

Vannamei shrimp *Litopenaeus vannamei* mortality correlation with water quality dynamics and blue-green algae in earthen pond

Korelasi mortalitas udang vaname *Litopenaeus vannamei* dengan dinamika kualitas air dan *blue-green algae* pada kolam tanah

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(Received December 26, 2024; Revised February 12, 2025; Accepted September 3, 2025)

ABSTRACT

Mortality represents a significant challenge in enhancing productivity in intensive vannamei shrimp (*Litopenaeus vannamei*) farming systems. In ponds with soil bottoms, shrimp mortality is often caused by poor water quality, influenced by fluctuations in physicochemical parameters and changes in phytoplankton communities. This study aims to analyze the correlation between water quality, phytoplankton succession, and shrimp mortality. Pond water samples (E9, E10, F9, F10, and F11) were collected periodically to measure key physicochemical parameters, such as temperature, pH, dissolved oxygen (DO), ammonia (NH₃), total ammonia nitrogen (TAN), and nitrite (NO₂), as well as the abundance and dominance of phytoplankton. The results showed that shrimp mortality positively correlated with plankton abundance (0.57) and the presence of blue-green algae (0.43) in the water. Further, descriptively, shrimp mortality followed a similar pattern across several observation ponds, with deaths occurring after the decline or disappearance of blue-green algae from previous observations. The water quality parameters that correlated with plankton abundance and blue-green algae dominance included TAN, BOD, and turbidity. The transformation in phytoplankton dominance to blue-green algae can increase BOD levels and produce toxic compounds upon lysis, which may disrupt physiology and lead to shrimp mortality. These results underscore the importance of water quality management and phytoplankton monitoring to reduce vannamei shrimp mortality.

Keywords: blue-green algae, correlation, earthen pond, Vaname shrimp, water quality

ABSTRAK

Kematian merupakan tantangan dalam meningkatkan produktivitas pada kegiatan budidaya udang vaname (*Litopenaeus vannamei*) dengan sistem intensif. Pada kolam budidaya dengan dasar kolam tanah sering kali kematian udang disebabkan oleh kualitas air yang buruk, yang dipengaruhi oleh fluktuasi parameter fisikokimia dan perubahan komunitas fitoplankton. Penelitian ini bertujuan untuk menganalisis korelasi antara kualitas air, suksesi fitoplankton, dan mortalitas *Litopenaeus vannamei*. Sampel air kolam budidaya (E9, E10, F9, F10 dan F11) diambil secara berkala untuk mengukur parameter fisikokimia utama, seperti suhu, pH, DO, amonia (NH₃), TAN dan nitrit (NO₂), serta kelimpahan dan dominansi fitoplankton. Hasil penelitian menunjukkan mortalitas udang memiliki nilai korelasi positif dengan kelimpahan plankton (0,57) dan *blue-green algae* (0,43) yang ada pada perairan. Selain itu secara deskriptif kematian udang memiliki pola yang sama pada beberapa kolam pengamatan dimana kematian terjadi setelah terjadinya kematian atau berkurangnya kelimpahan *blue-green algae* dari pengamatan sebelumnya. parameter kualitas air yang memiliki nilai korelasi terhadap kelimpahan plankton dan dominasi *blue-green algae* yaitu TAN, BOD dan Kecerahan. Pergeseran dominansi fitoplankton ke *blue-green algae* dapat meningkatkan BOD dan menghasilkan senyawa toksik ketika lisis yang dapat mengganggu fisiologi hingga menyebabkan kematian udang. Temuan ini menekankan pentingnya pengelolaan kualitas air dan pemantauan fitoplankton untuk mengurangi mortalitas udang vaname.

Kata kunci: *blue-green algae*, korelasi, kolam tanah, kualitas air, udang vaname

INTRODUCTION

The whiteleg shrimp (*Litopenaeus vannamei*) is one of the high-value aquaculture commodities in Indonesia, constituting a key sector within fisheries due to its significant economic importance. Global shrimp production in 2022 reached 9.4 million tons, a 63% increase from 2020 (FAO, 2022). This substantial growth can be attributed to advancements in aquaculture technology, increased market demand, and the expansion of shrimp farming practices in key producing countries such as India, Vietnam, and Indonesia. Indonesia is one of the leading contributors to global shrimp production, with a total yield of 731,249.815 tons (KKP, 2024). The increasing market demand for *Litopenaeus vannamei* has driven shrimp farmers to adopt intensive aquaculture system (Smith *et al.*, 2008; Sianturi *et al.*, 2022).

Intensive aquaculture systems require stringent water quality management to mitigate the risks associated with the accumulation of organic matter from leftover feed, shrimp metabolism, and excreta (Jescovitch *et al.*, 2018; Mohanty *et al.*, 2018; Kim *et al.*, 2020). The success of aquaculture depends not only on feed management, water quality, and pest and disease control but also on the condition of the pond sediment, which plays a critical role in supporting the productivity of shrimp ponds. According to the Ministry of Marine Affairs and Fisheries (KKP, 2023), earthen ponds represent a significant portion of the total pond area in Indonesia, covering 247,803 hectares, which constitutes approximately 82% of the nation's entire pond area. This highlights the dominant role of earthen ponds in Indonesia's aquaculture industry. However, the productivity and carrying capacity of earthen ponds decrease as they age.

