Study on periphyton composition in super intensive whiteleg shrimp (*Litopenaeus vannamei*) farming ponds

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Abstract. Periphyton in this study refers to the assemblage of attached organisms growing on submerged substrates in shrimp ponds. Periphyton plays an important role in assimilating excess nutrients, improving water quality, and providing a natural food source for shrimp. This study aimed to investigate water-quality parameters and the species composition of periphytic algae in super-intensive whiteleg shrimp (*Litopenaeus vannamei*) ponds in Ca Mau Province, Vietnam. Water-quality variables and periphytic algae were sampled from six shrimp ponds. The ponds were categorized into two groups: Group G1, consisting of three ponds stocked at an average density of 176 ± 3.53 individuals m^{-2}, and Group G2, consisting of three ponds with a higher average stocking density of 233 ± 2.12 individuals m^{-2}. Sampling was conducted during three periods corresponding to the beginning, middle, and late stages of the culture cycle. Results showed that nutrient concentrations (TAN, NO_3^-, PO_4^{3-}, TP) were higher in G1 than in G2, and nutrient levels tended to increase toward the end of the production cycle. A total of 20 periphytic algal species were identified, including eight cyanophytes, six diatoms, five chlorophytes, and one dinoflagellate species. Species composition and algal density in ponds of Group G2 (180,289 ± 203,762 to 203,986 ± 165,947 inds cm^{-2}) were significantly higher than in ponds of Group G1 (71,920 ± 36,393 to 96,692 ± 67,787 inds cm^{-2}). In both pond groups, the density of periphytic algae increased progressively toward the late culture stage. Diatoms dominated during the beginning stage, whereas cyanophytes increased markedly during the mid and late stages. Genera consistently present across ponds included *Oscillatoria*, *Nannochloropsis*, *Chroococcus*, *Ulothrix*, and *Thalassiosira*. Algal biomass ranged from 13.718 to 27.395 g m^{-3}. The Shannon–Wiener index (H’), Pielou’s index (J’), and Simpson’s index (D) ranged from 1.08–1.58, 0.43–0.70, and 0.26–0.54, respectively. These findings provide valuable insights for the appropriate management of periphyton in brackish-water shrimp ponds.

Keywords: algal diversity, biofilm, Cyanobacteria, water quality parameters.

Introduction. Aquaculture is rapidly developing worldwide as well as in Vietnam, particularly the farming of whiteleg shrimp (*Litopenaeus* vannamei, synonym *Penaeus vannamei*) (WoRMS 2026). This species has high economic value and desirable quality, making it well suited to consumer preferences. *L. vannamei* grows quickly, is relatively easy to culture, and can be reared at high densities and on a large scale. Super-intensive shrimp farming systems have increasingly improved in terms of culture technology to enhance productivity and provide high economic returns for farmers. Among these improvements, water-quality management and algal community control in shrimp ponds are crucial.

Aquatic environments contain a diverse assemblage of algae, including both planktonic species and benthic or attached forms. Periphytic algae represents the dominant component of the periphytic community (periphyton) and play an important role in aquatic ecosystems (Vadeboncoeur & Steinman 2002; Larned 2010). In aquaculture systems, periphytic algae contribute to oxygen production and serve as a natural food source;

compared with planktonic algae, attached periphyton communities are less prone to rapid fluctuations in the water column and can be continuously utilized by cultured animals (Biswas et al 2022). In addition, periphyton communities function as effective bioindicators of water quality because they comprise diverse natural species that are highly sensitive to environmental fluctuations (Flynn et al 2013). The presence of *Oscillatoria subbrevis* and *Oscillatoria tenuis* (Cyanophyta), as well as *Strombomonas scabra* and *Euglena viridis* (Euglenophyta), in polluted downstream environments, were characterized by high concentrations of organic matter (Giorgi & Malacalza 2002). Periphytic biofilm systems have also been widely applied as biological treatment methods for contaminated water (Bradac et al 2009). Furthermore, in shrimp ponds, periphyton can efficiently assimilate nitrogenous waste from effluents and reduce the feed conversion ratio (FCR) during culture stages (Avnimelech & Kochba 2009; Santhana Kumar et al 2017). Bamboo substrates were used to promote periphyton development in *L. vannamei* ponds and demonstrated that ponds with periphyton had higher shrimp growth rates and profitability (Amirtharaj & Oli 2017). These benefits were attributed to periphyton serving as a natural food source, reducing the need for supplemental feed, and helping to maintain favourable water quality. Therefore, periphyton can enhance productivity and overall efficiency in aquaculture systems (Ruby et al 2018).

Despite these demonstrated advantages, research on periphytic algae in shrimp pond systems remains limited, particularly in *L. vannamei* culture. Consequently, investigating the species' composition of periphytic algae and examining the correlation between the periphytic algae community and water-quality parameters is essential for supporting the sustainable development of brackish-water shrimp farming.

Material and Method

Study period, location, and sampling schedule. The study was conducted from April 2024 to January 2025. Periphytic algal samples were collected from six *Litopenaeus vannamei* culture ponds in Phu Tan Commune, Ca Mau Province, Vietnam (Figure 1). The ponds were categorized into two groups: Group G1 consisted of three ponds with an average stocking density of 176 ± 3.53 individuals m^{-2}, while Group G2 included three ponds with a higher average stocking density of 233 ± 2.12 individuals m^{-2}. Sampling was carried out during three stages corresponding to key stages of the super-intensive *L. vannamei* culture cycle: the beginning culture stage (25 days), mid-culture stage (54 days), and late culture stage (73 days).

Figure 1. Sampling sites in Phu Tan Commune, Ca Mau Province, Vietnam (map generated using Google Maps).

Water quality parameters analysis methods. Water-quality parameters measured in this study included temperature, pH, salinity, and dissolved oxygen (DO), which were recorded directly in the shrimp ponds. Additional parameters included alkalinity, total suspended solids (TSS), total ammonia nitrogen (TAN), nitrate (NO_3^-), phosphate (PO_4^{3-}), total nitrogen (TN), total phosphorus (TP), and chlorophyll-a, which were collected and analysed following APHA (2017) standard methods (Table 1).

Table 1

Collection and analysis methods of water quality parameters

No.	*Parameters*	*Sampling and Storage methods*	*Analysis method*
1	Temperature	Measured directly at sampling points	Measured directly with HANNA meter (HI9828)
2	pH		
3	Dissolved oxygen (DO)		Measured by the AQUA D.O. test kit
4	Alkalinity	All these parameters were sampled in 1L flasks and stored at 4°C.	Acid-base titration method
5	TSS		Method 2540 D, drying at 103-105°C (APHA 2017)
6	TAN		4500-NH_3-F. Phenate Method (APHA 2017)
7	NO_3^-		ISO 7890-3:1988. Sulfosalicylic Acid Method (APHA 2017)
8	PO_4^{3-}		4500-PO_4^{3-}-D. Stannous Chloride Method (APHA 2017)
9	TN		4500-N C-Persulfate Method (APHA 2017)
10	TP		4500-P B-Persulfate Digestion Method (APHA 2017)
11	Chlorophyll-a		Acetone extraction and spectrophotometric measurement (10200 H) (APHA 2017)

Qualitative sampling of periphytic algae. In the shrimp ponds, periphytic algae were collected from natural substrates available within the culture system, including pond liners, aeration hoses, gravel, and support pillars (Figure 2). Sampling was performed by gently scraping the algal layer from the substrate surface using a small brush (toothbrush). The collected material was transferred into 180 mL plastic bottles and diluted with an appropriate volume of distilled water. Samples were then preserved with commercial formalin (37–40%) at a final concentration of approximately 2–4%. The sampling procedures for each substrate type followed the methods described by Stevenson and Bahls (1999).

Quantitative sampling of periphytic algae. Quantitative samples were collected using the same procedure as qualitative samples, with the additional step of recording the surface area of the sampled substrate.

Qualitative analysis. Periphytic algae were identified based on morphological characteristics. Morphological traits of the algal cells were first examined, after which taxa were identified using published taxonomic keys. Major taxonomic references included Ward and Whipple (1918), Shirota (1966), Tien (1996), An (1993), Carmelo et al (1996), and Tien and Hanh (1997).

Quantitative analysis. Step 1: Periphytic algal samples were diluted to an appropriate volume, and the number of algal individuals in the sample was enumerated. Step 2: A 1 mL aliquot of the sample was transferred into a Sedgewick–Rafter counting chamber, and the number of individuals at the genus or species level was counted using the method described by Boyd and Tucker (1992). Counting proceeded until more than 400 individuals were recorded, and the number of cells counted per grid was documented. Step 3: Algal density in the collected samples was calculated using the following formula:

$$X = \frac{T \ x \ 1000 \ x \ V_{condensed} \ x \ 10^3}{A \ x \ N \ x \ V_{sample}}$$

Where: X is the density of periphytic algae (individuals cm^{-2})
T is the number of individuals counted
$V_{condensed}$ is the volume of concentrated sample
V_{sample} is the volume of the original collected sample
N is the total number of counted grids
A is the area of each grid (1 mm^2)

Algae biomass in water. Algal biomass (g/m^3) was calculated using the following formula:

$$\text{Biomass } (g/m^3) = \text{Chlorophyll-a} \times 67$$

Biological indices. Shannon–Wiener diversity index (H') was calculated using the formula:

$$H' = -\sum Pi \times \ln(Pi)$$

Where: Pi = n/N (n = abundance of species i, N = total abundance in the sample).

