

ORIGINAL RESEARCH

Growth dynamics and productivity of Pacific white shrimp (*Litopenaeus vannamei*) in polyculture under different stocking densities

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ABSTRACT. Stocking density is a critical factor influencing growth performance, survival, and production efficiency in Pacific white shrimp culture. In traditional shrimp polyculture systems, increasing stocking density is commonly applied to enhance production; however, excessive density often leads to reduced growth performance, lower survival, and inefficient feed utilization due to intensified biological competition and system carrying capacity limitations. This study therefore evaluated the effect of stocking density on the growth performance, survival, and feed utilization of *Litopenaeus vannamei* cultured in a traditional polyculture pond system. The experiment was conducted using three stocking densities (10, 20, and 30 ind. m⁻²) with three replications over an eight-week culture period. The polyculture system involved co-culturing shrimp with milkfish (*Chanos chanos*), which contributes to nutrient cycling and improves ecological balance within the pond environment. Results showed that shrimp reared at 10 ind. m⁻² exhibited the best performance in terms of growth, survival, and feed efficiency, while higher densities resulted in reduced performance. The lowest feed conversion ratio (FCR) was observed at the lowest density, indicating efficient feed utilization within the optimal range for *L. vannamei*, whereas higher densities led to a substantial increase in FCR, reflecting reduced efficiency. Water quality parameters remained within suitable ranges and did not differ significantly among treatments. These findings suggest that stocking density primarily influences shrimp performance through biological interactions rather than environmental changes. Optimizing stocking density is therefore essential to achieve sustainable and efficient production in traditional shrimp polyculture systems.



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Key words: Shrimp culture, growth performance, feed conversion ratio.

Dinámica de crecimiento y productividad del camarón blanco del Pacífico (*Litopenaeus vannamei*) en policultivo bajo diferentes densidades de siembra

RESUMEN. La densidad de siembra es un factor crítico que influye en el crecimiento, supervivencia y eficiencia de producción en el cultivo de camarón blanco del Pacífico. En los sistemas tradicionales de policultivo de camarón, el aumento de la densidad de siembra se aplica comúnmente para mejorar la producción; sin embargo, una densidad excesiva a menudo conduce a un rendimiento de crecimiento reducido, menor supervivencia y utilización ineficiente del alimento debido a la intensificación de la competencia biológica y las limitaciones de la capacidad de carga del sistema. Por lo tanto, este estudio evaluó el efecto de la densidad de siembra sobre crecimiento, supervivencia y utilización del alimento de *Litopenaeus vannamei* cultivado en un sistema tradicional de estanques de policultivo. El experimento se llevó a cabo utilizando tres densidades de siembra (10, 20 y 30 ind. m⁻²) con tres réplicas durante un período de cultivo de ocho semanas. El sistema de policultivo implicó el cultivo

del camarón con el sabalote (*Chanos chanos*), lo que contribuye al ciclo de nutrientes y mejora el equilibrio ecológico dentro del entorno del estanque. Los resultados mostraron que el camarón criado a 10 ind. m⁻² exhibió el mejor rendimiento en términos de crecimiento, supervivencia y eficiencia alimenticia, mientras que densidades más altas resultaron en un rendimiento reducido. El índice de conversión alimenticia (FCR) más bajo se observó a la menor densidad, lo que indica una utilización eficiente del alimento dentro del rango óptimo para *L. vannamei*, mientras que las densidades más altas provocaron un aumento sustancial del FCR, lo que refleja una menor eficiencia. Los parámetros de calidad del agua se mantuvieron dentro de rangos adecuados y no mostraron diferencias significativas entre los tratamientos. Estos hallazgos sugieren que la densidad de siembra influye principalmente en el rendimiento del camarón a través de interacciones biológicas, más que por cambios ambientales. Por lo tanto, optimizar la densidad de siembra es esencial para lograr una producción sostenible y eficiente en los sistemas tradicionales de policultivo de camarón.