One often-overlooked factor is the effect of pond sediment age on mineral content, nitrogen cycling, and phytoplankton diversity, including the dominance of specific phytoplankton species such as Blue-green algae (BGA). The availability of minerals in sediment decreases with pond age, impacting water quality, nutrient availability, and plankton abundance, ultimately affecting shrimp growth (Cole *et al.*, 2019; Tulsankar *et al.*, 2021). Mineral composition in aquaculture is crucial for the growth of microorganisms, including bacteria involved in nitrogen cycling. Most phytoplankton rely on these nutrients for photosynthesis and growth. When mineral levels

decline, more adaptive phytoplankton species such as cyanobacteria (BGA), tend to dominate. Cyanobacteria are more efficient at utilizing nitrogen and phosphorus under nutrient-deficient conditions compared to other phytoplankton species, especially in older earthen ponds.

An investigation by Zimba *et al.* (2003) and Cole *et al.* (2019) indicates that shrimp ponds with aged sediment often exhibit characteristics favorable for BGA proliferation. BGA dominance in shrimp pond ecosystems can negatively impact the environment. Studies by Kurniawinata *et al.* (2021) found that shrimp ponds affected by disease often exhibited high BGA dominance. BGA, or cyanobacteria, are photosynthetic microorganisms commonly found in freshwater and marine ecosystems (Paerl & Otten, 2013; Buratti *et al.*, 2017). Many BGA species produce toxins harmful to surrounding organisms, including shrimp (Smith & Schindler, 2009).

Toxins such as *microcystin*, *anatoxin*, and *saxitoxin* can disrupt shrimp's nervous and digestive systems, ultimately leading to mortality (Smith *et al.*, 2008; Buratti *et al.*, 2017; Zhang *et al.*, 2022b). In earthen ponds, BGA can thrive if adequate nutrients are available from leftover feed, shrimp excreta, or other organic waste, creating significant challenges for shrimp aquaculture (Jescovitch *et al.*, 2018; Zhang *et al.*, 2022a). BGA dominance also suppresses the diversity of beneficial phytoplankton species and disrupts the overall ecological balance of the pond ecosystem. Excessive BGA growth increases the risk of pond contamination with cyanotoxins. Further, BGA consumes oxygen at night and produces toxins that can alter pH, dissolved oxygen (DO) levels, and nutrient concentrations in water, disrupting pond environmental balance and increasing shrimp mortality risks (Smith & Schindler, 2009; Ferrão-Filho & Kozlowsky-Suzuki, 2011; Buratti *et al.*, 2017).

The decline in water quality due to BGA dominance and reduced DO levels directly impacts *L. vannamei* growth. Shrimp are highly sensitive to environmental changes, especially reductions in oxygen levels and increased exposure to toxins such as *microcystin*. These conditions can induce stress, hinder growth rates, and cause mortality. Shrimp mortality caused by BGA is a significant concern in aquaculture and environmental science (Maa-iad *et al.*, 2023). For instance, cases in Southeast Asia have shown substantial shrimp losses linked to *microcystin*-producing cyanobacteria.

Similarly, research conducted in India highlights how inadequate water management has exacerbated BGA blooms, leading to economic losses for small-scale shrimp farmers. Factors such as limited water circulation, high nutrient availability, and ineffective environmental management can create optimal conditions for BGA proliferation (Paerl & Otten, 2013). Although traditional ponds are more prone to excessive BGA growth, effective environmental management can help mitigate shrimp mortality risks due to toxins and water quality degradation. This study aims to analyze the correlation between water quality and BGA dominance with shrimp mortality and production performance in earthen ponds.

MATERIALS AND METHODS

Experimental site and management

This study was conducted at PT. Indonusa Yudha Perwita, Indramayu, over a 91-day cultivation period from October to January 2023. Shrimp cultivation was carried out following the company's standard operating procedures in five earthen ponds (E9, E10, F9, F10, and F11), each with an approximate volume of 4,000 m³ (Figure 1). All ponds were stocked with *L. vannamei* PL 10 at a density of 77/m². Water quality measurements were performed at the PT. Indonusa Yudha Perwita Laboratory and the Environmental Laboratory of the Department of

Aquaculture, Faculty of Fisheries and Marine Science, IPB University.

Water quality sampling

Water quality parameters were measured throughout the cultivation period. Water samples were collected as composites from the culture and stored in 100 mL sample bottles for immediate laboratory analysis. This volume was chosen to ensure an adequate representation of the water quality parameters while being manageable for laboratory procedures. The use of 100 mL bottles was standardized across the study for consistency in sampling and analysis. Parameters measured included physical, chemical, and biological factors: salinity, temperature, pH, dissolved oxygen (DO), clarity, oxidation-reduction potential (ORP), hardness, alkalinity, total organic matter (TOM), biological oxygen demand (BOD), total ammonia nitrogen (TAN), nitrite, nitrate, phosphate, and N/P ratio (ions), as well as phytoplankton abundance, total bacterial count (TBC), and total vibrio count (TVC) (Table 1).

