CTU Journal of Innovation and Sustainable Development
ISSN 2588-1418 | e-ISSN 2815-6412

DOI:10.22144/ctujoisd.2026.008

Diversity of phytoplankton species in aquaculture ponds of Dak Ha, Sa Thay, Kon Plong districts, Quang Ngai province

Pham Thi Tam[1*], Le Tri Khai[1], Doan Van Quang[1], Dang Thi Thuy[1], Le Thi Thom[2], Ngo Thi Hoai Thu[2], Nguyen Cam Ha[2], Le Anh Huy[2], Nguyen Manh Dat[2], Nguyen Thuy Lien[2], and Dang Diem Hong[2*]

[1]*Faculty of Economics and Agriculture-Forestry, Kon Tum College, Viet Nam*
[2]*Institute of Biology, Vietnam Academy of Science and Technology, Viet Nam*
**Corresponding author (phamthitamkt2@gmail.com, ddhong60vn@yahoo.com)*

Article info.

Received 06 Feb 2025
Revised 20 Mar 2025
Accepted 02 Oct 2025

Keywords

Aquaculture, biodiversity, diversity of phytoplankton species, Quang Ngai province, similarity coefficient

ABSTRACT

This paper studied the diversity of phytoplankton species at 9 sampling points of aquaculture ponds in Dak Ha, Sa Thay and Kon Plong districts, Kon Tum province (now Quang Ngai province) in 2022–2023. The results recorded 7 phyla, 98 genera, and 142 species, of which 22 genera and 23 species of phytoplankton were present in all 3 sampling periods. The values of the biodiversity index (H') and the diversity value index (Dv) at 9 sampling points ranged from 2.51–3.66 and 2.39–3.58, indicating that the diversity of phytoplankton in aquaculture ponds is high and very high, respectively. The regulation index (J) ranged from 0.95 to 0.99, indicating that phytoplankton species were evenly distributed at all studied sampling points. The similarity coefficient of species composition of phytoplankton populations at 9 sampling points ranged from 0.43 - 0.85. In water samples collected at 9 study locations, the number of phytoplankton species was negatively correlated with impedance. In particular, at the sampling locations, the main environmental factors such as suspended solids, salinity, and conductivity affecting the cell density of phytoplankton communities had a positive correlation and a negative correlation with impedance.

1. INTRODUCTION

Phytoplankton (microalgae) is a very important producer in aquatic ecosystems because it is the first link in the marine food web. Microalgae are rich in nutrients such as proteins, lipids, and carbohydrates, and also in macro- and micronutrients, pigments, and biologically active substances (Hong, 2019; Tan et al., 2020). In addition, microalgae have a high growth rate, play a key role in the production of primary materials for aquatic ecosystems, have a much higher photosynthetic efficiency than terrestrial plants, a short generation doubling time of only about 8 - 24 hours, the ability to be cultivated on an industrial and semi-industrial scale, a suitable cell size that fits the mouth of larvae of shrimp, crabs, fish, mollusk, and have low toxicity (Hong, 2019). In aquatic ecosystems, microalgae also play an important role in stabilizing the water quality of freshwater, brackish, and saltwater ecosystems. Therefore, for a long time, microalgae have been utilized as live and fresh feedstock for aquaculture species in the world in general and in Vietnam in particular (Hong, 2019).

The composition, abundance and diversity of phytoplankton species are important indicators of water quality in the aquatic ecosystems. Certain phytoplankton species and their population characteristics can serve as bioindicators to assess

overall ecosystem health or detect changes in water quality caused by human activities (Zhang et al., 2021).

In addition, microalgae cells have the ability to absorb nutrients such as nitrogen and phosphorus as well as selectively consume different heavy metals depending on different species specifications. Besides beneficial nutrient-rich microalgae species, there are also harmful algae blooms that grow excessively, causing water discoloration, polluting the aquatic environment and, in some cases, producing toxins that have negative effects on humans and animals if too much is ingested. As algal cells die, toxins tend to be released into the surrounding water (Wan et al., 2020; Luu et al., 2020), and monitoring measures are required to reduce the negative socio-economic impacts (Hu & Rzymski, 2019).

Tuyen (1979) published on Northern Vietnam's freshwater algae with 979 species and subspecies, including 136 species of euglenophyta; 18 of cyanobacteria; 288 of green algae; 10 of dinophyta; and 260 of diatom, of which 766 were novel species from Viet Nam. Tien (1982) demonstrated 1,402 species and sub-species of microalgae in inland waterbodies in Viet Nam including 530 species of green algae, 388 species of diatoms, 344 species of cyanobacteria, 78 species of euglenophyta, 30 species of dinophyta, 14 species of golden algae, 9 species of charophyta, 5 species of dinoflagellates, and 4 species of red algae. San (2000) published on the addition of 16 novel species of Vietnamese microalgae. 205 cyanobacterial taxonomic groups from different regions of Vietnam have been recorded by Tien (1996). The quantity, species composition, and ecological indicators related to phytoplankton diversity in Easoup, Eanhai, and Dak Minh lakes in Dak Lak province were reported by Thuong (2010). In Ea Nhai and Buon Phong lakes, Dak Lak province, a list of 34 cyanobacteria species belonging to 14 genera, 6 families and 3 orders (Chroococcales, Oscillatoriales and Noctoscales) and producing cylindrospermopsin toxin (CYN) was determined. The main environmental factors ($P\text{-}PO_4^{3-}$, $N\text{-}NH_4^+$, TP, TN and temperature) affecting the population fluctuations of CYN-producing cyanobacteria species were also determined (My, 2022).

