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A case study of phytoplankton used as a biological index for water quality assessment of Nhu Y river, Thua Thien - Hue

Thi Trang Le[1*], Quang Doc Luong[2], Thi Thu Ha Vo[2] , Van Tu Nguyen[1]

[1]Institute of Tropical Biology, Vietnam Academy of Science and Technology
[2]Department of Biology, Hue University of Sciences

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Abstract:

Studies of the composition and density of phytoplankton and the water quality of Nhu Y river were conducted over six months (March to August 2011). Phytoplankton samples were collected by filtration and immediately preserved in Lugol's solution. The phytoplankton species composition recorded 117 species belonging to six divisions: Cyanobacteria (24 taxa), Bacillariophyta (14 taxa), Chlorophyta (45 taxa), Euglenophyta (31 taxa), Cryptophyta (2 taxa), and Dinophyta (1 taxa), of which Chlorophyta and Euglenophyta were dominant in terms of species numbers. The total phytoplankton density fluctuated from 110,146 to 5,964x10^3 individuals/litre and Cyanophyta were dominant in terms of individual density. The algal genus pollution index (Palmer index) ranged from 30 to 41, indicating that the water was highly organically polluted, and the Shannon-Weiner index results of 0.66-2.92 showed moderately to heavily polluted water. With values for the Diatomeae index of more than 0.2, the quality of the eight sites during the period of the study showed that the aquatic environment was eutrophic. Phytoplankton and their indexes are useful tools for assessing water environment quality.

Keywords: **Nhu Y river, Palmer index, phytoplankton, Shannon-Weiner index, water quality.**

Classification number: **3.4**

Introduction

Phytoplankton are free-floating microscopic organisms with the potential to produce energy from photosynthesis. They play a significant role in their environment as primary producers and are the base of the food web in aquatic ecosystems. The algal groups are strongly sensitive to even a slight rise or fall in water quality. The composition and abundance of phytoplankton are extremely dependent on the environmental factors of their habitat, such as sunlight, dioxide, carbon, and nutrients. These conditions affect the density and distribution of algae throughout the water levels [1-5]. The presence of algae is important for assessing the resources and biodiversity of the water body. Evaluating the presence and distribution of phytoplankton contributes to clarifying the environmental characteristics and impact of changes in water quality on algal communities because of their high sensitivity to changing environmental conditions [6].

This article includes a status assessment of nutrient and organic pollution of Nhu Y river using the Palmer index [7], Shannon-Weiner diversity index [8], and Diatomeae index [9]. These contribute to quickly developing an environmental monitoring tool based on the distribution of phytoplankton in Nhu Y river.

Materials and methods

Study area and sample collection

Nhu Y river is located in the northeast of Hue city and is approximately 12 km in length. Generally, Nhu Y river plays an important role in the daily life and productive activities of Hue citizens, such as the supply household water, irrigation, and agriculture. Currently, Nhu Y river receives a volume of wastewater from the processes associated with living, farming, agriculture and the traditional craft activities of

*Corresponding author: Email: letrangenvi@gmail.com

human beings.

Nhu Y river is an artificial river and is separated from Huong river by Dap Da dam. The water volume of the Nhu Y river receives a small flow from Loi Nong river as well as wastewater from the surrounding residents and fields. Moreover, Nhu Y river flows slowly and therefore its aquatic ecosystem is similar to the aquatic ecosystems of standing waterbodies.

The qualitative and quantitative samples were collected monthly from March to August in 2011 at eight sites (Table 1, Fig. 1). Phytoplankton samples were collected by means of a pyramid-shaped phytoplankton net that was 0.9 m long, 0.3 m in diameter, and had a mesh size of 20 µm; they were preserved in a solution of Lugol in the field. These samples were kept on ice until they were analysed in the laboratory.

Table 1. The sampling sites along Nhu Y river.