Palabras clave: Cultivo de camarón, crecimiento, índice de conversión alimenticia.

INTRODUCTION

The culture of Pacific white shrimp (*Litopenaeus vannamei*) represents one of the leading commodities in the fisheries sector and plays a significant role in supporting the economic growth of Indonesia, particularly through export expansion and employment generation (Bosman et al. 2021; Mustafa et al. 2023). Shrimp farming practices have steadily transitioned to more intensive systems as market demands have increased. However, intensification without adequate environmental management leads to a variety of problems, including deterioration of water quality, elevated physiological stress in cultured organisms, reduced feed utilization efficiency, and increased risks of mass mortality, affecting productivity and the long-term sustainability of shrimp farming operations (Murthada and Dwiyantri 2025; Shilman et al. 2025).

Stocking density is recognized as one of the primary factors determining the success of *L. vannamei* culture. While increasing stocking density can accelerate organic waste accumulation and negatively affect shrimp health and growth performance, excessively low densities may result in suboptimal land use efficiency. These trade-offs have been widely reported in pond-based shrimp culture systems (Emerenciano et al. 2022; Chen et al. 2023; Kumar et al. 2024).

To improve system stability, polyculture has been widely applied as an ecological approach to

enhance resource utilization and reduce environmental impacts through species complementarity and nutrient recycling (Emerenciano et al. 2022; He et al. 2025; Pazmiño et al. 2025). In traditional pond systems, *L. vannamei* is commonly co-cultured with milkfish (*Chanos chanos*), where species complementarity can promote more efficient nutrient cycling and reduce organic matter accumulation. However, the effectiveness of such systems depends strongly on the balance between stocking density and the environmental carrying capacity of the pond (He et al. 2025).

Although numerous studies have examined the effects of stocking density on shrimp performance, most have been conducted in monoculture or intensive systems (Emerenciano et al. 2022; Irani et al. 2023; Kumar et al. 2024). Studies specifically addressing stocking density in traditional shrimp-milkfish polyculture systems, particularly those integrating growth performance, feed efficiency, and environmental dynamics, remain limited (He et al. 2025; Valentine et al. 2025). This gap highlights the need for a more integrated evaluation of how stocking density influences biological performance and environmental responses under realistic pond-based farming conditions. Such understanding is essential to support the development of adaptive and sustainable management strategies in shrimp aquaculture (Emerenciano et al. 2022; He et al. 2025; Pazmiño et al. 2025). Therefore, this study aimed to: (1) evaluate the effect of different stocking densities on the growth performance of *L. vannamei* in a traditional polyculture system;

(2) assess their impact on survival rate and feed conversion efficiency; and (3) analyse the relationship between water quality parameters and shrimp production performance. The findings are expected to provide a scientific basis for optimizing stocking density in accordance with pond carrying capacity, thereby improving productivity, environmental management, and sustainability of traditional shrimp aquaculture systems.

MATERIALS AND METHODS

Study area and experimental period

The experiment was conducted in a traditional earthen pond in Pangkahkulon Village, Ujungpangkah Subdistrict, Gresik, East Java, Indonesia (7° 2'-7° 5' S; 112° 33'-112° 36' E). The pond had an effective area of approximately 2,000 m² and was supplied with brackish water from nearby coastal channels. The culture system followed conventional practices without mechanical aeration. The experiment lasted eight weeks (December 2025 to January 2026) under field conditions to represent typical farming practices in the area. The culture system in this study was a traditional polyculture pond in which *L. vannamei* was reared together with milkfish (*C. chanos*).

Experimental design

The experiment used a completely randomized design (CRD) to minimize bias with three stocking densities: 10, 20, and 30 ind. m⁻², coded as Treatments A, B, and C, respectively, each with three replications (nine experimental units in total) (Figure 1). Each unit consisted of a 1 × 1 m enclosure supported by an independent frame and installed within the same pond. All enclosures were maintained under similar environmental conditions, including water circulation, light exposure, and nutrient availability. Each unit was managed individ-

ually, including feeding and monitoring, to minimize interaction among treatments and maintain experimental independence. This design aimed to reduce spatial variation so that differences among treatments were primarily attributable to stocking density (Hossain et al. 2013; Irani et al. 2023).