Shannon - Weiner index (Shannon & Weiner, 1949) is a commonly used diversity index, including both the richness and balance of species present in a community. The diversity index is widely used to compare diversity between various habitats. The higher the diversity index, the more complex the community structure, the more stable it is, and the stronger its ability to tolerate environmental pressures. In addition, the phytoplankton community diversity was shown through the diversity value index (Dv) and the regulation index (J) (Lien, 2017; Pielou, 1966). This is an essential research method for building a database on conservation solutions, policymaking, and the sustainable use of biodiversity resources.

Currently, in Quang Ngai province, using freshwater phytoplankton for post-aquaculture wastewater treatment has not been studied, the problem of water pollution is becoming more alarming, affecting the productivity of cultured objects. This was due to activities of freshwater aquaculture and seafood processing, which have released waste sources containing toxic components that caused environmental contamination, such as decomposition of excess sludge, chemical disinfectants commonly used in aquaculture and excess antibiotics in aquaculture wastewater. In addition, research on the potential of nutrient-rich freshwater phytoplankton as live feed for aquaculture species and for wastewater treatment in Quang Ngai province has not yet received much attention. Monitoring the changes in phytoplankton populations in aquaculture ponds and what environmental factors affect these populations was considered a scientific issues that need to be addressed in all aquaculture areas in the country, including Quang Ngai province. In this report, we presented the initial results of the survey on the diversity of phytoplankton species in freshwater aquaculture ponds of Dak Ha, Sa Thay and Kon Plong districts, Quang Ngai province in 2022 – 2023.

This study aimed to investigate the dynamics of phytoplankton communities in aquaculture ponds and to identify key aquatic environmental factors influencing these communities. The findings aim to provide a scientific foundation for the effective application of native phytoplankton in post-aquaculture wastewater treatment, ensuring high efficiency, environmental friendliness, and the absence of secondary pollution.

2. MATERIALS AND METHOD

2.1. Research subjects

Water samples of 9 aquaculture ponds in Dak Ha, Sa Thay, and Kon Plong districts, Quang Ngai

province, were collected in 3 periods: Period 1 (from November 15th - 18th, 2022); Period 2 (from January 5th - 7th, 2023); Period 3 (from October 28th - 30th, 2023).

2.2. Research scope

Water samples were collected from aquaculture ponds at 9 different locations in Quang Ngai province (Figure 1).

Figure 1. Locations of different sampling points in Quang Ngai province

Note: Point 1 (Đ1): Red tilapia pond, Village 1, Dak Ma commune, Dak Ha district; (Coordinates: 14º32'28''N, 107º55'38''E); Point 2 (Đ2): Black carp pond, Residential Group 3, Dak Ha town, Dak Ha district (14º30'35''N, 107º54'44''E). Point 3 (Đ3): Giant freshwater prawn pond of Mr. Duong Trong Quy, Residential Group 10, Dak Ha town, Dak Ha district (14º30'35''N, 107º54'44''E); Point 4 (Đ4): Goby pond of Mr. Nhu Song Hau, Residential Group 10, Dak Ha Town (14º31'19''N, 107º55'58''E); Point 5 (Đ5): Grass carp pond of Mr. Ta Van Vien, Village 4, Sa Thay Town (14º31'19''N, 107º55'58''E; Point 6 (Đ6): Uncle Ho' fish pond, Sa Thay district (14º24'32''N, 107º47'32''E); Point 7 (Đ7): Dak Ke Lake, Kon Plong district (14º58'06''N, 108º26'67''E); Point 8 (Đ8): Central Lake, Kon Plong district (14º36'23''N, 107º17'29''E); Point 9 (Đ9): Fish pond, Mang Canh commune, Kong Plong district (14º40'25''N, 108º16'42''E), Quang Ngai province.

2.3. Phytoplankton sampling

Sampling locations were dependent on the natural characteristics of the waterbody (including pond area, depth, flow, and flowing water source into the pond/lake). Plankton samples were collected at 3 locations in 9 ponds/lakes and 3 replicates/1 location. The total of 3 sampling periods has 243 samples. In total, 9 aquaculture ponds were sampled, resulting in 81 qualitative samples to determine phytoplankton species composition, 81 quantitative samples to analyse phytoplankton cell density, and 81 samples for the analysis of hydrochemical factors in the aquaculture water. All samples used for qualitative, quantitative, and environmental factor analyses were collected on the same day at 3 fixed sampling locations in each of the 9 identified aquaculture ponds.

2.4. Field research methods

2.4.1. Sampling for qualitative analysis

Plankton samples were collected using plankton nets with a mesh size of < 25 µm at 3 locations in 9 ponds/lakes raising fish and shrimp in Dak Ha, Sa Thay, Kon Plong districts, Quang Ngai province. The collected algae samples were fixed in formaldehyde solution (final concentration 4% (v/v) (Findlay & Kling, 2001) and stored at 18°C - 25°C until studied at the laboratory of the Faculty of Economics and Agriculture-Forestry, Kon Tum College, Quang Ngai province.

2.4.2. Sampling for quantitative analysis

Water samples (depth 0 - 2 m) were collected with a tool attached to the Luppe device, 2 m long and 10 cm in diameter, at the sampling locations. The samples were mixed well in a bucket. One liter of water was taken out and fixed with 1% Lugol acid solution, settled for 48 hours, and the supernatant was siphoned off until 100 mL remained. 1 mL aliquot was transferred into the Sedgewick-Rafter chamber (PYSER-SGI-Anh, model S52) (Findlay & Kling, 2001) for cell density counting.