Plankton observation

Plankton observations were conducted weekly to determine species proportions and dominance in the shrimp culture. Composite water samples were collected from five representative points in each pond, filtered using a 25 µm plankton net, and stored in 100 mL bottles for microscopic analysis. Plankton samples were observed under

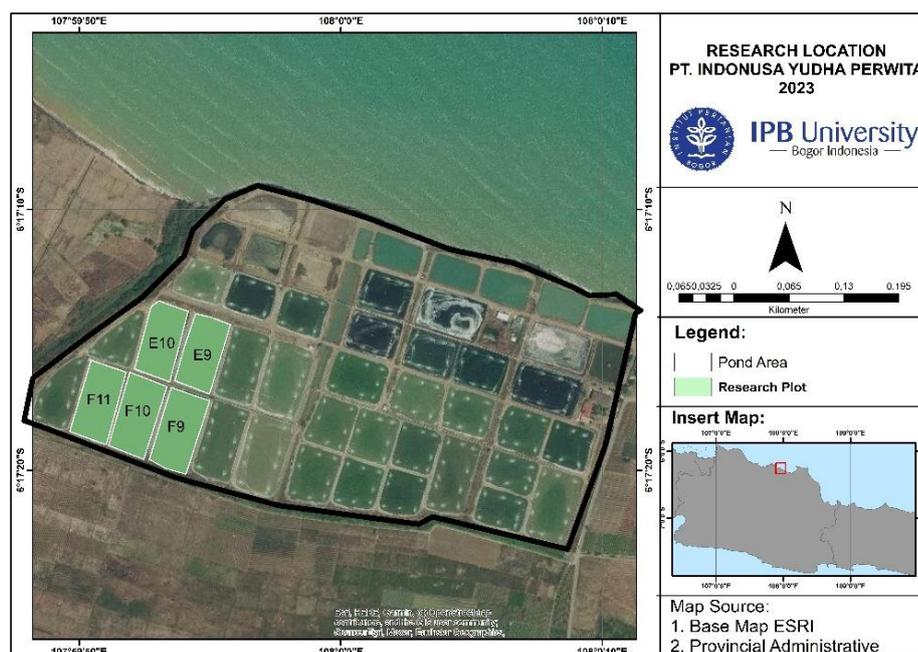


Figure 1. Research location PT. Indonusa Yudha Perwita, Patrol, Indramayu, West Java.

an Olympus CX23 binocular microscope with magnifications up to 1,000 \times .

Shrimp growth observation and measurement

Shrimp growth was monitored through periodic sampling using a cast net, conducted biweekly to ensure consistent data collection. Samples were designed to be representative of the entire pond population by selecting multiple points across each pond for measurement. Growth performance parameters evaluation included mean body weight (MBW), average daily gain (ADG), survival rate (SR), and feed conversion ratio (FCR). MBW was calculated using the formula by Aprilia *et al.* (2024), ADG can be calculated using the formula by Katmoko *et al.* (2021), the number of SR was calculated using the formula by Zhang *et al.* (2022a), and FCR can be calculated using the formula by Rahi *et al.* (2021).

Statistical analysis

Water quality data were analyzed using Pearson correlation to evaluate relationships between water quality factors and shrimp mortality. Data processing was conducted using R Studio version 4.3.1. Growth and water quality data were analyzed descriptively and presented graphically using Microsoft Excel 2021 and OriginPro 2024 version 10.1.0.170 (Learning Edition), which are presented in the form of tables or graphs.

RESULTS AND DISCUSSION

Result

Water quality dynamics

Water quality measurements showed fluctuations across all ponds throughout the cultivation period, showing similar trends. Temperature initially increased before stabilized, salinity declined in the early stages, DO decreased at the start but later stabilized, and pH initially dropped before recovering to stable levels.

Parameters such as transparency, alkalinity, TOM, hardness, BOD, and ORP also showed consistent patterns across all ponds. Nutrient levels varied among ponds. Ammonia-N concentrations were highest in pond F11, ranging from 0.077 to 2.226 mg/L, while nitrite peaked in pond E10 (0.02 to 2.65 mg/L) on DOC-56. Nitrate concentrations were highest in pond E9, ranging from 0.19 to 1.4653 mg/L, with phosphate levels peaking on DOC-77 and 84. TBC and TVC values fluctuated but showed similar trends, with TBC declining on DOC-14 in pond E9 and TVC increasing in pond F9 on DOC-28.

Water quality dynamics and mortality correlation

The mortality rates of vannamei shrimp cultivated over 91 days are presented in Figure 5. The results of cultivation in each pond showed that the highest shrimp mortality occurred in pond F9, followed by ponds F10, E10, F11, and E9. Pearson's correlation analysis produces a correlation coefficient (r), where values closer to -1 or 1 indicate a stronger relationship between two variables. Results of the Pearson correlation analysis between water quality factors and shrimp mortality are presented in Figure 6. Generally, mortality is significantly positively correlated with plankton, BGA, TBC, and TGV parameters, and significantly negatively correlated with pH and clarity.

The Pearson correlation analysis between water quality factors and shrimp mortality in each pond revealed that in pond E9, shrimp mortality was positively correlated with plankton and TVC parameters. Shrimp mortality was positively correlated with TYV, TVC, plankton, BOD, and phosphorus and negatively correlated with temperature and salinity in E10. In pond F9, shrimp mortality was positively correlated with BGA, plankton, and nitrate and negatively correlated with pH. In pond F10, shrimp mortality was positively correlated with plankton and TBC parameters. In pond F11, shrimp mortality was

Table 1. Classification of variables in shrimp aquaculture.

Daily Monitored	Weekly monitored	
Temperature	Total Ammonia Nitrogen	Biological Oxygen Demand
Dissolve Oxygen	Nitrates	Total Organic Matter
Salinity	Nitrite	Plankton
PH	Orthophosphate	Total Bacteria Count
Water Clarity	Hardness	Total Vibrio Count
	Alkalinity	Oxidation Reduction Potential

positively correlated with TGV, TYV, TBC, nitrate, plankton, and BGA, and negatively correlated with pH, salinity, and hardness.