Juvenile Pacific white shrimp with uniform size (7.5-8.5 cm total length) and weigh (0.7-1.0 g) were obtained from a commercial hatchery. In addition to shrimp, milkfish were co-cultured in the pond as part of the traditional polyculture system. *Litopenaeus vannamei* were acclimated to pond conditions for 24 h before stocking. After acclimation, shrimp were randomly distributed into experimental units according to stocking density treatments. Initial weight and length were recorded before stocking for baseline measurements.

Litopenaeus vannamei were fed a commercial pelleted diet containing 30-35% crude protein (Ferrando-Juan et al. 2026). Feeding was conducted three times daily (07:00, 13:00, and 18:00 h). During the first two weeks, blind feeding was applied, followed by adjustments based on biomass, feeding activity, and uneaten feed. The initial feeding rate was 8-10% of biomass, with daily rations adjusted according to stocking density. Feed amounts were then modified weekly based on growth and consumption to improve efficiency and reduce waste (Xu et al. 2020).

Sampling was conducted biweekly by randomly collecting ten *L. vannamei* from each treatment. Body weight was measured using an analytical balance (± 0.01 g), while total length was measured using a digital caliper (± 0.01 cm). Total length was defined as the distance from the tip of the rostrum to the end of the telson. The absolute length growth (cm) was calculated according to Zhang et al. (2024) as $L_t - L_o$, where L_t is the final total length and L_o is the initial total length. The absolute weight (g) was $W_t - W_o$, where W_t is the final body weight and W_o is the initial body weight (Hudi et al. 2025).

Survival rate (SR) was used to evaluate shrimp survival under different stocking densities. At the