2.4.3. Determination of environmental parameters

Water temperature, salinity, pH, and DO parameters were measured directly at the sampling sites using a Starter 400 series multi-function meter (Ohaus - Shanghai, China), a DO210 meter (Extech instruments - Taiwan) and light intensity was measured using an EA430 meter (Extech instruments - Taiwan). Measurements were taken at three locations per pond, with three repetitions at each location.

2.5. Laboratory research method

2.5.1. Qualitative analysis of phytoplankton community

Cell morphology of algae species in the collected water samples was recorded using Olympus CX21 microscope (OLYMPUS, Japan) under 100 X and 400 X magnification. By morphological

comparative method based on body shape (single cell, colony or filamentous), cell shape and filament structure (especially the shape of the tip or base of the phytoplankton filament), sheath surrounding the filament, the branching of the filament or the position, the number of heteromorphic cells on the algal filament were used for the scientific name identification of cyanobacteria (Tien, 1996; Komárek et al., 2014, Komárek & Johansen, 2015; My, 2022). Identification of diatom species was based on the main taxonomic keys of Kulikovskiy et al. (2016), Genkal et al. (2020), Zabelina et al. (1951), referring to the document of Shirota (1966). The list of diatoms was systematically arranged on the AlgaeBase (Guiry & Guiry, 2022). Preliminary identification of other phytoplankton species was carried out using the methods published in Shirota (1966), Kokubo (1960), Hanh et al. (2022, 2023), based on comparison of cell morphology and species images of phytoplankton species of UTEX (https://utex.org/) and NIES (https://mcc.nies.go.jp/); Algaebase (https://algaebase.org/search/species). Nomenclature and taxonomy were updated according to Guiry and Guiry (2022).

2.5.2. Quantitative analysis of phytoplankton community

The quantitative analysis was determined using a Sedgewick-Rafter chamber: Cell density was determined as described by Karlson et al. (2010). The cell number of phytoplankton was counted under a light microscope (Olympus CX21 [OLYMPUS, Japan] at 100X, 200X and 400X magnification) using a Sedgewick-Rafter counting chamber. Specific counting method: For filamentous cyanobacteria, 30 filaments were counted on a glass slide at 400X magnification. Then, the average cell number per filament was calculated. Next, the average cell per square was calculated based on the average value of the number of filaments, which was counted using a Sedgewick-Rafter chamber. Then, filament number was counted at 100X magnification in 100 small squares (4 corners and the centre of the counting chamber). The procedure was repeated three times, and the final result was the average of these three counts (My, 2022). For the colony form (e.g. *Microcystis*): the water sample was sonicated briefly for 1-3 minutes to separate the cells in the colony into single cells before being placed in the chamber for counting cell density. Depending on the phytoplankton cell density, the sample may be diluted or concentrated (10-20 times) and mixed thoroughly before being placed in the counting chamber. The sample was settled for 60 minutes before counting the cell density using a microscope at 100X magnification. Cells were counted from 50 random squares in the counting chamber.

$$Cell\ density\ \left(\frac{cell}{mL}\right) = \frac{C.1000V1}{V2}$$

In which: C: Average cell number counted in 1 square (average of 3 count times); V1: Volume after siphoning (mL); V2: Initial sample volume (mL).

2.5.3. Data processing method

Determination of biodiversity indices: Diversity indices such as total number of genera (S), biodiversity index (H'), maximum diversity index (H'max), regulation index (J), diversity value index (Dv) were calculated according to the publication of Otero et al. (2020) using Past4.03 software. Species biodiversity index (H'): H'= - ΣP.LnP; in which, P = n/N (where n is the number of individuals in each genus, N is the total number of individuals of all genera). Maximum diversity index (H'max): H'max = Ln(S); Regulation index (J): $J = \frac{H'}{H'max}$; Diversity value index (Dv): Dv = H'. J. For qualitative data analysis data of phytoplankton, Microsoft Office software was used as a tool. Mapinfo 15.0 software was used to export the coordinates of the sampling points to Google Earth. Similarity index Sorensen (S) was calculated according to the formula:

$$S = \frac{2c}{(a + b)}$$

In which: a is the total number of species found at point A; b is the total number of species found at point B; c is the total number of common species found at both points A and B. The value of S ranges from 0 to 1. The closer the S value is to 1, the higher the similarity level will be, meaning that the larger the S value, the more similar the species composition between the two study areas.

Analysing the correlation between phytoplankton communities, their density, and environmental parameters: To analyse the correlation between phytoplankton communities and environmental parameters, the Pearson correlation coefficient was determined using SPSS ver.16 and Past4.03 software according to the publication of Lan et al. (2021).

2.6. Statistical analysis

Experimental data were processed using Excel software and statistically processed by one-way

ANOVA at a significance level of $p \leq 0.05$. Biodiversity indices were calculated using Primer 7.0 software (Primer-E Ltd, Plymouth UK). Analyze the correlation between phytoplankton community and environmental parameters, Pearson correlation coefficient was determined using SPSS ver.16 and Past4.03 software. The similarity coefficient of species composition and phylogenetic tree construction among 9 phytoplankton communities was analyzed using NTSYSpc 2.02 on a computer program.