Plankton abundance and shrimp mortality

The dynamics of plankton observed during the study are presented in Figure 7. Phytoplankton abundance in the observed ponds tended to fluctuate. In ponds E9 and E10, BGA began to grow during the DOC-21 observation and shrimp mortality began at DOC-31 and DOC-25, respectively. In pond F9, BGA began to grow in the initial observation but did not dominate, with shrimp mortality beginning at DOC-34 as abundance increased. In pond F10, BGA began to grow at DOC-7, with shrimp mortality beginning at DOC-30. In pond F11, BGA began to grow at DOC-14, with shrimp mortality commencing at DOC-28. Dominant species obtained in observations made during the research are presented in Figure 8.

A descriptive comparison of shrimp mortality, dead plankton, and BGA abundance in each cultivation pond is presented in Figure 9. The graph indicates that shrimp mortality occurred after the emergence and dominance of BGA. Several peaks in shrimp mortality coincided with the increased death of plankton and specific

patterns where shrimp mortality rose as BGA abundance declined from previous observations and as dead plankton increased in the same DOC.

Litopenaeus vannamei growth performance

The growth performance of vannamei shrimp cultivated for 91 days is presented in Table 2. The highest productivity rate of 4.14654 tons/ha was achieved in pond E9, followed by F10, E10, F9, and F11. The highest survival rate (SR) was recorded in pond E9, followed by F10, F9, E10, and F11. Pond E10 achieved the highest average daily gain (ADG), followed by ponds F11, E9, F10, and F9, with an average of 0.307 g/day. The highest mean body weight (MBW) was recorded in pond E10. The highest feed conversion ratio (FCR) was observed in pond E9, while the highest FCR was in pond F9.

Discussion

Phytoplankton plays essential roles in maintaining ecological functions, including balancing aquatic ecosystems, which are vital for achieving maximum shrimp production in aquaculture. The proportion and population of plankton in water are significantly influenced by environmental quality. However, there is limited understanding about which water quality

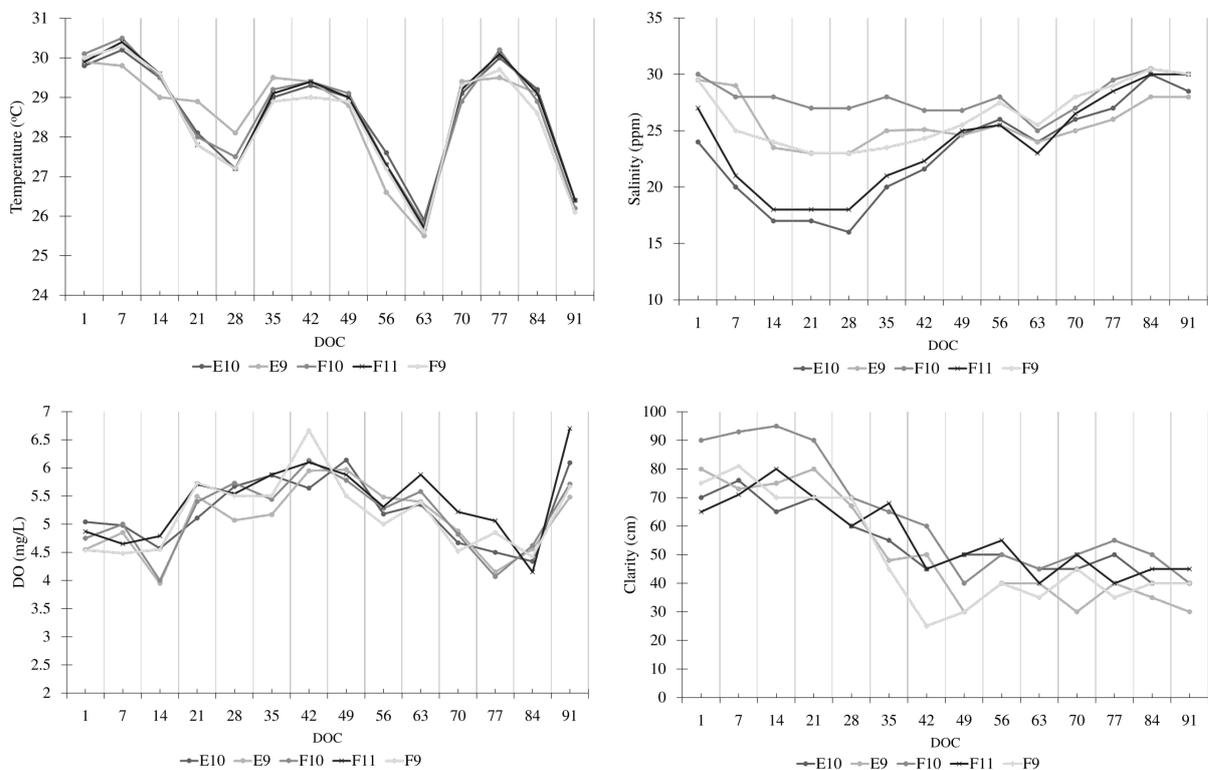


Figure 2. Physical parameters values for vannamei shrimp cultivation ponds using earthen pond based on the DOC (days of culture).