Sampling sites	Local names	Latitude	Longitude
Y1	Dap Da bridge	16^0 28.400' N	107^0 35.711' E
Y2	Vi Da bridge	16^0 28.285' N	107^0 36.039' E
Y3	Van Duong village, Xuan Phu commune, Hue city	16^0 28.461' N	107^0 36.411' E
Y4	Tung Thien Vuong bridge	16^0 28.944' N	107^0 36.258' E
Y5	Chiet Bi village, Phu Thuong commune, Phu Vang district	16^0 29.330' N	107^0 36.649' E
Y6	Cong Luong village, Thuy Van commune, Huong Thuy town	16^0 29.464' N	107^0 37.330' E
Y7	Sam bridge	16^0 28.894' N	107^0 38.961' E
Y8	Next to rice fields, Thuy Thanh commune	16^0 28.321' N	107^0 38.521' E

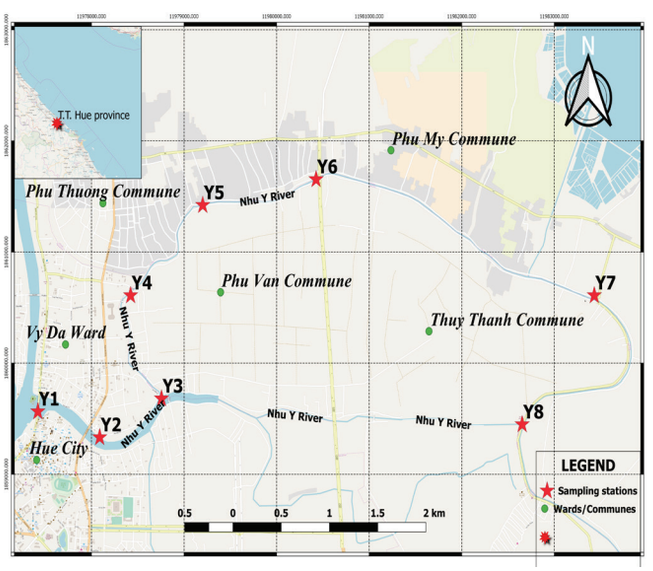

Fig. 1. Sampling sites in Nhu Y river.

Phytoplankton analyses

Phytoplankton were observed under at 200-400X magnification (Olympus BX51 microscope). Species identification was based on morphology according to studies such as Shirota (1966) [10]; Fukuyo, et al. (1990) [11]; Komarek and Anagnostidis (1999; 2005) [12, 13]; Yamagishi and Akiyama (1995) [14]; Canter-Lund and Lund (1995) [15]; Nguyen (2003) [9]; Nguyen, et al. (2007) [16]; and Duong and Vo (1997) [17]. A Sedgewick Rafter counting chamber was used to determine phytoplankton density.

Calculation of indexes

Palmer index:

The Palmer index is based on the presence of algal genera, which have the organic pollution tolerance in water bodies. The score was fixed in a range from 1 to 5 depending on the genus, the larger number indicating greater pollution. Algal genera that are less tolerant to organic pollution were assigned a lower number. Algal genera that are highly tolerant of organic pollution were assigned a higher number (Table 2).

Table 2. List of algal genera of tolerant organic-pollution according to Palmer [7].

Genus	Pollution index	Genus	Pollution index
1. *Anacystis*	1	11. *Micractinium*	1
2. *Ankistrodesmus*	2	12. *Navicula*	3
3. *Chlamydomonas*	4	13. *Nitzschia*	3
4. *Chlorella*	3	14. *Oscillatoria*	5
5. *Closterium*	1	15. *Pandorina*	1
6. *Cyclotella*	1	16. *Phacus*	2
7. *Euglena*	5	17. *Phormidium*	1
8. *Gomphonema*	1	18. *Scenedesmus*	4
9. *Lepocinclis*	1	19. *Stigeoclonium*	2
10. *Melosira*	1	20. *Synedra*	2

After confirming the presence of these algal genera in the sample, the pollution index factors of the algae present were calculated. A pollution index score ≥ 20 was considered to indicate high organic pollution; a score from 15 to 19 indicated probable organic pollution. Lower scores indicated less organic pollution.

The Shannon-Wiener diversity and Diatomeae indexes were calculated following Wilhm (1975) [8] and Nguyen (2003) [9], respectively.