Pielou's evenness index (J') was calculated using the formula:

$$J' = H'/\ln S$$

Where: S is the total number of species
H' is the Shannon–Wiener diversity index

Figure 2. Sampling on substrates in super-intensive whiteleg shrimp (*Litopenaeus vannamei*) farming ponds in Phu Tan Commune, Ca Mau Province, Vietnam.

Statistical analysis. All data in this study were compiled, processed, and visualized using Microsoft Excel. Pearson correlation analyses between water-quality parameters and the species composition, density, and biological indices of periphytic algae were conducted using SPSS software version 22.0.

Results. The water quality parameters in super-intensive whiteleg shrimp (*Litopenaeus vannamei*) ponds fluctuated throughout the culture period (Figure 3). The average temperature in both groups (G1 and G2) showed an increasing trend toward the end of the cycle (G1 increased from 29.2 ± 0.1 °C to 30.3 ± 0.6 °C; G2 increased from 30.0 ± 0.1 °C to 30.8 ± 0.8 °C), with G2 exhibiting slightly higher mid-cycle values. The pH declined slightly toward the end of the culture period, with no significant differences between the two groups (G1 ranged from 7.8 ± 0.1 to 8.0 ± 0.1; G2 ranged from 7.7 ± 0.1 to 8.1 ± 0.1). Dissolved oxygen (DO) concentrations tended to decrease over time (G1: from 5.7 ± 0.3 mg L^{-1} at the beginning to 5.5 ± 0.5 mg L^{-1} at the end; G2: from 8.1 ± 0.2 mg L^{-1} at the beginning to 6.5 ± 0.5 mg L^{-1} at the end). In contrast, total suspended solids (TSS) decreased across the three sampling intervals (G1 declined from 313.3 ± 60.6 mg L^{-1} at mid-cycle to 201.0 ± 31.4 mg L^{-1} at the end; G2 declined from 302.7 ± 64.3 mg L^{-1} at

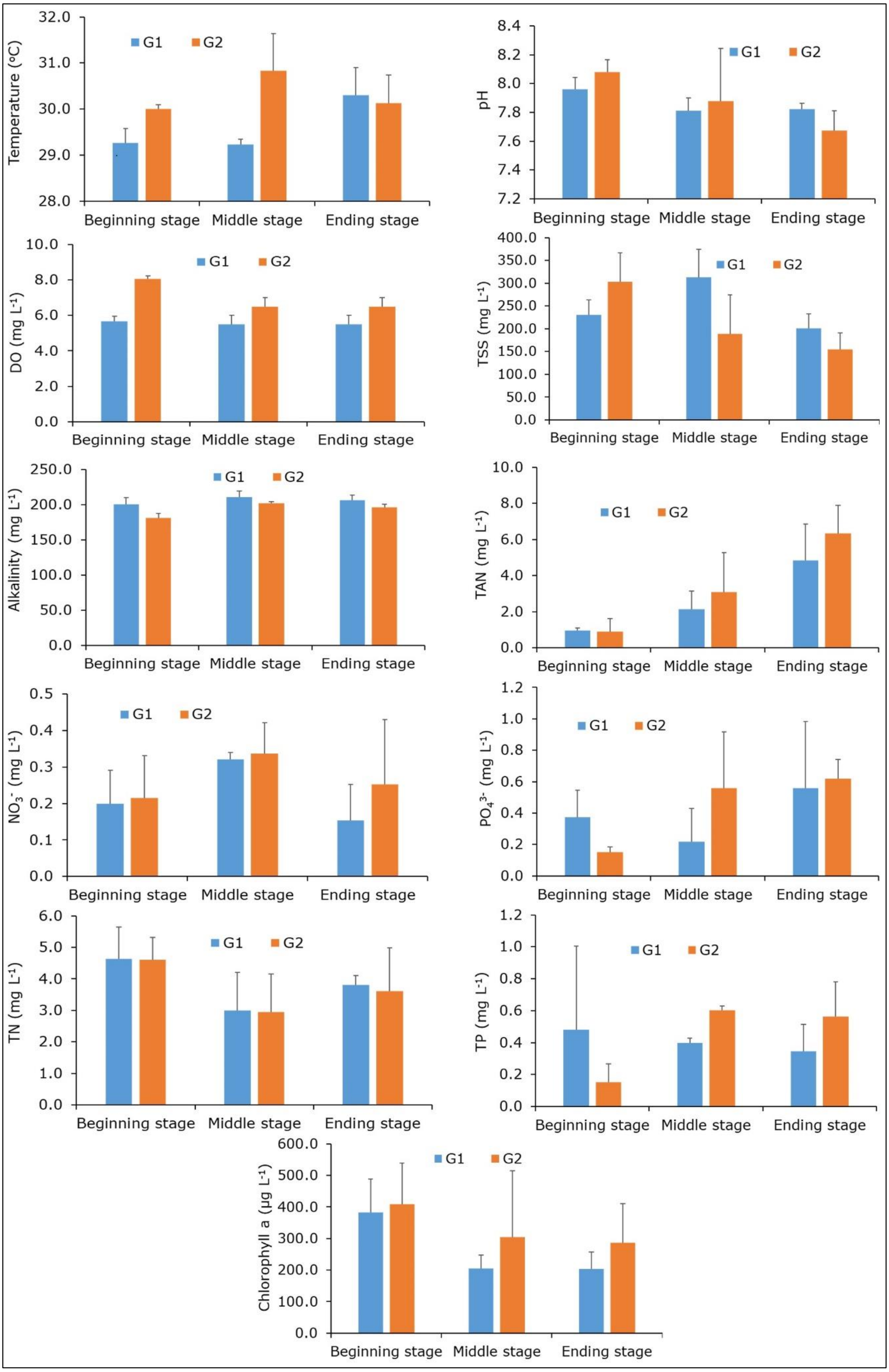

Figure 3. Fluctuations in water environmental parameters through surveys in whiteleg shrimp (*Litopenaeus vannamei*) ponds.

the beginning to 154.3 ± 36.2 mg L^{-1} at the end). Alkalinity increased slightly in the mid-cycle and subsequently decreased toward the end (G1: 200.7 ± 9.5 to 211.0 ± 8.5 mg $CaCO_3$ L^{-1}; G2: 181.0 ± 6.6 to 202.0 ± 2.0 mg $CaCO_3$ L^{-1}). Salinity was measured directly in the ponds, ranging from 12 to 13‰.

Nutrient parameters showed marked temporal changes. Total ammonia nitrogen (TAN) increased substantially toward the end of the culture period, reaching 4.9 ± 2.0 mg L^{-1} in G1 and 6.4 ± 1.6 mg L^{-1} in G2 (compared with the initial concentration of approximately 0.9 mg L^{-1}). Average nitrate (NO_3^-) concentrations were not significantly different between the two groups, which increased to mid-cycle and decreased afterward (approximately 0.2 ± 0.1 to 0.3 ± 0.1 mg L^{-1}). Phosphate (PO_4^{3-}) concentrations generally increased as harvest approached, ranging from 0.2 ± 0.1 to 0.6 ± 0.1 mg L^{-1}. Total nitrogen (TN) fluctuated, decreasing at mid-cycle and rising again toward the end (example in G2, the highest value was 4.6 ± 0.7 mg L^{-1} on day 25 and the lowest was 2.9 ± 1.2 mg L^{-1} on day 54). In G1, total phosphorus (TP) ranged from 0.3 ± 0.2 to 0.5 ± 0.5 mg L^{-1} across the three sampling periods, peaking at the beginning and reaching the lowest values at the end of the cycle. Conversely, TP concentrations in G2 varied from 0.2 ± 0.1 to 0.6 ± 0.2 mg L^{-1}, with the highest values observed at the end of the cycle and the lowest at the beginning. Finally, average chlorophyll-a concentrations in the high-density group (G2) were consistently higher than in G1, and both groups showed a decreasing trend toward the end of the cycle (G1 ranged from 203.8 ± 54.1 to 383.0 ± 105.8 μg L^{-1}; G2 from 286.6 ± 123.9 to 408.9 ± 130.9 μg L^{-1}), with maximum concentrations recorded early in the cycle and minimum concentrations recorded at the end.

Species composition of periphytic algae in super-intensive whiteleg shrimp ponds. Across three sampling events, a total of 20 periphytic algal species were recorded in the super-intensive shrimp ponds, representing four major algal divisions: Cyanobacteria, Chlorophyta, Heterokontophyta (predominantly Bacillariophyceae), and Dinoflagellata. Among these, Cyanobacteria were the most species-rich group with eight species (38%), followed by Heterokontophyta with six species (29%), Chlorophyta with five species (25%), while Dinoflagellata was represented by only a single species (1.5%). Commonly encountered taxa included *Chroococcus turgidus*, *Oscillatoria* sp.1, *Oscillatoria* sp.2, *Lyngbya* sp., *Pseudanabaena* sp. (Cyanobacteria); *Oocystis* sp., *Chlorella* sp., *Ulothrix* sp.1, *Ulothrix* sp.2 (Chlorophyta); and *Thalassiosira* sp., *Cymbella* sp., *Nannochloropsis* sp., *Nitzschia longissima*, *Cylindrotheca closterium* (Heterokontophyta) (Figure 4).