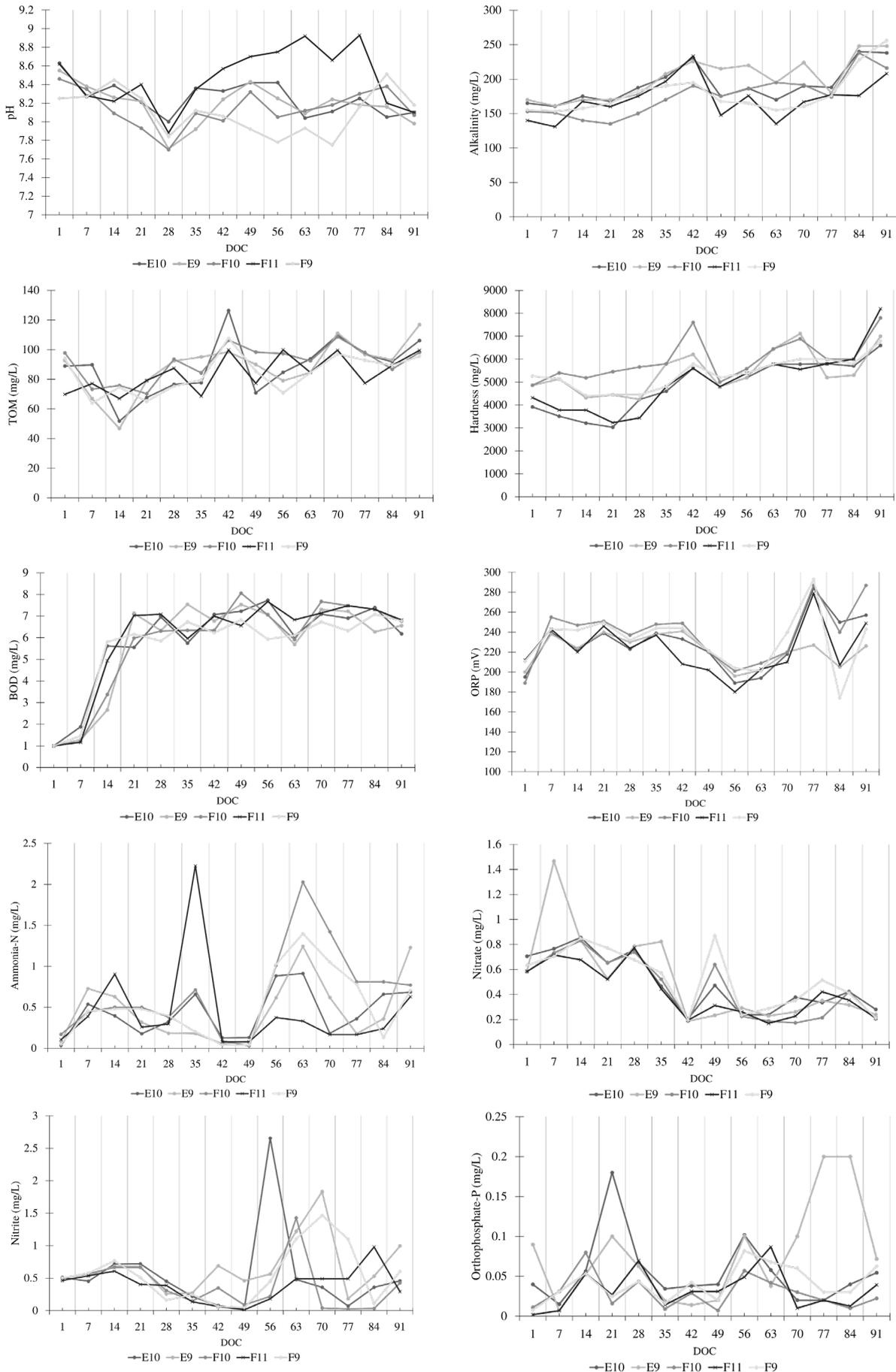


Figure 3. Chemical parameters values for vannamei shrimp cultivation ponds using earthen pond based on the DOC.

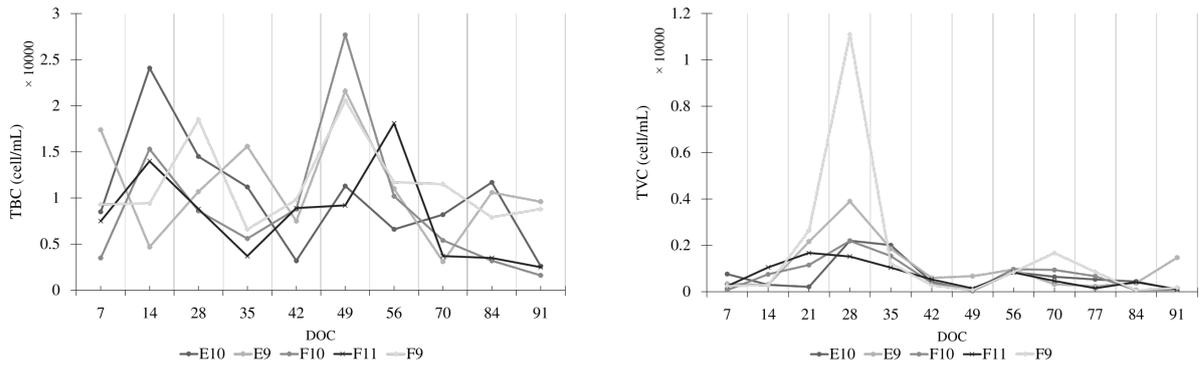


Figure 4. Biological parameters values for vannamei shrimp cultivation ponds using earthen pond based on the DOC.