3. RESULTS AND DISCUSSION

3.1. Analysis of composition and diversity of phytoplankton species

Through analysis of water samples collected from 3 sampling periods in 2022 − 2023 (Table 1), it was found that the composition of classes, orders, and families was different at 9 sampling points. The results (Table A1 of the supplementary file, Table 1) recorded 7 phyla, 98 genera, and 142 species, of which 22 genera and 23 species of phytoplankton appeared in all 3 sampling periods in 2022 − 2023. Of which, the first period had 6 phyla, 12 classes, 30 orders, 43 families, 61 genera, and 87 species; the second period had 7 phyla, 12 classes, 21 orders, 31 families, 49 genera, and 55 species; the third period had 6 phyla, 13 classes, 24 orders, 38 families, 59 genera, and 71 different phytoplankton species.

The research results in Table 2 showed that the diversity and even distribution of phytoplankton in aquaculture water samples collected at 9 different locations in Quang Ngai in 2022 − 2023 were demonstrated via the diversity index (H'), ranging from 2.51 to 3.66, with the average value of 9 sampling locations being 3.15 ± 0.44. According to the study of Lien (2017), water quality was divided into 5 diversity level based on H' values: H' > 4.5 showed that phytoplankton has a very high diversity; 3 ≤ H' ≤ 4.5 - high diversity of phytoplankton; 2<H'<3 - medium diversity of phytoplankton, 1<H'<2 - low diversity of phytoplankton and H'<1 - very low diversity of phytoplankton. An H' index value of 3.15 ± 0.44 indicated that the phytoplankton community in water samples collected from 9 aquaculture ponds in Quang Ngai province in 2022 − 2023 had high diversity. In addition, the diversity of the phytoplankton community was also shown through the diversity value index (Dv) with the diversity assessment levels as following: Dv value < 0.6, the phytoplankton community has low diversity; DV value from 0.6 to 1.5: the phytoplankton community has average diversity; Dv value from 1.6 to 2.5: the phytoplankton community has relatively rich diversity; Dv value: 2.6 - 3.5: the phytoplankton community was rich; and when Dv value > 3.5: the phytoplankton community has very rich diversity (Lien, 2017). The research results in Table 2 showed that point Đ6, with a Dv value, exhibited a very rich phytoplankton community in the water sample, while points Đ1, Đ2, Đ3, Đ5, Đ7, and Đ9 also exhibited rich phytoplankton communities. Meanwhile, the phytoplankton community at Đ4 and Đ8 had an average diversity. According to Pielou (1966), the regulation index (J) was always between 0 and 1. When the J value was closer to 1, the sample was evenly distributed. The J of water samples collected from 9 aquaculture ponds in Quang Ngai province ranged from 0.95 to 0.99, indicating that the recorded phytoplankton species were evenly distributed at the sampling points and that the average total number of genera was 26.89 ± 10.56.

Table 1. Composition of phytoplankton phyla in post-aquaculture water samples of 9 sampling points

No	Phylum	Period 1				Period 2				Period 3			
		C	O	F	G	C	O	F	G	C	O	F	G
1	Chlorophyta	3	4	12	21	2	5	13	23	2	4	16	29
2	Euglenophyta	1	1	2	3	1	1	1	3	1	1	2	2
3	Cyanobacteria	1	6	7	11	1	3	3	4	1	4	4	6
4	Heterokontophyta	5	10	10	12	5	7	7	7	7	11	11	11
5	Dinoflagellata	1	8	11	12	1	3	5	5	1	3	4	4
6	Charophyta	1	1	1	2	1	1	1	6	1	1	1	2
7	Ciliophora	0	0	0	0	1	1	1	1	0	0	0	0
	Total	12	30	43	61	13	21	31	49	13	24	38	59

Notices: C: Class; O: Order; F: Family; G: Genus

Table 2. Diversity index of phytoplankton communities in water samples of 9 sampling points

Sampling point	Diversity index (H')	Total number of genus (S)	Maximum diversity (H'max)	Regulation index (J)	Diversity value index (Dv)
Đ1	3.35	31.00	3.43	0.98	3.27
Đ2	3.47	36.00	3.58	0.97	3.37
Đ3	3.52	35.00	3.56	0.99	3.48
Đ4	2.51	14.00	2.64	0.95	2.39
Đ5	3.42	32.00	3.47	0.99	3.38
Đ6	3.66	42.00	3.74	0.98	3.58
Đ7	2.86	18.00	2.89	0.99	2.82
Đ8	2.51	13.00	2.56	0.98	2.46
Đ9	3.02	21.00	3.04	0.99	2.99
Average value	3.15 ± 0.44	26.89 ± 10.56	3.21 ± 0.44	0.98 ± 0.01	3.08 ± 0.44

Note: Đ1: Red tilapia pond, Village 1, Dak Ma commune, Dak Ha district; Đ2: Black carp pond, Residential Group 3, Dak Ha town, Dak Ha district. Đ3: Giant freshwater prawn pond of Mr. Duong Trong Quy, Residential Group 10, Dak Ha town, Dak Ha district; Đ4: Goby pond of Mr. Nhu Song Hau, Residential Group 10, Dak Ha town; Đ5: Grass carp pond of Mr. Ta Van Vien, Village 4, Sa Thay town; Đ6: Uncle Ho's fish pond, Sa Thay district; Đ7: Dak Ke lake, Kon Plong district; Đ8: Central lake, Kon Plong district; Đ9: Fish pond, Mang Canh commune, Kon Plong district.

3.2. Analysis of dominance and phytoplankton community diversity

The similarity index was the similarity in species composition (% common species) between sampling points (% common species at the same sampling locations), with a value range from 0-1 (Sorensen, 1948). The higher the similarity index (closer to 1), the closer the relationship between species composition in the phytoplankton community, meaning that the diversity of phytoplankton species composition between survey points is low and vice versa. The results on the similarity index of phytoplankton species composition in water samples from post-aquaculture sites at 9 sampling points in Quang Ngai province in 2022 − 2023 were presented in Table 3 and Figure 2.