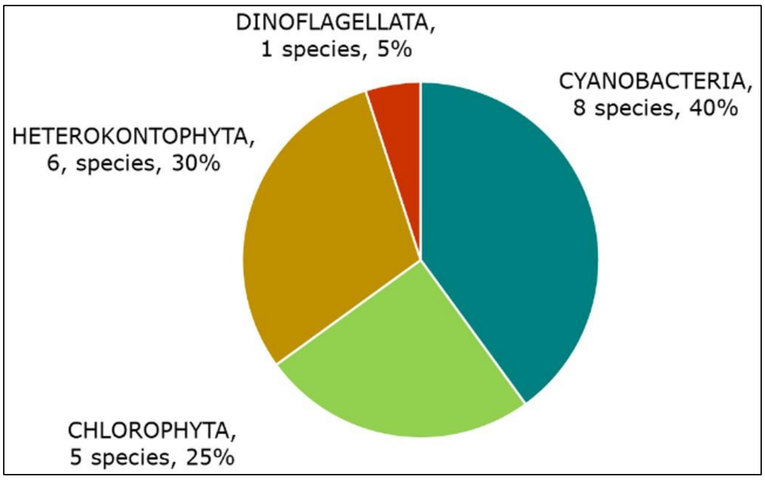

Figure 4. Species composition of periphytic algae in super-intensive whiteleg shrimp (*Litopenaeus vannamei*) ponds.

Temporal variation in periphytic algal composition across sampling periods. The periphytic algal community in super-intensive whiteleg shrimp ponds exhibited moderate diversity, with relatively stable species composition across sampling events, ranging from 15 to 18 recorded species (Figure 5). Species richness peaked at day 25 of the culture period, while lower numbers were observed during the remaining sampling times.

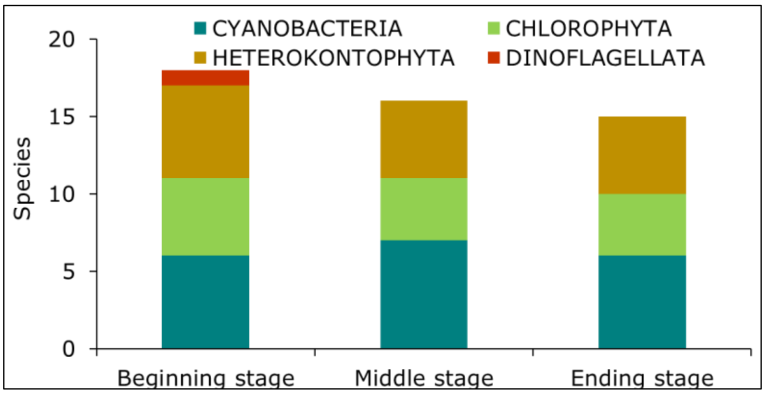

Figure 5. Periphytic algae species composition in whiteleg shrimp (*Litopenaeus vannamei*) ponds in each survey period.

The periphytic algal composition differed slightly between the two groups, with G1 recording a maximum of 15 species and G2 recording 17 species (Figure 6). At the early culture stage, 11 species were observed in G1, including five Cyanobacteria, three Chlorophyta, and three Heterokontophyta. In contrast, G2 contained 16 species, comprising five Cyanobacteria, four Chlorophyta, six Heterokontophyta (including five diatom species), and one Dinoflagellata species. At this stage, two species were found exclusively in G1 (*Oscillatoria* sp.2 and *Ulothrix* sp.1), whereas six species occurred only in G2, including *Chroococcus minutus*, *Chlorella* sp., *Monoraphidium* sp., *Nitzschia longissima*, *Navicula* sp., and *Cylindrotheca closterium*. By mid-cycle, the number of cyanobacterial species increased in G2 compared with G1, reaching seven species; two of these (*Spirulina* sp. and *Oscillatoria* sp.2) were detected only in G2. Conversely, G1 exhibited greater chlorophyte diversity, with five species recorded. A similar pattern was observed at the end of the culture period, where G2 continued to show a higher number of Cyanobacteria (six species) than G1. Diatoms were also more diverse in G2, with five species compared with three in G1. Notably, *Cylindrotheca closterium* and *Cymbella* sp. were recorded exclusively in ponds with higher stocking density (G2).

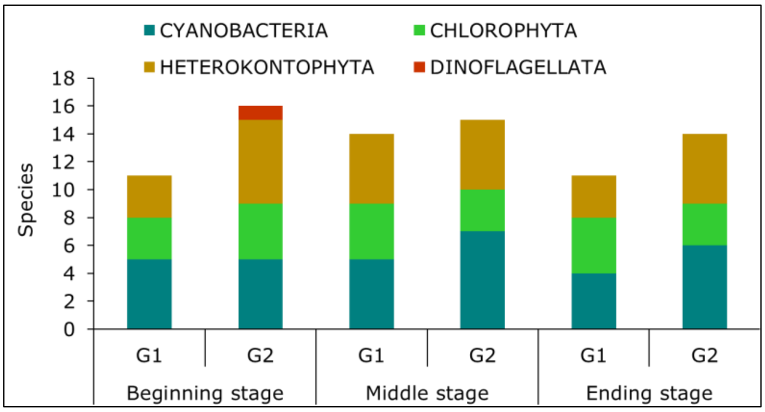

Figure 6. Periphytic algae species composition of 2 groups of whiteleg shrimp (*Litopenaeus vannamei*) ponds.

Periphytic algal density in super-intensive whiteleg shrimp ponds. Across the three sampling periods, the average periphytic algal density in super-shrimp ponds ranged from 71,920 ± 36,393 to 203,986 ± 165,947 ind cm^{-2} for the combined G1 and G2 groups (Figure 7). In particular, G2 exhibited higher densities, fluctuating between 180,289 ± 203,762 and 203,986 ± 165,947 ind cm^{-2}, approximately 2.1 times greater than the mean density observed in G1 (71,920 ± 36,393 to 96,692 ± 67,787 ind cm^{-2}). Overall, periphytic algal density in the shrimp ponds was relatively high, reaching its lowest levels at the beginning of the culture cycle and increasing toward the end. Cyanobacteria, especially filamentous forms, were the most abundant group, with densities ranging from 19,212 ±

16,652 to 176,633 ± 158,410 ind cm^{-2}. Representative cyanobacterial taxa observed during this period included *Oscillatoria* sp.2 and *Chroococcus turgidus*. In contrast, diatom density declined markedly toward the end of the culture period, decreasing from 143,843 ± 207,061 to 14,427 ± 6,053 ind cm^{-2}. Dinoflagellates were recorded only at the beginning of the crop, with an average density of 94 ± 162 ind cm^{-2}.

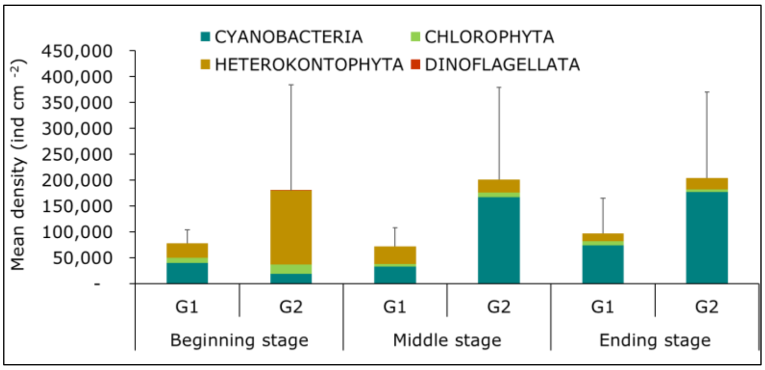

Figure 7. Periphytic algal density in super-intensive whiteleg shrimp (*Litopenaeus vannamei*) ponds in each survey period.

In the super-intensive whiteleg shrimp ponds, eight Cyanobacteria species were identified, which is more than any other algal group. In both pond groups, Cyanobacteria density was low at the beginning of the culture cycle and increased progressively toward the end (Figure 8). At the early stage, G1 showed a higher Cyanobacteria density (39,578 ± 19,026 ind cm^{-2}) compared with G2 (19,212 ± 16,652 ind cm^{-2}). From mid-cycle to harvest, the density in G2 increased sharply, reaching 176,633 ± 153,410 ind cm^{-2}.

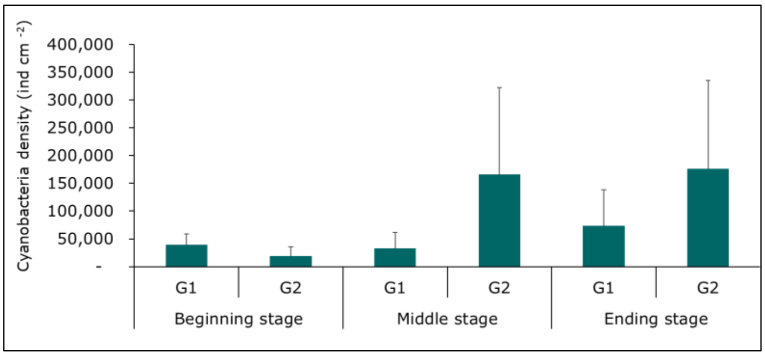

Figure 8. Cyanobacteria density in super-intensive whiteleg shrimp (*Litopenaeus vannamei*) ponds in each survey period.