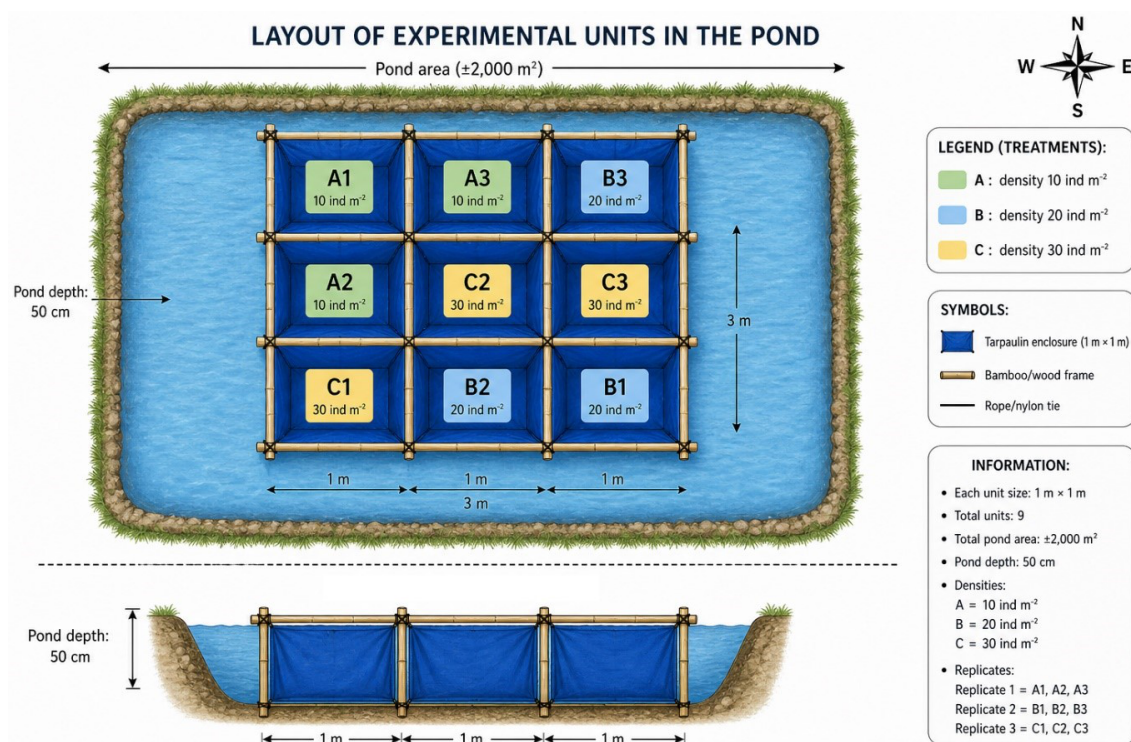


Figure 1. Nine $1 \times 1 \text{ m}^2$ experimental units installed in a $2,000 \text{ m}^2$ traditional polyculture pond with a water depth of approximately 50 cm.

end of the experiment, the number of surviving *L. vannamei* in each unit was counted and SR was calculated as $\text{SR (\%)} = \text{Nt}/\text{No} \times 100$ (Ritonga 2025), where Nt represents the number of shrimp harvested at the end of the culture period, and No represents the number of shrimp initially stocked at the beginning of the experiment.

Feed conversion ratio (FCR) was used to evaluate feed utilization efficiency under different stocking densities. The FCR was calculated as the ratio of total feed input (g) to biomass gain (g) following standard aquaculture practice (Martínez-Córdova et al. 1998).

Water quality was measured weekly in each experimental unit. Parameters included temperature ($^{\circ}\text{C}$, digital thermometer), pH (portable pH meter), dissolved oxygen (mg l^{-1} , DO meter), salinity (hand refractometer), transparency (cm, Secchi disk), and redox potential (mV). All observations

were conducted in the morning, and instruments were calibrated prior to measurement to ensure accuracy (APHA 2017). Although daily fluctuations may occur, weekly measurements were considered sufficient to capture overall water quality trends under the relatively stable conditions of the experimental system.

Pond management

Routine pond management was applied uniformly across all treatments following Widiassa et al. (2025). Partial water exchange was conducted as needed based on water quality conditions. Sediment and organic waste were removed regularly to maintain environmental quality. The system relied on natural water circulation without aeration. No chemicals or antibiotics were used during the experiment.

Statistical analysis

Data were analyzed using descriptive and inferential statistics. Normality and homogeneity were tested using Shapiro-Wilk and Levene's tests. Differences among treatments were evaluated using one-way ANOVA followed by Tukey's HSD test ($p < 0.05$) (Montgomery 2019). Pearson correlation and linear regression were used to examine relationships between water quality and *L. vannamei* performance (Zar 2010). Statistical analyses were conducted using Minitab software version 22.4 (Minitab LLC, USA). The number of replicates in this study was limited ($n = 3$ per treatment), which may constrain the statistical power and reduce the sensitivity for detecting small differences among treatments. Accordingly, the results should be interpreted with caution, particularly for parameters showing marginal differences.

RESULTS

Growth performance

This study was conducted in a traditional polyculture system involving *L. vannamei* co-cultured with milkfish (*C. chanos*). Although the performance of milkfish was not quantitatively evaluated in this study, its role as a companion species in the

Table 1. Absolute length (cm) and weight (g) of *Litopenaeus vannamei* under different stocking densities (mean $\pm$ SD).

Treatment	Absolute length	Absolute weight
A (10 ind. m ⁻²)	6.6 $\pm$ 0.16 ^a	13.0 $\pm$ 0.25 ^a
B (20 ind. m ⁻²)	6.1 $\pm$ 0.06 ^b	10.4 $\pm$ 0.14 ^b
C (30 ind. m ⁻²)	5.2 $\pm$ 0.10 ^c	7.9 $\pm$ 0.20 ^c

Different superscript letters indicate significant differences among treatments ($p < 0.05$).

polyculture system was considered important for maintaining environmental stability. The following results therefore focused on shrimp growth performance, survival, and feed utilization under different stocking densities. Stocking density significantly affected the growth of *L. vannamei* ($p < 0.05$; Table 1). The highest absolute length and weight were observed at 10 ind. m⁻² (6.6 $\pm$ 0.16 cm; 13.0 $\pm$ 0.25 g), followed by 20 ind. m⁻², while the lowest values occurred at 30 ind. m⁻² (Table 1).