Table 3. Similarity index of phytoplankton species composition in water samples of 9 sampling points

Row/Column	Đ1	Đ2	Đ3	Đ4	Đ5	Đ6	Đ7	Đ8	Đ9
Đ1	1,00000	21	17	8	10	14	9	6	7
Đ2	0,43284	1,00000	23	10	13	16	12	6	13
Đ3	0,51515	0,49296	1,00000	12	13	14	11	8	6
Đ4	0,73333	0,64000	0,59184	1,00000	6	5	3	2	2
Đ5	0,61905	0,55882	0,58209	0,69565	1,00000	16	7	7	12
Đ6	0,58904	0,64103	0,58442	0,75000	0,56757	1,00000	8	8	11
Đ7	0,59184	0,55556	0,58491	0,75000	0,64000	0,76667	1,00000	5	5
Đ8	0,72727	0,75510	0,70833	0,85185	0,68889	0,74545	0,61290	1,00000	6
Đ9	0,65385	0,75439	0,71429	0,82857	0,54717	0,65079	0,64103	0,52941	1,00000

Note: Đ1: Red tilapia pond, Village 1, Dak Ma commune, Dak Ha district; Đ2: Black carp pond, Residential Group 3, Dak Ha town, Dak Ha district. Đ3: Giant freshwater prawn pond of Mr. Duong Trong Quy, Residential Group 10, Dak Ha town, Dak Ha district; Đ4: Goby pond of Mr. Nhu Song Hau, Residential Group 10, Dak Ha town; Đ5: Grass carp pond of Mr. Ta Van Vien, Village 4, Sa Thay town; Đ6: Uncle Ho's fish pond, Sa Thay district; Đ7: Dak Ke lake, Kon Plong district; Đ8: Central lake, Kon Plong district; Đ9: Fish pond, Mang Canh commune, Kon Plong district.

The research results in Table 3 and Figure 2 showed that the similarity index of species composition of the phytoplankton community at 9 sampling points of Quang Ngai province in 2022 − 2023 ranged between 0.43-0.85. The tree diagram of the similarity of community at 9 survey points of Quang Ngai province (at 3 sampling periods, 2022 − 2023) showed that the correlation of the phytoplankton community of 9 sampling points was divided into 3 branches. The first branch included points Đ4, Đ8, and Đ9, with a similarity index ranging from 0.82 to 0.85, indicating that the species composition of the phytoplankton community was similar among these 3 sampling points. The second sub-branch included Đ6 and Đ7 with a similarity index of 0.76. The third sub-branch, including Đ1, Đ2, Đ3 and Đ5, has a similarity index of 0.43-0.61, and was separated into a separate sub-branch. Thus, the analysis of the

similarity in the phytoplankton species composition at the 9 sampling points showed that there were differences in the species composition of phytoplankton between the 9 sampling points. Specifically, point Đ4 had the most similarity in phytoplankton species composition compared with Đ8, Đ9; followed by Đ6 and Đ7, and finally Đ2, which had a similarity in phytoplankton species composition compared with Đ1, Đ5 and Đ3 points.

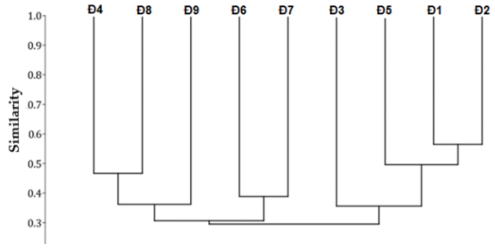

Figure 2. Tree diagram of similarity in phytoplankton community in 9 survey sites

The results obtained on species composition similarity across different sampling points. In which, point Đ4 have similarity to points Đ8, Đ9, Đ6 and Đ7 (natural lakes) and points Đ1, Đ2, Đ3 and Đ5 have similarity. This is due to the following factors: the data were collected at different locations, different conditions, in which points Đ1 - Đ5 are fish ponds of households belonging to Dak Ha and Sa Thay districts, and points Đ6 - Đ9 are natural lakes (Figure 1). Point Đ4 is a goby pond with the characteristic as continuous flow of water source in and out. Therefore, the water quality of the pond is relatively high and the phytoplankton system in point Đ4 is similar to points Đ8, Đ9, Đ6 and Đ7 (natural lakes). The points Đ1, Đ2, Đ3, and Đ5 share a similar species composition.