The temporal variation in the average density of Chlorophyta in the shrimp ponds across sampling periods is illustrated in Figure 9. In both G1 and G2, the density of Chlorophyta was highest at the beginning of the culture cycle and declined slightly toward harvest, ranging from 5,030 ± 3,662 to 17,140 ± 28,570 ind cm^{-2}. During the early and mid-culture stages, G2 exhibited higher mean densities than G1; however, by the end of the cycle, the density of chlorophyta in G2 decreased and fell below that recorded in G1.

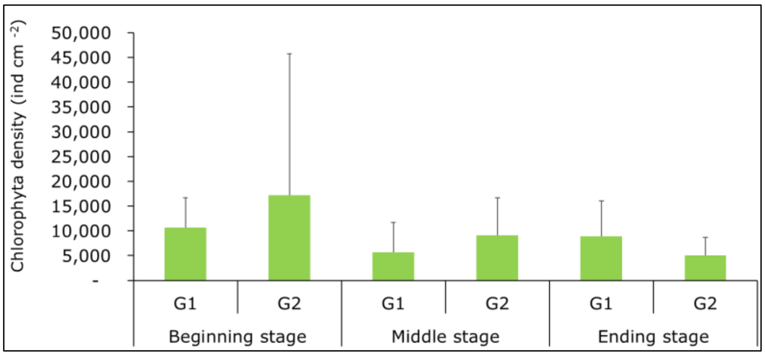

Figure 9. Chlorophytes density in super-intensive whiteleg shrimp (*Litopenaeus vannamei*) ponds in each survey period.

Six Heterokontophyta species were recorded in the super-intensive whiteleg shrimp ponds (Figure 10). The density of Heterokontophyta was high at the beginning of the culture cycle in both pond groups but declined markedly toward the end, with mean values ranging from 14,427 ± 6,053 to 143,843 ± 207,016 ind cm^{-2}. In G2, densities ranged from 22,323 ± 8,993 to 143,843 ± 207,016 ind cm^{-2}, whereas in G1, the corresponding values were lower, from 14,427 ± 6,053 to 33,774 ± 9,835 ind cm^{-2}.

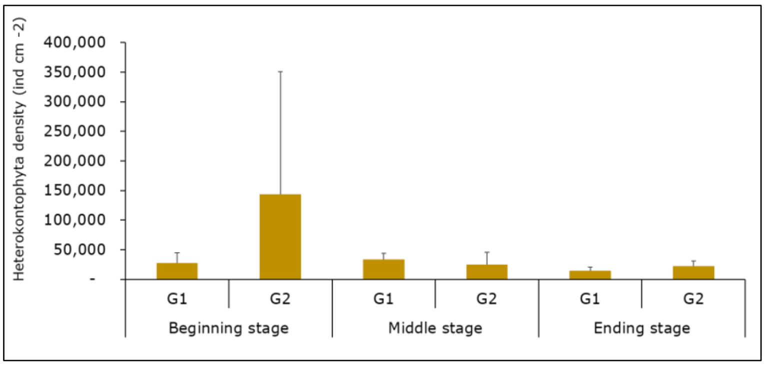

Figure 10. Heterokontophyta density in super-intensive whiteleg shrimp (*Litopenaeus vannamei*) ponds in each survey period.

Algal biomass. The average algal biomass in both G1 and G2 declined progressively toward the harvest phase (Figure 11). Biomass in G2 ranged from 19.205 ± 8.298 to 27.395 ± 8.771 g m^{-3}, consistently higher than that in G1, which varied from 13.653 ± 3.625 to 25.662 ± 7.086 g m^{-3}.

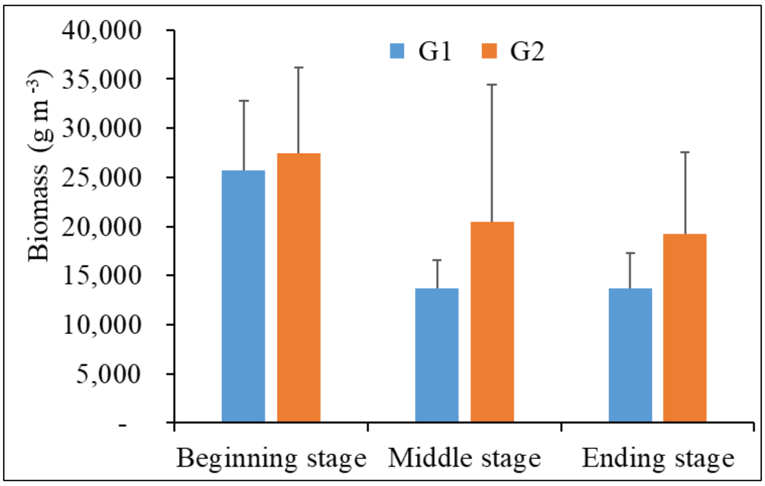

Figure 11. Algal biomass in super-intensive whiteleg shrimp (*Litopenaeus vannamei*) ponds in each survey period.

Diversity indices. The Shannon–Wiener diversity index (H′) and Pielou's index (J′) for the super-intensive whiteleg shrimp ponds are presented in Figure 12. The H′ values exhibited considerable variability, ranging from 1.08 ± 0.27 to 1.58 ± 0.18. At mid-culture, H′ in G1 continued to increase, whereas H′ in G2 gradually declined toward the end of the culture period. The J′ values also varied markedly, from 0.43 ± 0.10 to 0.70 ± 0.05, with consistently lower evenness in G2 (0.43 ± 0.10 to 0.61 ± 0.13) compared to G1 (0.52 ± 0.16 to 0.70 ± 0.05). These results indicate that ponds stocked at higher density exhibit lower community evenness than those with lower stocking density.

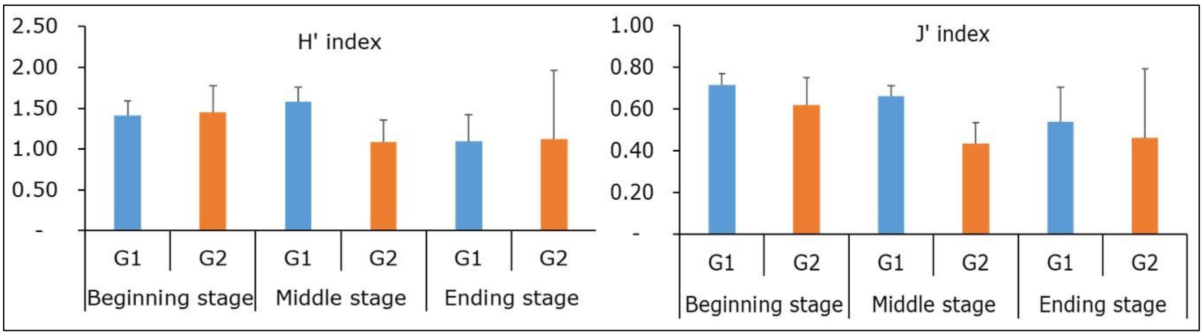

Figure 12. Diversity indices in super-intensive whiteleg shrimp (*Litopenaeus vannamei*) ponds in each survey period.

Discussion. Environmental parameters such as temperature were primarily influenced by daily weather conditions. Water temperature showed no substantial differences between groups G1 and G2 during the early and late stages of the culture cycle. In the mid-cycle, the TSS concentration in group G2 (188.3 mg L^{-1}) was lower than in group G1 (313.3 mg L^{-1}), resulting in reduced light penetration due to suspended solids in the water, which consequently caused the temperature in group G2 to be higher than in group G1. According to the Vietnamese National Standard TCVN 13656:2023 (MST 2023) for aquaculture water quality in intensive black tiger shrimp (*Penaeus monodon*) and whiteleg shrimp (*Litopenaeus vannamei*) culture, the optimal temperature ranges from 26 to 32°C. Likewise, Boyd and Tucker (1998) reported that shrimp grow well at temperatures between 25 and 30°C. Overall, the pH values in both shrimp-culture groups tended to decline toward the end of the culture cycle. According to the Vietnamese National Standard TCVN 13656:2023 (MST 2023), the suitable pH range is 7.5 – 8.5 with a daily fluctuation of no more than 0.5. Similarly, Ariadi et al (2019) indicated that a pH of 7.5 – 8.5 is optimal for shrimp growth. Dissolved oxygen (DO) decreased progressively as the culture cycle approached the harvest period. DO levels fluctuate with algal dynamics and weather conditions (Ngan & Phu 2010). In both pond groups, DO gradually declined over time due to the accumulation of organic matter from uneaten feed, shrimp feces, and the oxygen demand associated with shrimp metabolism (Lin et al 2005). Boyd and Tucker (1998) also noted that increasing feed input and shrimp excretion leads to organic matter accumulation, which elevates oxygen consumption for decomposition and consequently reduces DO. According to the Vietnamese National Standard TCVN 13656:2023 (MST 2023), the suitable DO concentration ranges from 5.0 to 9.0 mg L^{-1}. In general, total suspended solid (TSS) concentrations in both G1 and G2 decreased toward the end of the culture period across the three sampling events. From the early to mid-cycle, TSS levels increased, likely due to algal collapse, accumulation of organic matter, and high microbial oxygen demand, which together contributed to elevated TSS. No major differences in TSS were observed between the two pond groups. According to the Vietnamese National Standard TCVN 13656:2023 (MST 2023), the maximum allowable TSS concentration for intensive shrimp ponds is ≤100 mg L^{-1}. Alkalinity increased toward mid-cycle and declined near the end in both G1 and G2. Sampling was conducted during the dry season, when increasing salinity likely contributed to elevated alkalinity. For brackish-water aquaculture species, alkalinity should exceed 80 mg L^{-1} (Trung 2004). According to the Vietnamese National Standard (TCVN 13656:2023), the recommended alkalinity (as $CaCO_3$) ranges from 100 to 200 mg L^{-1}. Thus, water quality parameters such as temperature, pH, salinity, DO, and alkalinity in this study were within suitable ranges for *Litopenaeus vannamei* culture, whereas TSS exceeded the recommended threshold.