Survival rate

Stocking density significantly affected the survival rate of *L. vannamei* ($p < 0.05$; Table 2). The highest survival was observed at 10 ind. m⁻² (96.7 $\pm$ 5.77%), followed by 20 ind. m⁻² (88.3 $\pm$ 2.89%), while the lowest value occurred at 30 ind. m⁻² (83.3 $\pm$ 3.33%) (Table 2).

Feed conversion ratio (FCR)

Stocking density significantly affected FCR ($p < 0.05$; Table 3). The lowest FCR was observed at 10 ind. m⁻² (1.3 $\pm$ 0.06), followed by 20 ind. m⁻² (3.1 $\pm$ 0.06), while the highest value occurred at 30 ind. m⁻² (5.8 $\pm$ 0.26) (Table 3). FCR increased markedly from 1.3 in Treatment A to 3.1 in Treatment B and further to 5.8 in Treatment C, indicating a sharp decline in feed utilization efficiency with increasing stocking density.

Table 2. Effects of stocking density on survival rate (%) of *Litopenaeus vannamei*.

Treatment	Survival rate
A (10 ind. m ⁻²)	96.7 $\pm$ 5.77 ^a
B (20 ind. m ⁻²)	88.3 $\pm$ 2.89 ^{ab}
C (30 ind. m ⁻²)	83.3 $\pm$ 3.33 ^b

Values are mean $\pm$ SD. Different superscript letters indicate significant differences among treatments ($p < 0.05$).

Table 3. Effects of stocking density on feed conversion ratio (FCR) of *Litopenaeus vannamei*.

Treatment	FCR
A (10 ind. m ⁻²)	1.3 ± 0.06 ^a
B (20 ind. m ⁻²)	3.1 ± 0.06 ^b
C (30 ind. m ⁻²)	5.8 ± 0.26 ^c

Values are mean ± SD. Different superscript letters indicate significant differences among treatments ($p < 0.05$).

Water quality

No significant differences were observed among water quality parameters among treatments ($p > 0.05$; Table 4). Temperature ranged from 29.1–32.9 °C, pH from 6.50–7.98, DO from 4.0–5.6 mg l⁻¹, and salinity from 11–13. Transparency and redox potential also showed similar ranges.

Pearson correlation analysis indicated that DO had the strongest association with shrimp performance, showing positive relationships with length growth ($r = 0.82$), weight ($r = 0.79$), and survival ($r = 0.76$), and a negative relationship with FCR ($r = -0.85$) (Table 5). Linear regression further demonstrated that DO accounted for a substantial proportion of variability in these parameters, explaining 58–72% of the variation across growth, survival, and FCR ($R^2 = 0.58$ – 0.72 ; Table 6). In contrast, pH and redox potential exhibited weaker and less consistent relationships, indicating a more limited role in influencing shrimp performance under the observed conditions.

DISCUSSION

The present study demonstrates a clear density-dependent growth response in *L. vannamei*, where both length and weight decreased with increasing stocking density, with the highest growth observed at 10 ind. m⁻². This indicates that growth