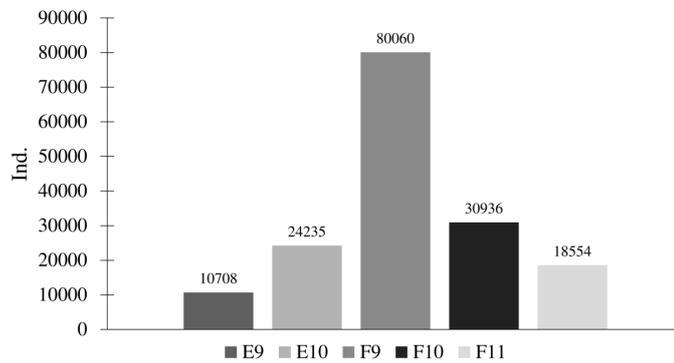
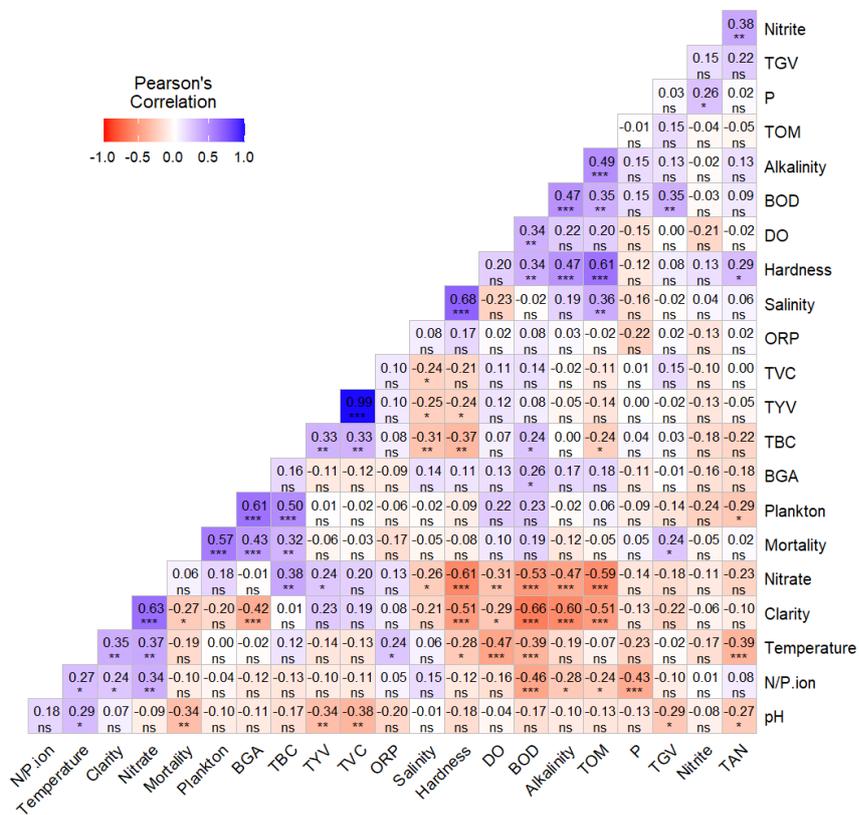


Figure 5. Number of mortalities in each cultivation pond during the rearing period.



ns p >= 0.05; * p < 0.05; ** p < 0.01; and *** p < 0.001

Figure 6. Pearson correlation results between the number of mortalities and water quality parameters.



Figure 7. Temporal variation in the relative abundance of different plankton during rearing.