Despite the substantial difference in total ammonia nitrogen (TAN) levels between G1 and G2, both groups exhibited a gradual increase, particularly toward the end of the cycle. According to the Vietnamese National Standard TCVN 13656:2023 (MST 2023), TAN concentrations should not exceed 3 mg L^{-1}, while Allan et al (1990) recommended keeping TAN below 4 mg L^{-1} to avoid adverse effects on shrimp growth. The average TAN concentrations at the end of the culture cycle in both groups exceeded these limits. Elevated TAN can induce stress, weaken shrimp immunity, and increase susceptibility to bacterial infections. This increase may be attributed to high stocking density; as the cycle progresses, shrimp waste accumulates, leading to higher TAN levels. TAN concentrations in this study were like those reported by Lien et al (2022) (1.99 – 5.70 mg L^{-1}) but higher than those observed by Fakhri et al (2015) in intensive *L. vannamei* ponds in Indonesia (0.027 – 0.437 mg L^{-1}).

Average NO_3^- concentrations showed no significant differences between G1 and G2; both increased in mid-cycle and declined toward the end. NO_3^- concentrations below 10 mg L^{-1} are considered suitable for super-intensive *L. vannamei* ponds according to the Vietnamese National Standard TCVN 13656:2023 (MST 2023). Likewise, Boyd and Tucker (1998) also recommended maintaining NO_3^- between 0.2 and 10 mg L^{-1}. Thus, NO_3^- concentrations in both groups were within acceptable limits. However, these values were lower than those reported by Fakhri et al (2015) (3.842 – 8.652 mg L^{-1}) and Son et al (2014) (0.15 ± 0.16 mg L^{-1}) at stocking densities of 130 – 140 inds m^{-2} in Soc Trang Province.

Phosphate (PO_4^{3-}) concentrations increased toward harvest in both groups, ranging from 0.2 ± 0.2 to 0.6 ± 0.4 mg L^{-1}. According to the Vietnamese National Standard TCVN 13656:2023 (MST 2023), optimal phosphate levels should not exceed 0.15 mg L^{-1}. Thus, phosphate concentrations exceeded the recommended limits across all sampling periods, indicating relatively high nutrient levels. Son et al (2014) also reported high PO_4^{3-} levels (1.23 ± 0.67 mg L^{-1}) in intensive *L. vannamei* ponds.

Total nitrogen (TN) fluctuated across sampling periods in both G1 and G2, decreasing mid-cycle and increasing again near harvest. Total phosphorus (TP) also fluctuated irregularly, likely influenced by farmers' use of probiotics and water-exchange practices. According to Trang et al (2022), TP decreases in low-density ponds (0.15 – 1.7 mg L^{-1}) but increases in high-density systems. Son et al (2014) recorded TP levels ranging from 0.9 mg L^{-1} to 1.9 mg L^{-1} at harvest. Overall, TN and TP levels in this study remained within acceptable limits for shrimp growth.

The average chlorophyll-a concentrations were higher in G2 than in G1, and both groups showed a declining trend toward the end of the cycle. This decrease may be attributed to grazing by shrimp and zooplankton. Chlorophyll-a was positively correlated with NO_3^- ($p < 0.01$) and negatively correlated with PO_4^{3-} ($p < 0.05$). Chlorophyll-a concentrations in this study were higher than those reported by Yusoff et al (2002) in intensive shrimp ponds, where they ranged from 35.6 to 186.0 μg L^{-1} with probiotics and from 42.1 to 242.8 μg L^{-1} in control ponds. The values also exceeded those reported by Lien et al (2022) (9.1–141.6 μg L^{-1}). Optimal chlorophyll-a concentrations in aquaculture ponds typically range from 50 to 200 μg L^{-1} (Boyd & Tucker 1998). Thus, chlorophyll-a was generally above the suitable range, especially early in the cycle.

Cyanobacteria were highly represented in this study, likely because they occur widely across freshwater to brackish environments, particularly in aquaculture ponds (Stevens Jr & Nierzwicki-Bauer 1991; Whitton & Potts 2012). Cyanobacteria respond strongly to phosphorus levels, which is consistent with the research of Wilkinson et al (2016). In this research, the authors concluded that the proliferation of Cyanobacteria is stimulated when phosphorus exceeds 50 μg L^{-1}. In the present study, phosphorus levels ranged from 200 to 600 μg L^{-1}, explaining the dominant presence of Cyanobacteria. Differences in species richness among algal groups may also be associated with environmental conditions, nutrient availability, and physicochemical parameters. The number of algal species recorded was lower than the 39 species reported by Santhana Kumar et al (2017) in improved extensive *L. vannamei* ponds. The genera identified in their study, including *Cymbella*, *Navicula*, *Nitzschia* (diatoms), *Lyngbya*, *Oscillatoria*, *Spirulina* (Cyanobacteria), and *Chlorella* (Chlorophyta), were also found in the present study.

In super-intensive culture ponds, water quality is well controlled, but the substrate composition is less diverse than in extensive ponds; as a result, the algal species composition is also lower. Algal richness in this study was higher than that reported by Anix et al (2020) in earthen shrimp ponds with coconut-fiber and bamboo substrates, which yielded 10 diatom, four dinoflagellate, and two cyanobacterial species. Conversely, Arfiati et al (2023) recorded 21 periphytic algae species in semi-biofloc shrimp ponds with bamboo substrates, with diatoms being the most diverse group (14 species), followed by Chlorophyta (four species) and Cyanobacteria (three species). Periphytic algae species composition differed between early and late stages of the culture cycle, likely because farmers commonly apply fertilizers early in the cycle to enhance pond colour and promote algal growth. Declines in algal richness toward the end of the cycle may be attributed to grazing by zooplankton, which are subsequently consumed by shrimp. Cyanobacteria, Chlorophyta, and Heterokontophyta dominated across sampling events with minimal variation. Dinoflagellates were detected at day 25; although they typically occur in brackish-marine environments, they are undesirable due to their potential toxin production during blooms. Their low abundance suggests good water management early in the cycle. Group G2 exhibited greater algal diversity than G1, likely due to higher stocking density and increased organic loading from uneaten feed and shrimp waste.

The higher average algal density observed in group G2 compared to group G1 is attributable to the higher shrimp stocking density in G2 ponds, which results in greater waste production and increased uneaten feed. These factors elevate nutrient concentrations, thereby stimulating biomass accumulation across multiple algal divisions. This pattern is supported by water quality data, in which TAN, TP, and NO_3^- levels in G2 were consistently higher than those of G1 across all three sampling periods. Cyanobacteria dominated at the end of the culture cycle in both groups. As the crop progressed, nutrient and organic matter concentrations increased, with TAN, TP and NO_3^- reaching 6.3 mg L^{-1}, 0.6 mg L^{-1}, and 0.3 mg L^{-1}, respectively, conditions that favour cyanobacterial proliferation, which is an algal group capable of thriving under a wide range of environmental conditions (Hood et al 2016; Ciebiada et al 2020). Several cyanobacterial taxa are known to produce harmful toxins that can cause acute or chronic health issues in shrimp. These toxins may suppress immune function, making shrimp more susceptible to infections, particularly from pathogenic *Vibrio* species (Zhang et al 2022; Najwa et al 2024; Delgado et al 2024). Cyanobacterial blooms can also disrupt nutrient dynamics, promote eutrophication, and facilitate the growth of other harmful algae, negatively affecting aquatic life (Zhang et al 2022).

Conversely, Heterokontophyta, particularly diatoms, declined toward the end of the culture cycle, likely because they are less tolerant of nutrient-enriched conditions. *Thalassiosira* sp. was consistently detected throughout all sampling events. In aquaculture, farmers generally prefer ponds dominated by diatoms due to their high nutritional value, including proteins, lipids, and fatty acids essential for shrimp growth and health. Diatoms have been shown to enhance the biochemical composition of shrimp, leading to elevated protein and lipid contents (Lien et al 2018). Concentrated *Thalassiosira* spp. have long been used in post larval shrimp rearing to improve growth and survival. Diatoms also contribute positively to water quality by stabilizing the culture environment, reducing fluctuations in water parameters, and mitigating the accumulation of harmful compounds. Moreover, their presence increases microbial diversity, which supports nutrient cycling and organic matter decomposition (Martínez-Montaño et al 2020). Arfiati et al (2023) similarly observed that Cyanobacteria represented 30–65% of the periphyton community over eight weeks in semi-biofloc ponds using bamboo substrates for whiteleg shrimp culture; diatoms also constituted a major proportion, reaching 17–69% of total algal density.