Based on the recorded results, the correlation between species composition, cell density of phytoplankton, and environmental parameters (Table A2, A3 - supplementary file) in water samples of post- aquaculture of 9 sampling points in Quang Ngai province in 2022 − 2023 was determined. The results in Table 4 showed that, when analysing the correlation between species composition and cell density with environmental parameters, different sampling points were influenced by different environmental factors. Specifically, at points Đ1 and Đ2, the species composition showed a negative correlation with light intensity (r^2 = -1.000, sig = 0.019) and DO (r^2 = -1.000, sig = 0.020), respectively. At points Đ5 and Đ7, species composition showed positive correlations with pH (r^2 = 1.000, sig = 0.004) and salinity (r^2 = 0.996, sig = 0.058), respectively. At point Đ6, cell density showed a positive correlation with electrical resistance (r^2 = 0.996, sig = 0.059). At point Đ4, the species composition showed a negative correlation with pH (r^2 = -0.996, sig = 0.054), electrical conductivity (r^2 = -0.998, sig = 0.043), and total dissolved solids (r^2 = -0.997, sig = 0.053), and a positive correlation with temperature (r^2 = 0.996, sig = 0.056). At points Đ3, Đ8, and Đ9, species composition and cell density were less influenced by environmental factors. My (2022) reported that in Ea Nhai Lake, the distribution and species composition of phytoplankton exhibited clear seasonal patterns, closely associated with hydrophysical factors such as pH, temperature, and water transparency, as well as hydrochemical parameters including silica (Si), dissolved oxygen (DO), ammonium ($N\text{-}NH_4^+$), nitrate ($N\text{-}NO_3^-$), orthophosphate ($P\text{-}PO_4^{3-}$), and total phosphorus. These factors significantly influenced phytoplankton community structure during the rainy season. Similarly, studies conducted in Dak Minh and Ea Suop lakes revealed a strong correlation between environmental variables and phytoplankton species composition during specific months (Le Thuong, 2010).

When analyzing the overall correlation of environmental factors on species composition and cell density at the 9 sampling points (Table 4), it shows that the number of phytoplankton species had a negative correlation with the impedance value (r^2 = -0.808, sig = 0.008) of water samples collected at 9 sampling points in Quang Ngai province in 2022 − 2023. Environmental factors had the greatest influence on phytoplankton cell density at 9 sampling points in Quang Ngai province. There were suspended solids (r^2 = 0.753 sig = 0.019), followed by salinity (r^2 = 0.726 sig = 0.027), impedance (r^2 = -0.666 sig = 0.05), and conductivity (r^2 = 0.607 sig = 0.08). The cell density of phytoplankton communities showed positive correlations with suspended solids, salinity, and conductivity, and a negative correlation with the impedance parameter.

Many studies have shown that environmental parameters such as temperature, salinity, TSS, pH, and nutrient content play an important role in shaping phytoplankton community structure (Ian & David, 2009; Rajkumar et al., 2009; Arumugam et al., 2016). The obtained results in this report has also been recorded similarity in phytoplankton communities in the Ba Lai River area, Ben Tre province (Luu, 2020; My, 2022).

Table 4. Correlation between species composition and cell density of phytoplankton communities with environmental parameters

Environmental parameters		pH	Temperature (°C)	Conductivity (µS/cm)	Resistance (KΩ.cm)	Salinity (‰)	Suspended solid (TSS) (mg/L)	Light intensity (klux)	DO (mg/L)
Đ1	Species composition	**-0.982**	0.262	-0.890	-0.858	0.990	0.969	**-1.000***	0.360
	Sig.	0.121	0.831	0.301	0.343	0.089	0.158	**0.019**	0.765
	Cell density	0.666	-0.794	0.431	0.994	-0.702	-0.621	0.777	0.280
	Sig.	0.536	0.416	0.716	0.072	0.504	0.573	0.434	0.820
Đ2	Species composition	-0.948	0.995	-0.799	0.573	-0.500	-0.288	-0.892	**-1.000**
	Sig.	0.206	0.063	0.411	0.612	0.667	0.814	0.298	**0.020**
	Cell density	0.057	-0.279	-0.261	0.548	-0.618	-0.782	0.752	0.401
	Sig.	0.963	0.82	0.832	0.631	0.576	0.429	0.459	0.737
Đ3	Species composition	0.319	0.969	-0.203	0.796	-0.197	-0.211	0.602	-0.981
	Sig.	0.794	0.158	0.870	0.414	0.874	0.864	0.588	0.123
	Cell density	0.686	0.778	0.225	0.470	0.231	0.216	0.881	-0.972
	Sig.	0.519	0.433	0.856	0.689	0.852	0.861	0.314	0.151
Đ4	Species composition	**-0.996***	**0.996***	**-.998***	-0.726	-0.240	**-0.997***	0.993	-0.916
	Sig.	**0.054**	**0.056**	**0.043**	0.483	0.846	**0.053**	0.075	0.263
	Cell density	-0.835	0.729	-0.826	-0.145	-0.789	-0.834	0.853	-0.471
	Sig.	0.371	0.480	0.382	0.907	0.421	0.372	0.349	0.688
Đ5	Species composition	**1.000****	-0.355	0.636	-0.825	0.866	0.673	0.943	0.425
	Sig.	**0.004**	0.769	0.561	0.383	0.333	0.530	0.215	0.721
	Cell density	-0.049	-0.918	0.743	-0.529	0.462	0.710	-0.373	0.886
	Sig.	0.969	0.259	0.467	0.645	0.694	0.497	0.757	0.307
Đ6	Species composition	0.955	-0.693	0.860	0.386	-0.500	0.877	0.642	0.858
	Sig.	0.193	0.513	0.341	0.747	0.667	0.319	0.556	0.343
	Cell density	0.185	-0.962	-0.047	**0.996***	0.530	-0.013	-0.376	0.856
	Sig.	0.882	0.176	0.970	**0.059**	0.644	0.992	0.755	0.346
Đ7	Species composition	-0.719	-0.507	-0.764	-0.777	**0.996***	0.506	-0.219	-0.821
	Sig.	0.489	0.661	0.447	0.434	**0.058**	0.662	0.860	0.387
	Cell density	-0.337	-0.577	-0.275	0.894	-0.492	-0.994	-0.800	0.858
	Sig.	0.781	0.608	0.823	0.296	0.672	0.068	0.410	0.344
Đ8	Species composition	-0.951	0.597	0.625	-0.742	0.991	0.656	-0.665	-0.802
	Sig.	0.201	0.593	0.570	0.467	0.084	0.545	0.537	0.407
	Cell density	-0.083	-0.918	-0.904	0.823	-0.357	-0.886	-0.573	0.766
	Sig.	0.947	0.259	0.282	0.385	0.768	0.307	0.611	0.445
Đ9	Species composition	0.771	0.525	-0.505	-0.510	-0.115	-0.585	-0.013	-0.400
	Sig.	0.439	0.648	0.663	0.659	0.927	0.602	0.992	0.738
	Cell density	-0.256	-0.922	0.913	0.916	-0.486	0.948	-0.572	0.859
	Sig.	0.835	0.253	0.267	0.263	0.677	0.206	0.613	0.342
General correlation on sampling points	Species composition	0.065	0.645	0.438	**-0.808**	0.504	0.540	-0.306	-0.537
	Sig.	0.867	0.061	0.238	**0.008**	0.166	0.133	0.423	0.136
	Cell density	0.447	0.556	0.607	**-0.666**	**0.726**	**0.753**	0.171	-0.237
	Sig.	0.227	0.120	0.083	**0.050**	**0.027**	**0.019**	0.660	0.539

