at 26 °C, typically occurring before sunrise due to reduced solar radiation and heat absorption. As sunlight entered the ponds, the aquatic environment from microscopic organisms to mariculture biota underwent dynamic physiological changes (Utami *et al*., 2023).

In addition, the use of paddlewheels plays a crucial role in enhancing the homogenization of oxygen distribution throughout the ponds, ensuring that the oxygen produced through photosynthesis is evenly dispersed and efficiently utilized by all aquatic organisms. Effective oxygen distribution not only promotes the growth of cultured biota but also helps prevent the accumulation of metabolic waste products that could otherwise deteriorate water quality (Sasmito *et al*., 2021). The optimal temperature conditions for shrimp mariculture are achieved during the evening to evening period. This finding aligns with the statement by Farabi and Latuconsina (2023), who reported that the optimal temperature range for shrimp mariculture is between 27 and 32 °C. The observed temperature range of 26.8–31.3 °C across the four ponds represents the optimal range that must be consistently maintained. Stability within this temperature range is essential to support the normal physiological processes of aquatic biota, sustain the activity of beneficial microorganisms, and prevent the buildup of toxic substances from uncontrolled decomposition of organic matter, thereby making continuous monitoring and management of water quality critical for the success and sustainability of mariculture operations (Suryadi *et al*., 2021).

Furthermore, dissolved oxygen (DO) levels and pH significantly influence planktonic movement and stress levels in mariculture biota. Elevated DO concentrations observed during the morning and midday are indicative of active photosynthesis, during which phytoplankton generate oxygen that supports the respiration and growth of cultured organisms (Suhendar *et al*., 2020). Typically, high DO levels are accompanied by elevated pH values because CO_2 consumption during photosynthesis renders the water more alkaline (Imrana *et al*., 2023). In contrast, lower DO levels at night are primarily driven by the respiration processes of phytoplankton and other microorganisms, which continuously release CO_2 into the pond water (Samadan *et al*., 2020). This accumulation of CO_2 leads to a decrease in pH levels toward the evening and nighttime. To mitigate the associated risks of respiratory stress in shrimp, liming is often applied to stabilize pH and support optimal physiological functioning (Supriatna *et al*., 2020). Proper management of plankton populations is also essential to prevent excessive competition for oxygen, particularly during nighttime hours.

The use of paddlewheels is recommended to enhance oxygen distribution and support plankton balance (Rozi, 2021). Special attention should be given to the development of phytoplankton, particularly Bacillariophyceae, which dominate oxygen consumption at night. Strategies such as maintaining adequate paddlewheel operation and appropriate liming are vital to minimizing hypoxia risks and promoting a stable mariculture environment (Aprilliani *et al*., 2018). According to Janna et al. (2020), the optimal DO range for aquatic organism growth is between 4.5–7.0 mg/L. The DO levels observed in this study indicate favorable conditions, particularly during the evening, for supporting metabolic activity, enhancing feed conversion efficiency, and maintaining the overall health of cultured species.

4.2 Improving Shrimp Pond Management

Water quality is a key factor in determining the success of shrimp growth in mariculture systems. Throughout the monitoring period in four mariculture ponds, water quality parameters such as temperature, salinity, dissolved oxygen (DO), and pH remained primary indicators for assessing the culture environment conditions. The pH levels were recorded to be stable within the optimal range of 7.3–8.2, supporting the shrimp's physiological processes. However, morning water temperatures reaching 26 °C may potentially reduce feed intake efficiency, slow growth rates, and weaken shrimp immune responses (Usman *et al*., 2022). Salinity levels exceeding the optimal threshold up to 33 ppt, particularly in the evening, were strongly suspected to be associated with seasonal changes and may disrupt the molting process, which is critical for shrimp growth (Jayanti *et al*., 2022). The DO values recorded as low as 4.7 mg/L in the morning also raised concerns, as low oxygen levels can induce metabolic stress and increase susceptibility to disease infections.

The optimal conditions for mariculture activities, where a stable pH between 7.3 and 8.2 is considered crucial for the healthy growth and metabolism of cultured aquatic organisms. Maintaining pH within this range supports enzymatic activities, stabilizes physiological processes, and minimizes stress responses in mariculture species. Furthermore, slight diurnal variations in pH are expected due to photosynthetic activity by phytoplankton during daylight hours, which reduces CO_2 concentrations and elevates pH levels. Consistent monitoring and management of pH are therefore essential to ensure optimal pond productivity and to prevent adverse conditions that could impair biota development and health (Setiyawan *et al*., 2020).

The relationship between water quality and growth performance was evident in Pond 2, located closer to the water treatment reservoir. This proximity enabled the pond to receive better-quality water, significantly reducing the risks of contamination and pathogen exposure (Naban *et al*., 2023). In contrast, Pond 3, characterized by water management practices, experienced a significant decline in Survival Rate (SR). Although biosecurity measures such as liming and chlorine application in the reservoir had been implemented, their effectiveness was not fully optimal. To strengthen biosecurity, the implementation of preventive strategies is highly recommended, including the installation of mesh fencing around the reservoir to prevent the entry of crawling animals and the use of finer inlet water filters to exclude undesirable organisms. With proper improvements in biosecurity management, the risk of decreased SR can be minimized, thereby supporting better growth performance and shrimp survival (Khumaidi *et al*., 2022).

5. Conclusions

This study highlights the importance of effective water quality management in supporting the growth and survival of Litopenaeus vannamei in intensive shrimp mariculture. Fluctuations in temperature, salinity, dissolved oxygen (DO), and pH were found to influence shrimp health and performance. Pond 2, showed the best results in terms of growth and survival, suggesting that access to cleaner and more stable water conditions contributes significantly to production success. Key management practices, such as the use of paddlewheels for aeration, regular monitoring of water parameters, and proper water exchange, proved essential in maintaining a healthy culture environment. However, the study also identified the need for improved biosecurity, particularly in ponds farther from the water source. Strengthening preventive measures, including finer water filtration and better physical barriers, is recommended to reduce pathogen risks. Overall, maintaining stable and optimal water quality, supported by good management and biosecurity, is vital for the shrimp mariculture systems.

Ethics approval

No permits were required.

Data availability statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Author contributions

FA: research ideas, supervising and writing

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Declaration of competing Interest

None

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