Cyanobacteria density was consistently higher in G2 than in G1 across sampling periods. Under high stocking densities and elevated nutrient loads, particularly TAN reaching 6.3 mg L^{-1}, nutrient-tolerant algae proliferate, resulting in lower algal species richness but higher overall densities. *Oscillatoria* sp.1 was the dominant species, reaching

384,708 inds cm^{-2}. Several *Oscillatoria* species are known to be harmful to shrimp larvae, and their high densities can significantly reduce larval survival due to mechanical obstruction in the digestive tract and potential toxin-mediated effects. Filamentous Cyanobacteria can clog the gills and interfere with feeding, resulting in weakened shrimp that are more vulnerable to disease (Lu et al 2021). Khatoon et al (2007) reported that *Oscillatoria* is widely distributed across various substrate types and often dominates over other Cyanobacteria genera.

In contrast, green algae declined toward the end of the culture cycle. Variability across sampling periods may be explained by energy flow within the system, as algae are consumed by zooplankton and shrimp, leading to fluctuations in density. Environmental factors and pond management practices also contribute to these changes. In this study, the dominant green alga was *Ulothrix* sp., reaching a peak density of 306,245 inds cm^{-2}. Numerous studies highlight the nutritional value of green algae as natural feed, particularly for postlarval shrimp (Soeprapto et al 2023). However, excessive proliferation may trigger algal blooms that reduce dissolved oxygen, induce large diel pH fluctuations, and cause stress and poor growth in shrimp (Shaari et al 2011). Amirtharaj (2019) observed that *Ankistrodesmus* dominated in both earthen and cement-lined ponds, whereas Anix et al (2020) reported no chlorophyta on coconut fiber or bamboo substrates in whiteleg shrimp ponds.

Similarly, Heterokontophyta, primarily diatoms, decreased sharply in both groups, especially at the end of the cycle. With elevated nutrient loads late in culture, diatoms are disadvantaged while Cyanobacteria become dominant. In this study, *Nannochloropsis* sp. was the predominant species and contributed significantly to the phytoplankton community. This genus plays a key role in maintaining water quality by assimilating nitrogen and preventing toxin accumulation, which is critical for shrimp health (Guimarães et al 2021). Dietary supplementation with *Nannochloropsis* has been shown to enhance thermal tolerance and immune responses in whiteleg shrimp (Guimarães et al 2021). Studies demonstrate that adding 1–2% *Nannochloropsis* powder to shrimp diets can modulate gut microbiota and improve performance, partly by increasing reactive oxygen species (ROS) production, indicating enhanced immune activity (Santanumurti et al 2022). Due to higher algal density and nutrient levels, algal biomass in G2 was also greater than in G1, although it declined slightly toward the end of the crop. In shrimp ponds, algal biomass serves as a natural food source for zooplankton and shrimp, explaining the reductions observed across sampling events as it is consumed.

At the beginning of the culture cycle, the Shannon–Wiener diversity index (H′) was relatively high in both G1 and G2, with no major differences. At this stage, waste accumulation is still low, and nutrient and organic matter concentrations remain stable, allowing many algal species to coexist. Similarly, Pielou's index (J′) was high, indicating a balanced distribution of species. By mid-cycle, H′ index increased slightly in G1 but decreased in G2. In G2, high stocking density and greater feeding lead to elevated organic matter and nutrient accumulation, promoting the proliferation of a few well-adapted algal species that outcompete others and reduce diversity and evenness. By the end of the cycle, when shrimp biomass and waste inputs are highest, nutrient imbalances intensify, favouring nutrient-loving species and causing marked decreases in both H′ and J′. These trends align with Arfiati et al (2023), who reported H′ values from 1.988 – 2.880 and J′ values from 0.460 – 0.666 in semi-biofloc ponds with bamboo substrates.

In contrast, the Simpson's index (D) reflects the extent to which one or a few species dominate. Early in the cycle, when H′ index and J′ index are high, D index remains low, indicating no dominant species. From mid- to late-cycle, the D index increases markedly in both groups, indicating growing nutrient enrichment. Species such as *Oscillatoria* sp.2 and *Ulothrix* sp. proliferate and suppress others, increasing the D index. Dominance values in this study were generally higher than those reported by Arfiati et al (2023), who observed D values of 0.169 – 0.314 in semi-biofloc systems.

Correlation analysis revealed that total periphytic algal richness in intensive whiteleg shrimp ponds was positively associated with water quality parameters such as temperature, DO, TAN, NO_3^-, PO_4^{3-}, TSS, TP, and chlorophyll-a; however, these correlations were not statistically significant ($p > 0.05$) (Table 2). In shrimp ponds, nutrients such as NO_3^-, PO_4^{3-}, and TAN primarily originate from feed inputs, shrimp waste, and organic matter decomposition. Elevated concentrations promote algal growth (Shaari et al 2011). As nutrient levels rise, only a few tolerant species proliferate and suppress others, explaining why algal richness was not significantly correlated with nutrient concentrations.

Algal density was strongly associated with nutrient levels, particularly NO_3^- and chlorophyll-a, showing significant positive correlations ($p < 0.01$). Nitrate is an essential nutrient that promotes algal biomass; increases in NO_3^- typically result in higher algal densities (Fermino et al 2011; Ferragut & De Campos Bicudo 2010, 2012). Chlorophyll-a is widely used as an indicator of algal biomass, and several studies have shown that chlorophyll-a is positively correlated with total algal density, especially Chlorophyta and Cyanobacteria (Cremen et al 2007; Lien et al 2023).

Table 2

Correlation between species composition, density, algal biomass, and biological indicators with water quality parameters

	Temperature	*pH*	*DO*	*Alkalinity*	*TSS*	*TAN*	*NO_3^-*	*PO_4^{3-}*	*TN*	*TP*	*Chlorophyll-a*
Cyano	0.05	-0.39	0.16	0.05	0.18	0.33	0.40	0.26	0.06	0.27	0.18
Chloro	0.22	0.13	0.17	-0.13	0.05	0.11	-0.43	0.10	-0.15	0.13	-0.27
Hetero	0.09	-0.22	0.33	0.09	0.13	0.12	0.63^{**}	0.01	-0.21	-0.12	0.20
Dino	0.01	0.28	0.43	-0.39	0.21	-0.17	-0.36	-0.21	0.30	-0.23	-0.06
Tspec	0.15	-0.29	0.38	0.00	0.21	0.28	0.43	0.17	-0.11	0.11	0.13
Cyano Den	0.05	-0.66^{**}	-0.07	0.21	-0.22	0.74^{**}	0.58^{*}	0.51^{*}	0.20	0.20	0.39
Chloro Den	0.05	0.30	0.24	-0.35	0.46	-0.31	0.09	-0.28	0.09	-0.39	0.33
Hetero Den	-0.09	0.12	0.47	-0.27	0.10	-0.19	0.21	-0.26	0.25	-0.16	0.49^{*}
Dino Den	0.01	0.28	0.43	-0.39	0.21	-0.17	-0.36	-0.21	0.30	-0.23	-0.06.
TDen	-0.02	-0.43	0.28	-0.04	-0.07	0.44	0.62^{**}	0.22	0.34	0.02	0.67^{**}
H'	-0.24	0.34	0.12	-0.15	0.34	-0.57^{*}	-0.38	-0.51^{*}	-0.20	0.06	-0.06
J'	-0.32	0.41	-0.04	-0.13	0.25	-0.65^{**}	-0.49^{*}	-0.56^{*}	-0.14	0.05	-0.07
D	0.29	-0.46	-0.08	0.16	-0.41	0.73^{**}	0.35	0.63^{**}	0.18	-0.01	0.02
Oscilla	0.08	-0.66^{**}	-0.06	0.17	-0.29	0.79^{**}	0.56^{*}	0.57^{*}	0.17	0.16	0.32
Nanno	-0.20	0.09	0.35	-0.20	0.24	-0.24	0.26	-0.18	0.30	-0.05	0.58^{*}
Ulo	0.27	-0.18	-0.22	0.19	-0.05	0.23	0.15	-0.03	-0.10	0.02	-0.04
Chroo	-0.31	-0.12	-0.21	0.20	-0.30	-0.02	0.04	0.20	0.43	0.28	0.30
Thalass	-0.07	0.01	0.44	-0.24	-0.01	-0.03	0.25	-0.23	0.25	-0.19	0.46
Biomass	-0.28	-0.09	0.37	-0.29	0.26	-0.08	0.47	-0.18	0.59^{**}	-0.37	1.00^{**}

Note: * Correlation is statistically significant ($p < 0.05$); ** Correlation is statistically significant ($p < 0.01$). Cyano: number of Cyanobacteria species; Chloro: number of Chlorophyta species; Hetero: number of Heterokontophyta species; Dino: number of Dinoflagellata species; Tspec: total number of algal species; Cyano Den: Cyanobacteria density; Chloro Den: Chlorophyta density; Hetero Den: Heterokontophyta density; Dino Den: Dinoflagellata density; TDen: Total algal density; Oscilla: Density of *Oscillatoria*; Nanno: Density of *Nannochloropsis*; Ulothrix: Density of *Ulothrix*; Chroo: Density of *Chroococcus*; Thalass: Density of *Thalassiosira*.