4. CONCLUSIONS

During the 3 study periods in 2022 − 2023, 7 phyla, 98 genera and 142 species of phytoplankton, of which common 22 genera and 23 species of phytoplankton were recorded in water samples collected in all 9 aquaculture ponds of Kontum province (now Quang Ngai province). The diversity H' index showed that the high diversity in the phytoplankton community of Quang Ngai province was recorded with the average H' value of 3.15 ± 0.44. In particular, point Đ6 exhibited the highest H' and Dv indices (3.66 and 3.58, respectively), indicating that the species composition of the phytoplankton community in its water sample was significantly richer compared to the other sampling points.

Additionally, the regulation index (J) ranges from 0.95 to 0.99, indicating that phytoplankton species were evenly distributed across the water samples at all sampling points.

Phytoplankton species composition showed a notable similarity across the 9 sampling sites in Quang Ngai province during 2022–2023, with similarity indices ranging from 0.43 to 0.85. The number of phytoplankton species in water samples exhibited a negative correlation with impedance values. Among environmental factors, suspended solids, salinity, and conductivity were positively correlated with phytoplankton cell density, while impedance showed a negative correlation.

ACKNOWLEDGMENT

This research is funded by the project "Research on the application of microalgae to treat wastewater environment in freshwater aquaculture in Kon Tum province" managed by the Department of Science and Technology of Kon Tum province (now Quang Ngai province) and implemented by Kon Tum College from June 2022 to June 2024.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

REFERENCES

Arumugam, S., Sigamani, S., Samikannu, M. & Perumal, M. (2016). Assemblages of phytoplankton diversity in different zonation of Muthupet mangroves. *Regional Studies in Marine Science, 3*, 234-241. https://doi.org/10.1016/j.rsma.2015.11.005

Findlay, D. L., & Kling, H. J. (2001). *Protocols for measuring biodiversity: phytoplankton in freshwater.* Winnipeg: Department of Fisheries and Oceans, 9. https://www.researchgate.net/publication/264881321

Genkal, S. I., Kulikovskiy, M. S., & Kuznetsova, I. V. (2020). *Modern freshwater centric diatom algae in Russia*. Filigran', Yaroslavl. https://www.researchgate.net/publication/348352056_The_recent_freshwater_sentric_diatoms_of_Russia (in Russian).

Guiry, M. D., & Guiry, G. M. (2022). *AlgaeBase.* World-wide electronic publication, National University of Ireland, Galway, https://www.algaebase.org/

Hanh, V., Hanh, H. S., Dien, N. D., Vinh, N. L. A., Ha, L. T. T., Chung, M. V., & San, N. D. (2023). *Soil Algae in some provinces of Central Vietnam.* Science and technics publishing house (in Vietnamese).

Hanh, V., San, N. D., Ha, L. T. T., Chung, M. V., Hanh, H. S., & Dien, N. D. (2022). *Phytoplankton in the water bodies of the North Central region.* Science and technics publishing house (in Vietnamese).

Hong, D. D. (Editor) (2019). *The cultivation of microalgae rich in nutrition used for functional food and animal feed in Vietnam.* Monographs; Natural resources and environment of Vietnam; Publisher of Science and Technology (in Vietnamese).

Hu, C., & Rzymski, P. (2019). Programmed cell death-like and accompanying release of microcystin in freshwater bloom-forming cyanobacterium Microcystis: From identification to ecological relevance. *Toxins*, *11*(12), 706. https://doi.org/10.3390/toxins11120706

Ian, M. S., & David, R. (2009). *Plankton: A guide to their ccology and monitoring for water quality.* CSIRO Publishing (Australia).

Karlson, B., Cusack, C., & Bresnan, E. (2010). *Microscopic and molecular methods for quantitative phytoplankton analysis* (IOC Manuals and Guides, no. 55) (IOC/2010/MG/55). UNESCO, Paris.

Kokubo, S. (1960). *Planktonic diatoms*. Shanghai Scientific and Technical House.

Komárek, J., & Johansen, J. R. (2015). *Filamentous cyanobacteria.* Chapter 4. In Freshwater Algae of North America. Academic Press (pp. 135-235). http://dx.doi.org/10.1016/B978-0-12-385876-4.00004-9

Komárek, J., Kaštovský, J., Mareš, J., & Johansen, J. R. (2014). Taxonomic classification of cyanoprokaryotes (cyanobacterial genera) 2014, using a polyphasic approach. *Preslia, 86,* 295-335. https://www.preslia.cz/P144Komarek.pdf

Kulikovskiy, M. S., Glushchenko, A. M., & Skuznetsova, S. I. (2016). *Identification book of diatoms from Russia, Yaroslav*: Filigree (in Russian).