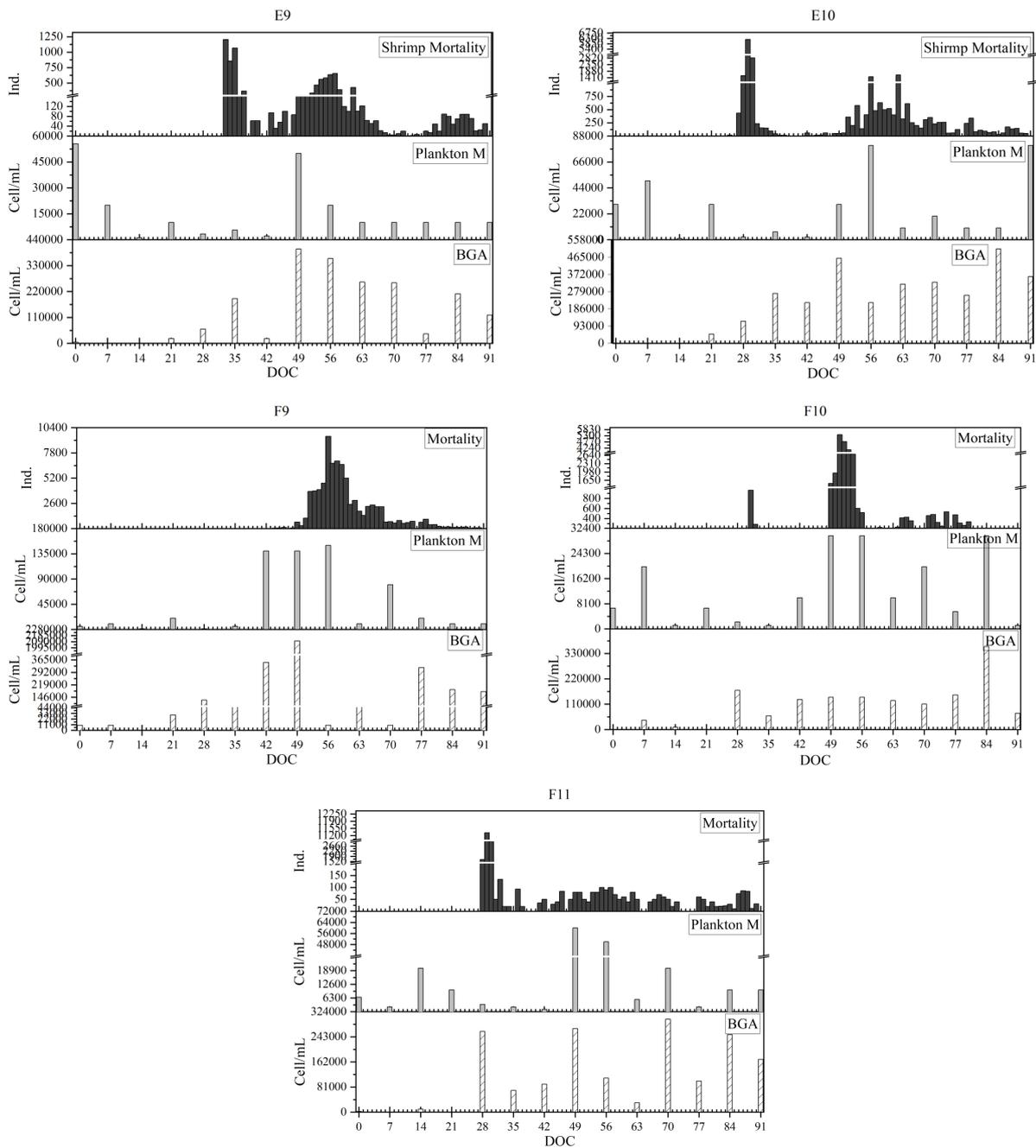


Figure 9. Shrimp mortality, plankton abundance, and BGA in cultivation ponds.

Table 2. Stocking density, productivities, mean body weight, average daily gain, survival rate and feed conversion ratio.

	E9	E10	F9	F10	F11
Stocking density (Ind/m ²)	77	77	77	77	77
Productivities (Ton/Ha)	4.14654	2.84768	2.81427	3.77944	1.6818
MBW (g)	11.75	13.07	10.04	10.89	12.12
ADG	0.326	0.3631	0.291	0.314	0.317
SR (%)	28	17	22	27	10
FCR	1.29	1.64	3.01	1.76	2.03

parameters most impact the abundance and types of phytoplankton in aquaculture. Changes in environmental factors generally influence temporal variations of phytoplankton in aquatic ecosystems, either directly or indirectly (Li *et al.*, 2019a; Niu *et al.*, 2020). Research by Spatharis *et al.* (2007) and Cloern and Dufford (2005) indicates that the presence and variation of phytoplankton communities in water are affected by various environmental and ecological factors, including water temperature, salinity, light intensity, nutrient availability, inter- and intraspecific competition among algae, and predation.

Monitoring and evaluating water quality dynamics is essential for sustainable fisheries activities (Nugraha *et al.*, 2023). In this study, water quality parameters were measured to monitor cultivation activities until the end of the rearing period. Measurements showed fluctuations in physical, chemical, and biological parameters during cultivation, but these remained within the tolerable range for shrimp (Figures 2, 3, & 4). Changes in water quality parameters, such as increased nutrient concentrations from organic waste and fertilizers, can lead to eutrophication, significantly increasing a single phytoplankton population or causing algal blooms (Egerton *et al.*, 2014). Correlation analysis was conducted to examine the influence of water quality parameters on plankton abundance (Figure 6). Additionally, plankton abundance and variation during cultivation were observed (Figure 7).

In intensive aquaculture, the feed given is higher, but its efficiency and utilization are low (Chen *et al.*, 2018). This results in fluctuating nitrogen and phosphorus concentrations during cultivation (Figure 3), affecting plankton growth and variation (Figure 7). Variations in plankton growth in each pond showed no clear patterns (Figure 7), with total ammonia nitrogen (TAN) being a primary parameter affecting plankton growth and variation. Nitrogen (N) and phosphorus availability influence plankton growth and community structure in most aquatic ecosystems (Qiao *et al.*, 2020; Li *et al.*, 2019b). However, each species has different nutrient requirements based on its capacity and processing ability (Lin *et al.*, 2016). Certain species may be affected by changes in N and P concentrations in water, influencing their abundance.

During cultivation, green algae dominated all ponds, and diatoms were dominant during the early rearing period until DOC-14, as nitrate

levels were high in all ponds. This is consistent with research by Liu *et al.* (2022), which found that diatoms tend to utilize nitrate more efficiently than other nitrogen forms. Plankton dominance in rearing media began to change around DOC-28. The dominance shifted from green algae and diatoms to include BGA in some ponds, with their numbers increasing until the end of the rearing period. The emergence of BGA in rearing media coincided with declining nitrate levels and increasing TAN during certain observations.

Andersen *et al.* (2019) found that Nitrogen (N) and phosphorus (P) inputs influence algal community structure and function. BGA grows better under limited N and P conditions in water. This likely explains the negative correlation between nitrate and BGA dominance in the rearing media, although it was statistically insignificant (Figure 6). Additionally, temperatures during cultivation were within the range favorable for BGA growth, at approximately 28°C (Paerl & Husman, 2008). Dominant phytoplankton, especially BGA, are known to produce toxins harmful to aquatic organisms. Observations after DOC-21 in all ponds showed BGA dominance (Figure 7). This condition is influenced by various water quality factors.