limitation was primarily driven by biological interactions rather than physicochemical constraints, as water quality remained relatively stable (Said et al. 2024). The decline in growth can be attributed to increased competition and crowding stress, which reduce feeding efficiency and increase metabolic costs (Emerenciano et al. 2022; Bajracharya et al. 2025). The greater reduction in weight compared to length suggests that biomass accumulation is more sensitive to density pressure, likely due to limitations in nutrient assimilation and energy allocation (Kumar et al. 2024). From a production perspective, these findings indicate that increasing stocking density does not necessarily improve productivity, as reduced individual growth may offset the benefits of higher stocking levels (Irani et al. 2023). Therefore, stocking density should be aligned with the biological carrying capacity of the system to maintain optimal growth and resource efficiency (Kumar et al. 2024). Furthermore, this study highlights that density-related stress may not be fully reflected by conventional water quality parameters, emphasizing the importance of biological indicators such as growth performance (Emerenciano et al. 2022). Although not directly measured, the presence of milkfish (*C. chanos*) in the polyculture system may have contributed to nutrient recycling and environmental stability (Pazmiño et al. 2025). Milkfish are known to utilize natural food resources and organic matter, which can help reduce waste accumulation and improve ecological balance in pond systems (He et al. 2025). This ecological interaction may partially explain the relatively stable water quality observed across treatments.

The survival rate of *Litopenaeus vannamei* declined with increasing stocking density, with shrimp at 10 ind. m⁻² maintaining near-optimal survival (96.7%). The reduced survival at higher densities indicates that mortality was primarily driven by biomass pressure rather than environmental variation, as water quality remained comparable across treatments (Chen et al. 2023). This decline can be attributed to intensified intraspecific competition and crowding stress, which reduce resource availability,

Table 4. Water quality parameters under different stocking densities of *Litopenaeus vannamei*.

Treatment	Temperature (°C)	pH	DO (mg l ⁻¹)	Salinity	Transparency (cm)	Redox (mV)
A (10 ind. m ⁻²)	29.1-32.6	6.50-7.48	4.2-5.6	11-13	25-52	-40 to -345
B (20 ind. m ⁻²)	29.3-32.3	6.85-7.96	4.1-5.4	11-12	29-51	-60 to -315
C (30 ind. m ⁻²)	30.0-32.9	6.62-7.98	4.0-5.6	11-12	27-49	-48 to -290

Values are presented as minimum-maximum ranges.

Table 5. Correlation between water quality parameters and Pacific white shrimp performance.

Parameter	Length growth	Absolute weight	SR	FCR
Temperature	-0.32	-0.35	-0.28	0.31
pH	0.41	0.38	0.36	-0.40
DO	0.82	0.79	0.76	-0.85
Salinity	-0.21	-0.24	-0.19	0.22
Transparency	0.45	0.42	0.39	-0.44
Redox potential	0.51	0.48	0.46	-0.53

Values are Pearson correlation coefficients (r). Positive values indicate a direct relationship, while negative values indicate an inverse relationship between variables.

Table 6. Linear regression between water quality parameters and Pacific white shrimp performance.

Parameter	Variable	Equation	R ²
DO	Length growth	$Y = 1.12 + 0.87DO^*$	0.67
	Weight	$Y = 2.41 + 1.95DO^*$	0.62
	SR	$Y = 58.3 + 7.62DO^*$	0.58
	FCR	$Y = 6.21 - 0.96DO^*$	0.72
pH	Length growth	$Y = -2.11 + 1.21pH$	0.17
	FCR	$Y = 8.43 - 0.97pH$	0.16
Redox	Weight	$Y = 9.21 + 0.014Redox$	0.23
	FCR	$Y = 5.92 - 0.011Redox^*$	0.28

*Indicates significant regression ($p < 0.05$).

increase physiological stress, and suppress immune responses, thereby elevating mortality risk (Melo Filho et al. 2020; Emerenciano et al. 2022). In addition, higher biomass likely increases localized oxygen demand and organic waste accumulation at micro-scales, creating transient suboptimal conditions that may not be detected by routine monitoring (Liu et al. 2017; Bull et al. 2021). These findings suggest that survival can decline before detectable changes in conventional water quality parameters, highlighting survival rate as a sensitive indicator of biological carrying capacity (Chapman and Byron 2018; Chen et al. 2023). From a management perspective, increasing stocking density without improving oxygen supply and feed distribution can compromise survival stability, emphasizing the need to align stocking density with system capacity.