Lan, N. T., Kovyazin, V. F., & Huan, P. T. (2021). Phytoplankton composition of the mangrove ecosystem in Khanh Hoa province, Vietnam. *In IOP Conference Series: Earth and Environmental*

Science, 876, 012061. doi:10.1088/1755-1315/876/1/012061

Lien, N. T. K. (2017). *Research on biological monitoring method in water quality assessment on Hau river using macroinvertebrates.* PhD Thesis in Aquaculture. Can Tho University. Can Tho City (in Vietnamese).

Luu, P. T. (2020). *Toxins and secondary metabolites from cyanobacteria.* Publishing House of natural sciences and technology (in Vietnamese).

My, N. T. D. (2022). *Identification of species composition and the ability to produce cylindrospermopsin toxin of Cyanobacteria in some water bodies in Dak Lak.* PhD thesis in biology. Hue University (in Vietnamese).

Otero, J., Álvarez-Salgado, X. A., & Bode, A. (2020). Phytoplankton Diversity Effect on Ecosystem Functioning in a Coastal Upwelling System. *Frontiers in Marine Science, 7,* 592255. https://doi.org/10.3389/fmars.2020.592255

Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology*, *13*, 131-144. https://doi.org/10.1016/0022-5193(66)90013-0

Rajkumar, M., Perumal, P., Prabu, V. A., Perumal, N. V., & Rajasekar, K. T. (2009). Phytoplankton diversity in pichavaram mangrove waters from south-east coast of India. *Journal of Environmental Biology*, *30*, 489-498. https://jeb.co.in/journal_issues/200907_jul09/paper_04.pdf

San, N. D. (2000). *Microalgae in some polluted water bodies in Thanh Hoa, Nghe An, Ha Tinh provinces and their role in wastewater treatment process* (PhD Thesis in Biology). Vinh University (in Vietnamese).

Shannon, C. E., & Weiner, W. (1949). The Mathe matical Theory of Communication University of Illinois Press. *Urbana, USA.* https://pure.mpg.de/rest/items/item_2383164_3/component/file_2383163/content

Shirota, A. (1966). *The Plankton of South Vietnam. Fresh water and marine plankton.* Colombo Plan Expert on Planktology: Faculty of Science, Saigon Univesity and the Oceanographic Institute of Nha Trang, Viet Nam. Overseas Technical Cooperation Agency, Japan. https://openjicareport.jica.go.jp/pdf/10424372_01.pdf

Sorensen, T. (1948). A method of establishing groups of equal amplitudes in plant sociology based on similarity of species content and its application to analyses of the vegetation on Danish commons. *Kongelige Danske Videnskabernes Selskab, Biologiske Skrifter*, *5*, 1-34.

Tan, J. S., Lee, S. Y., Chew, K. W., Lam, M. K., Lim, J. W., Ho, S. H., & Show, P. L. (2020). A review on microalgae cultivation and harvesting, and their biomass extraction processing using ionic liquids. *Bioengineered*, *11*(1), 116-129. https://doi.org/10.1080/21655979.2020.1711626

Thuong, L. (2010). *Variation in species composition and number of phytoplankton in EaNhai and EaSup reservoirs, Dak Lak province.* PhD thesis in Biology. Institute of Oceanography, Vietnam Academy of Science and Technology. https://luanvan.org/luan-van-su-bien-doi-ve-thanh-phan-loai-va-so-luong-thuc-vat-noi-o-ho-eanhai-va-easup-tinh-daklak-428/ (in Vietnamese).

Tien, D. D. (1982). *Algal flora in freshwater bodies of Vietnam.* PhD thesis in Biology. Academy of Sciences of the USSR (in Vietnamese).

Tien, D. D. (1996). *Taxonomy of Cyanobacteria of Viet Nam.* Agricultural Publishing House. https://lib.husc.edu.vn/Portal/BookDetail?bibid=14725&dbID=-1&display=icon (in Vietnamese).

Tuyen, N. V. (1979). *Data on freshwater in northen Vietnam.* Vietnam National University, Hanoi. https://thongtinkhcn.vinhlong.gov.vn/tailieuso/46184 (in Vietnamese).

Wan, X., Steinman, A. D, Gu, Y., Zhu, G., Shu, X., Xue, Q., ..., & Xie, L. (2020). Occurrence and risk assessment of microcystin and its relationship with environmental factors in lakes of the eastern plain ecoregion, China. *Environmental Science and Pollution Research*, *27*(36), 45095-45107. https://doi.org/10.1007/s11356-020-10384-0

Zabelina, M. M., Kiselev, I. A., Proshkina, A. N., & Sheshukova, V. S. (1951). *Diatoms, Key to identifying freshwater algae (former Soviet Union).* Publishing House "Soviet Science", Moscow (in Russian).

Zhang, Y., Gao, W., Li, Y., Jiang, Y., Chen, X., Yao, Y., Messyasz, B., Yin, K., He, W., & Chen, Y. (2021). Characteristics of the Phytoplankton Community Structure and Water Quality Evaluation in Autumn in the Huaihe River (China). *International Journal of Environmental Research and Public Health*, *18*(22), 12092. https://doi.org/10.3390/ijerph182212092