Aquatic biota, including phytoplankton as primary producers, are highly affected by water quality (Syafriani & Apriyadi, 2017). Xu *et al.* (2022) noted that BGA dominance often occurs in water with high nitrogen and phosphorus levels. The dominant BGA species in this study were *Oscillatoria*, *Microcystis*, and *Anabaena* (Figure 8). The dominance of BGA in cultivation ponds poses risks to aquaculture organisms and reduces water quality, causing causes mortality of cultured organisms (Carstensen *et al.*, 2015; Yilmaz *et al.*, 2021). BGA are regarded as an unfavorable microalgal group due to their limited nutritional quality and their potential to generate toxic compounds detrimental to cultured aquatic organisms (Lukwambe *et al.*, 2019). Huisman *et al.* (2018) found that *Oscillatoria* dominance in aquaculture systems can lead to algal blooms, producing foul odors and *microcystins* toxic to aquaculture organisms. Pearson correlation analysis results showed that shrimp mortality during the study positively correlated with BGA abundance ($r = 0.43$), indicating that mortality was associated with BGA abundance (Figure 6).

The dominance of BGA in rearing media can endanger cultivated organisms. BGA produces

toxins, including *hepatotoxins*, *cytotoxins*, *neurotoxins*, and *dermatotoxins* (Yu *et al.*, 2017; Smith *et al.*, 2008). These toxins can damage shrimp tissues, reduce immunity, alter immunity-related enzymes, cause histological variations and apoptotic characteristics, and increase oxidative stress (Duan *et al.*, 2020; Duan *et al.*, 2022; Chen *et al.*, 2017). Furthermore, the decomposition of dead BGA can deplete dissolved oxygen in water, leading to hypoxic conditions that are dangerous for shrimp (Yu *et al.*, 2017). Shrimp mortality during the study is suspected to have been caused by BGA-produced toxins in rearing media. Figure 9 shows mortality patterns during certain observations in rearing ponds, where shrimp mortality occurred after plankton “crashes” marked by increased dead plankton in those observations and reduced plankton dominance from previous observations.

A high mortality rate was observed in pond F10, peaking between DOC-49 and DOC-56, coinciding with significant plankton deaths and a sharp decline in BGA abundance from the previous week (Figure 9). Julianto (2021) reported that BGA toxins are released into the water when algae die and cell walls rupture, dispersing toxins into the water. Additionally, plankton crashes increase oxygen demand for decomposition, potentially causing oxygen deficits and increased toxic ammonia levels, leading to shrimp stress and disease susceptibility. This suggests that high BGA mortality releases toxins into the water, affecting shrimp survival. Yu *et al.* (2017) found that high concentrations of crude BGA extracts (≥ 2.52 mg/mL) caused high shrimp mortality ($\geq 86.67\%$), while lower concentrations (< 0.504 mg/mL) reduced mortality to 2.22%.

In aquaculture, controlling BGA abundance remains challenging, particularly in intensive fish farming (Smith *et al.*, 2008). Effective water quality management is crucial in vannamei shrimp cultivation. Farmers must ensure that water quality parameters remain within optimal ranges to support shrimp health and growth and prevent the dominance of potentially harmful plankton, especially BGA. The findings underscore the need to monitor TAN, BOD, and clarity to optimize shrimp production and mitigate mortality risks (Figures 2 & 3). BGA dominance in cultivation media can also affect shrimp production, producing foul odors and reducing productivity (Kulabtong *et al.*, 2019;

Masithah *et al.*, 2019; Ariadi *et al.*, 2019). Due to BGA-related mortality, production outcomes were suboptimal.

If we look at Figure 5, pond F9 should have the lowest survival rate (SR) and be significantly lower than that of other ponds. This phenomenon may be attributed to potential discrepancies in mortality recording under field conditions. A plausible explanation is that not all shrimp mortality events were accounted for, as some deaths may have resulted from cannibalistic behavior among shrimp. As known vannamei shrimp have cannibalistic traits (Romano & Zeng, 2017; He *et al.*, 2020). Consequently, deceased shrimp could have settled at the pond bottom and eventually been buried in sediment. This process may have led to an underestimation of actual shrimp mortality, thereby affecting the calculated SR values.

As shown in Table 2, productivity, SR, and FCR values in some ponds were not optimal. Good SR values for vannamei shrimp cultivation exceed 70% (Arsad *et al.*, 2017), with FCR values for intensive shrimp farming generally around 1.4 (Fahrurrozi *et al.*, 2023).

CONCLUSION

This study demonstrates a significant positive correlation between shrimp mortality and the abundance of blue-green algae (BGA) in the water of earthen ponds, as revealed through Pearson correlation analysis. Mortality tended to follow a specific pattern across several ponds, occurring after a reduction or mortality of BGA observed in earlier assessments. Water quality parameters, including total ammonia nitrogen (TAN), biochemical oxygen demand (BOD), and water clarity, were strongly correlated with both plankton abundance and BGA dominance. The observed mortality during cultivation adversely affected production performance, as evidenced by suboptimal survival rate (SR) and feed conversion ratio (FCR) values.

ACKNOWLEDGMENT

The authors are deeply thankful to IPB University for their academic guidance and continuous support during the course of this research. We also extend our appreciation to PT. Indonusa Yudha Perwita for providing the

necessary funding and resources that made this study possible. Our heartfelt thanks go to Mr. Dilip Satyanathan and Mr. Ratno Timur for their constructive feedback, encouragement, and invaluable contributions to the completion of this research.

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