In this study, cyanobacterial density showed significant correlations with key nutrients in the water column, including TAN, NO_3^-, and PO_4^{3-} ($p < 0.05$), but was negatively correlated with pH ($p < 0.05$). Although specific studies on the relationship between TAN and cyanobacterial abundance remain limited, general trends indicate that increasing nutrient availability, including ammonia, can promote cyanobacterial proliferation. Concentrations of NO_3^- and PO_4^{3-} have been reported to positively correlate with cyanobacterial density in aquatic environments (Pérez-González et al 2023). Several studies have shown that higher pH levels may be associated with lower cyanobacterial abundance, potentially due to pH-mediated changes in nutrient accessibility or competitive interactions with other algal groups (de Oliveira et al 2022). Conversely, some cyanobacterial taxa thrive under elevated pH conditions, contributing to bloom formation in alkaline waters (Piontek et al 2023). In contrast, Chlorophyta, Heterokontophyta, and Dinoflagellata exhibited negative correlations with nutrient concentrations and positive correlations with pH ($p > 0.05$). Similarly, the dominance of *Oscillatoria* was significantly influenced by TAN, NO_3^-, and PO_4^{3-}, as indicated by positive correlations ($p < 0.05$), while showing a negative correlation with pH ($p < 0.05$). Meanwhile, taxa that appeared frequently and maintained relatively stable densities, such as *Ulothrix*, *Chroococcus*, *Thalassiosira*, and *Nannochloropsis,* showed positive but non-significant correlations with NO_3^-.

Overall, algal biomass in super-intensive whiteleg shrimp ponds tended to show positive correlations with DO, TSS, and NO_3^-, and negative correlations with temperature, pH, alkalinity, TAN, PO_4^{3-}, and TP; however, these relationships were not statistically significant. In addition, algal biomass was strongly influenced by TN and chlorophyll-a, as indicated by significant positive correlations ($p < 0.05$). Numerous studies have demonstrated that algal biomass in aquatic environments, particularly in aquaculture ponds, is closely associated with nutrient availability, and TN is one of the essential nutrient parameters. Consequently, increases in TN generally correspond to increases in periphytic algal biomass (Sruthisree et al 2015).

Correlation analysis between biological indices and water quality parameters showed that the Shannon–Wiener index (H’) was significantly and negatively correlated with TAN and PO_4^{3-} ($p < 0.05$). The Pielou index (J’) was also strongly affected by TAN, NO_3^-, and PO_4^{3-} through significant negative correlations ($p < 0.05$). This pattern can be explained by the fact that elevated nutrient concentrations promote the dominance of nutrient-tolerant taxa, which outcompete other species, thereby reducing overall diversity and community evenness in the ponds. This interpretation aligns with the findings of the present study, where increased TAN, NO_3^-, and PO_4^{3-} concentrations corresponded with higher densities of *Oscillatoria* ($p < 0.05$), leading to a decline in both H’ and J’.

Conclusions. Water quality parameters, including temperature, DO, pH, alkalinity, NO_3^-, TN, and TP, were within the suitable range for shrimp growth. However, TSS, PO_4^{3-}, TAN, and chlorophyll-a exceeded the recommended thresholds towards the end of the culture period. Ponds with higher stocking densities exhibited higher concentrations of nutrients such as TAN, NO_3^-, PO_4^{3-}, and TP, which tended to increase further as the culture progressed.

The study identified 20 periphytic algal species, including 8 Cyanobacteria, 6 Heterokontophyta, 5 Chlorophyta, and 1 Dinoflagellata. Dominant and frequently occurring genera in the shrimp ponds were *Oscillatoria*, *Nannochloropsis*, *Chroococcus*, *Ulothrix*, and *Thalassiosira*. Heterokontophyta predominated in the early stage of the culture, whereas Cyanobacteria increased during the mid and late stages, particularly in ponds with higher stocking densities. Algal biomass and diversity indices (H’ and J’) were high at the beginning of the culture but decreased towards the end. Ponds with higher stocking densities exhibited greater algal species diversity, as well as higher periphytic algal density and biomass. Periphytic algal density was significantly influenced by NO_3^- concentrations. Moreover, increasing levels of nutrients such as NO_3^-, TAN, and PO_4^{3-} were associated with decreasing H’ and J’ values. Based on these results, it is recommended that shrimp farmers carefully monitor water quality and cyanobacterial development from the mid to late culture stages to minimize the negative impacts of harmful algae on shrimp growth.

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References

Allan G. L., Maguire G. B., Hopkins S. J., 1990 Acute and chronic toxicity of ammonia to juvenile *Metapenaeus macleayi* and *Penaeus monodon* and the influence of low dissolved-oxygen levels. Aquaculture 91(3):265–280.

Amirtharaj K. S. V., 2019 Evolving suitable technology for periphyton-based inland farming of Pacific white shrimp (*Penaeus vannamei*) in low-saline ground water. PhD Thesis, Fisheries College and Research Institute, India. 213 pp.

Amirtharaj K. S. V., Oli G. A., 2017 Farm-level feeding and production response of Pacific white shrimp (*Penaeus vannamei*) in periphyton-based farming system. SKUAST Journal of Research 19(1):53–59.

An T. N., 1993 [Classification of marine planktonic diatoms of Vietnam]. Science and Technology Publishing House, Hanoi. 315 pp. [in Vietnamese]

Anix A., Santhiya V., Athithan S., Ahilan B., 2020 Comparison of periphyton biomass on coconut coir and bamboo poles as natural substrates in earthen lined pond. International Journal of Bio-Resource and Stress Management 11(5):494–500.

Arfiati D., Zakiyah U., Anitasari S., Inayah Z. N., Pratiwi R. K., 2023 Community structure of periphyton on bamboo substrate in white-leg shrimp (*Litopenaeus vannamei* Boone, 1931) pond with semi-biofloc system. Biodiversitas Journal of Biological Diversity 24(9):5080-5087.

Ariadi H., Fadjar M., Mahmudi M., Suprianta, 2019 The relationships between water quality parameters and the growth rate of white shrimp (*Litopenaeus vannamei*) in intensive ponds. AACL Bioflux 12(6):2103-2116.

Avnimelech Y., Kochba M., 2009 Evaluation of nitrogen uptake and excretion by tilapia in biofloc tanks, using 15N tracing. Aquaculture 287(1-2):163–168.

Biswas G., Kumar P., Ghoshal T. K., Das S., De D., Bera A., Anand P. S., Kailasam M., 2022 Periphyton: a natural fish food item for replacement of feed at optimized substrate surface area for cost-effective production in brackishwater polyculture. Aquaculture 561:738672.

Boyd C. E., Tucker C. S., 1992 Water quality and pond soil analyses for aquaculture. Agricultural Experiment Station, Auburn University, Alabama. 183 pp.

Boyd C. E., Tucker C. S., 1998 Water quality and aquaculture: preliminary considerations. In: Boyd C. E., Tucker C. S. (eds), Pond Aquaculture Water Quality Management. Springer, Boston, MA. 1–7 pp.

Bradac P., Navarro E., Odzak N., Behra R., Sigg L., 2009 Kinetics of cadmium accumulation in periphyton under freshwater conditions. Environmental Toxicology and Chemistry 28(2):2108–2116.

Carmelo R. J., Hasle G. R., Syvertsen E. E., Steidinger K. A., Tangen K., 1996 Identifying marine diatoms and dinoflagellates. Academic Press, Inc., Harcourt Brace and Company. 598 pp.

Ciebiada M., Kubiak K., Daroch M., 2020 Modifying the cyanobacterial metabolism as a key to efficient biopolymer production in photosynthetic microorganisms. International Journal of Molecular Sciences 21(19):7204.

Cremen M. C. M., Martinez-Goss M. R., Corre V. L., Azanza R. V., 2007 Phytoplankton bloom in commercial shrimp ponds using green-water technology. Journal of Applied Phycology 19(6):615–624.

de Oliveira C. S. P., da Silva Fonseca A., de Araújo M. F. F., 2022 Water quality and cyanobacterial blooms in the Piancó-Piranhas-Açu watershed, semi-arid region of Northeastern Brazil: relationships with education toward sustainability. Revista Ibero-Americana de Ciências Ambientais 13(3):339–355.

Delgado J. M. V., Pólit P. A., Panta-Vélez R. P., Rodríguez-Díaz J. M., Dapena J. D., Lozano A. L., Maddela N. R., 2024 Identification and composition of cyanobacteria in Ecuadorian shrimp farming ponds—possible risk to human health. Current Microbiology 81:237.

Fakhri M., Budianto B., Yuniarti A., Hariati A. M., 2015 Variation in water quality at different intensive white-leg shrimp farms in East Java, Indonesia. Nature Environment and Pollution Technology 14(1):65–70.

Fermino F. S., de Campos Bicudo D., Bicudo C., 2011 Seasonal influence of nitrogen and phosphorus enrichment on the floristic composition of the algal periphytic community in a shallow tropical mesotrophic reservoir (São Paulo, Brazil). Oecologia Australis 15(3):476–493.