Feed conversion ratio (FCR) increased markedly with stocking density, rising from 1.3 at 10 ind. m⁻² to 5.8 at 30 ind. m⁻², indicating a strong decline in feed utilization efficiency. This pattern reflects density-induced stress, where competition reduces feed access and increases feed wastage, while elevated metabolic demands divert energy toward maintenance rather than growth (Melo Filho et al. 2020; Vettor et al. 2020). Consequently, nutrient conversion into biomass becomes less efficient, even under stable water quality conditions, supporting the concept that biological carrying capacity may be exceeded before physicochemical deterioration occurs (Chapman and Byron 2018; Emerenciano et al. 2022). Similar FCR ranges (1.2-1.8) have been reported under optimal shrimp culture conditions, indicating that the low FCR observed at 10 ind. m⁻² reflects efficient feed utilization at lower densities (Xu et al. 2020; Kumar et al. 2024). From a practical perspective, increased FCR has economic and environmental implications, as it elevates feed costs and organic waste loading (Chaikaew et al. 2019). Therefore, optimizing stocking density and improving feed management and aeration are essential to maintain efficiency (Xu 2025; Xu et al. 2025).

Water quality parameters remained within similar ranges across treatments ($p > 0.05$) and with-

in acceptable limits for shrimp culture (Do et al. 2025). Despite this stability, growth, survival, and FCR declined with increasing density, indicating that system limitations were primarily biological rather than physicochemical. This suggests that conventional water quality parameters may not fully capture functional system limits, as density-related processes such as competition, stress, and uneven resource distribution play a dominant role (Emerenciano et al. 2022). Micro-scale processes, including localized oxygen depletion and sediment-water interactions, may occur without being detected by routine measurements (Bull et al. 2021). The consistently negative redox values indicate reduced sediment conditions typical of organic accumulation in earthen ponds, but their similarity across treatments suggests that sediment processes were not the main driver of performance differences. These findings reinforce that productivity decline can occur even when environmental indicators remain within acceptable thresholds (Xu 2025; Pazmiño et al. 2025).

Dissolved oxygen (DO) emerged as the key environmental factor influencing shrimp performance, as its positive relationship with growth and survival and negative relationship with FCR indicate its central role in metabolic processes and nutrient utilization (El Saadony et al. 2022). The strong explanatory power of DO highlights its function as a limiting factor under increasing biomass pressure, where even small variations can significantly affect performance (Boyd 2015; Emerenciano et al. 2022). This suggests that oxygen availability acts as an early indicator of system stress and carrying capacity limits. The inverse relationship between DO and FCR further indicates that reduced oxygen availability constrains digestion and nutrient assimilation while increasing maintenance energy demands (Chaikaew et al. 2019). In contrast, pH showed limited influence within the observed range, while redox potential affected system conditions indirectly through sediment processes (Wiyoto et al. 2016). These findings highlight the importance of prioritizing oxygen management through aera-

tion, monitoring, and biomass control to maintain system performance and resilience (Do et al. 2025; Muenzel et al. 2025).

Future research should focus on refining the optimal density range between 10 and 20 ind. m⁻² under varying management intensities, as well as explicitly evaluating the functional role and productivity contribution of co-cultured species such as milkfish. Such studies are essential to develop more adaptive, system-specific management strategies that balance productivity, resource efficiency, and environmental sustainability in polyculture aquaculture systems.

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Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this study. The authors also confirm that the research was conducted independently

and that no external funding or commercial organization influenced the study design, data collection, analysis, or publication of the results.

Author contributions

Andi Rahmad Rahim: conceptualization; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualization; writing-original draft preparation; writing-review and editing. Dwi Retnaningtyas Utami: formal analysis; funding acquisition; project administration; software; visualization; writing-original draft preparation. Rosmarlinasiah: data curation; formal analysis; investigation; methodology; project administration; supervision; writing-review and editing.

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