Ferragut C., de Campos Bicudo D., 2010 Periphytic algal community adaptive strategies in N and P enriched experiments in a tropical oligotrophic reservoir. Hydrobiologia 646:295–309.

Ferragut C., de Campos Bicudo D., 2012 Effect of N and P enrichment on periphytic algal community succession in a tropical oligotrophic reservoir. Limnology 13:131–141.

Flynn K. F., Chapra S. C., Suplee M. W., 2013 Modeling the lateral variation of bottom-attached algae in rivers. Ecological Modelling 267(1):11–25.

Giorgi A., Malacalza L., 2002 Effect of an industrial discharge on water quality and periphyton structure in a pampean stream. Environmental Monitoring and Assessment 75(2):107–119.

Guimarães A. M., Guertler C., do Vale Pereira G., da Rosa Coelho J., Costa Rezende P., Nóbrega R. O., do Nascimento Vieira F., 2021 *Nannochloropsis spp.* as feed additive for the Pacific white shrimp: effect on midgut microbiology, thermal shock resistance and immunology. Animals 11(1):150.

Hood R. D., Higgins S. A., Flamholz A., Nichols R. J., Savage D. F., 2016 The stringent response regulates adaptation to darkness in the cyanobacterium *Synechococcus elongatus*. Proceedings of the National Academy of Sciences 113(33):9122–9127.

Khatoon H., Yusoff F., Banerjee S., Shariff M., Bujang J. S., 2007 Formation of periphyton biofilm and subsequent biofouling on different substrates in nutrient-enriched brackishwater shrimp ponds. Aquaculture 273(4):470–477.

Larned S. T., 2010 A prospectus for periphyton: recent and future ecological research. Journal of the North American Benthological Society 29(1):182–206.

Lien T. K. N., Son N. V., Giang H. T., 2022 Water quality parameters and diatom composition in super-intensive white-leg shrimp (*L. vannamei*) farming ponds. Can Tho University Journal of Sciences 58:69–76.

Lien T. K. N., Tu T. C. P., Son N. V., Giang T. H., 2023 Phytoplankton composition in intensive shrimp ponds in Bac Lieu province, Vietnam. Fisheries and Aquatic Sciences 26(8):470–481.

Lien T. T. N., Son N. H., Quang H. T., Nhan L. T. T., 2018 Isolation and selection of *Skeletonema costatum* strains from the coastal waters of Thua Thien Hue for aquaculture feed. Hue University Journal of Science: Agriculture and Rural Development 127(3B):97–108.

Lin Y.-F., Jing S.-R., Lee D.-Y., Chang Y.-F., Chen Y.-M., Shih K.-C., 2005 Performance of a constructed wetland treating intensive shrimp aquaculture wastewater under high hydraulic loading rate. Environmental Pollution 134(3):411–421.

Lu L., Niu X., Zhang D., Ma J., Zheng X., Xiao H., Huang X., Lin Z., Hu H., 2021 The algicidal efficacy and the mechanism of *Enterobacter sp.* EA-1 on *Oscillatoria* dominating in aquaculture system. Environmental Research 197:111105.

Martínez-Montaño E., Rodríguez-Montes de Oca G. A., Román-Reyes J. C., Pacheco-Marges R., Llanos A., Bañuelos-Vargas I., 2020 Diatomaceous earth application to improve shrimp aquaculture: growth performance and proximate composition of *Penaeus vannamei* juveniles reared in biofloc at two salinities. Latin American Journal of Aquatic Research 48(2):197–206.

Najwa A. B. D., Elexson N., Dalene L., Teng S. T., 2024 *Vibrio* species and Cyanobacteria: understanding their association in local shrimp farm using canonical correspondence analysis. Microbial Ecology 87:51–63.

Ngan T. T. P., Phu Q. T., 2010 [Fluctuations of water quality parameters in intensive tiger shrimp (*Penaeus monodon*) farming ponds in Soc Trang province]. Can Tho University Journal of Sciences 15:179–188. [in Vietnamese]

Pérez-González R., Sòria-Perpinyà X., Soria J., Sendra M. D., Vicente E., 2023 Relationship between cyanobacterial abundance and physicochemical variables in the Ebro Basin reservoirs, Spain. Water 15(14):2538.

Piontek M., Czyżewska W., Mazur-Marzec H., 2023 Effects of harmful cyanobacteria on drinking-water source quality and ecosystems. Toxins 15(12):703.

Ruby P., Ahilan B., Prabu E., 2018 Periphyton-based aquaculture: a review. Journal of Aquaculture in the Tropics 33(1-2):51–64.

Santanumurti B., Khanza S., Abidin Z., Berta P., Hudaidah S., 2022 The performance of microalgae (*Nannochloropsis sp.*, *Tetraselmis sp.* and *Dunaliella sp.*) on white-shrimp (*L. vannamei*) wastewater cultivation media. Journal of Aquaculture and Fish Health 11(1):1–9.

Santhana Kumar V., Pandey P. K., Anand T., Rathi B. G., Kumar S., 2017 Effect of periphyton (Aquamat) on water quality, nitrogen budget, microbial ecology, and growth parameters of *Litopenaeus vannamei* in a semi-intensive culture system. Aquaculture 479:240–249.

Shaari A. L., Surif M., Abd Latiff F., Omar W. M. W., Ahmad M. N., 2011 Monitoring of water quality and microalgae species composition of *Penaeus monodon* ponds in Pulau Pinang, Malaysia. Tropical Life Sciences Research 22(1):51–69.

Shirota A., 1966 The plankton of South Vietnam: freshwater and marine planktons. Oversea Technical Cooperation Agency, Japan. 179 pp.

Soeprapto H., Ariadi H., Badrudin U., 2023 The dynamics of *Chlorella spp.* abundance and its relationship with water quality parameters in intensive shrimp ponds. Biodiversitas Journal of Biological Diversity 24(5):2919-2926.

Son N. V., Nguyen T. T., Phuong T. N., 2014 [Comparison of farming practice and water quality between intensive tiger shrimp (*Penaeus monodon*) and white-leg shrimp (*L. vannamei*) ponds in Soc Trang province]. Can Tho University Journal of Sciences 30:70–78. [in Vietnamese]

Sruthisree C., Nayak H., Gowda G., Kumar B. T. N., 2015 Evaluation of periphyton and biofilm growth on different substrates in shrimp culture pond. Journal of Experimental Zoology India 18(2):625–630.

Stevens Jr S. E., Nierzwicki-Bauer S. A., 1991 The cyanobacteria. In: Stolz JF (ed). Structure of Phototrophic Prokaryotes. CRC Press, Boca Raton, Florida. 15–47 pp.

Stevenson R. J., Bahls L. L., 1999 Periphyton protocols. In: Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Vol. 6, Chapter 6. U.S. EPA, Washington D.C. 344 pp.

Tien D. D., 1996 [Taxonomy of Cyanobacteria of Vietnam]. Agriculture Publishing House, Hanoi. 219 pp. [in Vietnamese]

Tien D. D., Hanh V., 1997 [Identification of the order Chlorococcales]. Agriculture Publishing House, Hanoi. 503 pp. [in Vietnamese]

Trang T. D. N., Duy D. T., Toan P. T., Thanh N. H., San N. T., Nam T. S., 2022 [Water quality and effluent discharge from intensive white-leg shrimp (*L. vannamei*) farming ponds in Soc Trang province]. Can Tho University Journal of Sciences 58:213–225. [in Vietnamese]

Trung D. N., 2004 [Water quality management on aquaculture]. Agriculture Publishing House, Ho Chi Minh City. 157 pp. [in Vietnamese]

Vadeboncoeur Y., Steinman A. D., 2002 Periphyton function in lake ecosystems. The Scientific World Journal 2:1449–1468.

Ward H. B., Whipple G. C., 1918 Fresh-water biology. Harvard University. John Wiley & sons Inc. 1111 pp.

Whitton B. A., Potts M., 2012 Introduction to the cyanobacteria. In: Whitton B. A. (ed.), Ecology of Cyanobacteria II. Springer, Netherlands. 1–13 pp.

Wilkinson J. L., Hooda P. S., Barker J., Barton S., Swinden J., 2016 Ecotoxic pharmaceuticals, personal care products, and other emerging contaminants: a review of environmental risk assessment challenges and potential future research. Critical Reviews in Environmental Science and Technology 46(4):336-381.

Yusoff F. M., Zubaidah M. S., Matias H. B., Kwan T. S., 2002 Phytoplankton succession in intensive marine shrimp culture ponds treated with a commercial bacterial product. Aquaculture Research 33(4):269–278.

Zhang W., Liu J., Xiao Y., Zhang Y., Yu Y., Zheng Z., Liu Y., Li Q., 2022 The impact of cyanobacteria blooms on the aquatic environment and human health. Toxins 14(10):658.

*** American Public Health Association (APHA), 2017 Standard methods for the examination of water and wastewater, 23rd edition. American Public Health Association, Washington D.C. 26 pp.

*** Ministry of Science and Technology (MST), 2023 [National technical regulation No. TCVN 13656:2023 date on January 01, 2023. Water for aquaculture, Water quality for intensive culture of black tiger shrimp, whiteleg shrimp]. 11 pp. [in Vietnamese]

*** World Register of Marine Species (WoRMS), 2026 *Litopenaeus vannamei* (Boone, 1931). Accessed on. 12 June 2026. Available at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=247789

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