Shannon-Wiener diversity index (H'):

$$H' = -\sum_{i=1}^{n} \frac{n_i}{N} \log_2 \frac{n_i}{N}$$

where H': diversity index; N: the number of individuals in the samples; and n_i: the number of individuals in the i^{th} [8].

Diatomeae index:

Diatomeae index = $C*P^{-1}$

in which: C: number of species of Centrales; and P: number of species of Pennales [9].

Results

Species composition and density of phytoplankton

Phytoplankton from the eight monitoring sites on Nhu Y river comprised 117 species distributed among six divisions (Table 3). Among the phytoplankton groups, the Chlorophyta phylum dominated with 45 species, 38.5% of the total. This was followed by the Euglenophyta phylum with 31 species (26.5%). There were 24 species of Cyanobacteria (20.5%); 14 species of diatoms (11.9%), two species of the Cryptophyta phylum (1.7%), and only one species of the Dinophyta phylum (0.9%). In general, the number of phytoplankton species was higher in June, July, and August, and lower in March, April, and May. The number of species of phytoplankton fluctuated from 76 (March) to 113 (August) in each survey (Table 4).

Table 3. Structure of phytoplankton communities from Nhu Y river during the period of the study.

Phylum	March	April	May	June	July	August	Total	%
Cyanobacteria	4	9	15	21	23	23	24	20.5
Bacillariophyta	13	12	12	13	11	14	14	11.9
Chlorophyta	32	36	41	39	43	43	45	38.5
Euglenophyta	24	19	26	29	30	30	31	26.5
Cryptophyta	2	2	2	2	2	2	2	1.7
Dinophyta	1	1	1	1	1	1	1	0.9
Total species	**76**	**79**	**97**	**105**	**110**	**113**	**117**	**100**

Almost all the phytoplankton species and genera present in Nhu Y river were those found in fresh water, such as *Anabaena*, *Anthrospira, Microcystis, Oscillatoria, Pandorina, Scenedesmus*, *Ankistrodesmus, Pediastrum*, *Crucigenia, Coelastrum, Chlorella, Actinastrum, Euglena, Phacus, Trachelomonas, Melosira, Cyclotella, Rhodomonas*, and *Cryptomonas* (Fig. 2). Hence, the aquatic ecosystem in the area studied was mostly influenced by fresh water from the hinterland.

Table 4. List of algal species present at Nhu Y river.

No.	Taxa	March	April	May	June	July	August
	Cyanobacteria						
1	*Anabaena affinis* Lemmermann, 1898			+	+	+	+
2	*Anabaena circinalis* Rabenhorst ex Bornet and Flahault, 1886			+	+	+	+
3	*Anabaena spiroides* Klebahn, 1895		+	+	+	+	+
4	*Anabaena* sp.				+	+	+
5	*Anthrospira platensis* Gomont, 1892		+	+	+	+	+
6	*Anthrospira* sp.				+	+	+
7	*Aphanocapsa delicatissima* West and West, 1912			+	+	+	+
8	*Aphanizomenon aphanizomenoides* (Forti) Horecká and Komárek, 1979				+	+	
9	*Aphanizomenon* sp.			+	+	+	+
10	*Jaaginema* sp.		+	+	+	+	+
11	*Limnothrix planctonica* (Woloszynsk) Meffert, 1988		+	+	+	+	+
12	*Merismopedia punctata* Meyen, 1839	+	+	+	+	+	+
13	*Merismopedia tenuissima* Lemmermann, 1898	+	+	+	+	+	+
14	*Microcystis aeruginosa* (Kützing) Kützing, 1846			+	+	+	+
15	*Microcystis flosaquae* (Wittrock) Kirchner, 1898					+	+
16	*Microcystis protocystis* Crow, 1923				+		+
17	*Microcystis wesenbergii* (Komárek) Komárek, 1968			+	+	+	+
18	*Oscillatoria curviceps* Agardh and Gomont, 1892					+	+
19	*Oscillatoria limosa* Agardh ex Gomont, 1892	+	+		+	+	+
20	*Oscillatoria perornata* Skuja, 1949			+	+	+	+
21	*Oscillatoria agardhii* Gomont, 1892	+	+	+	+	+	+
22	*Phormidium* sp.		+		+	+	+
23	*Raphidiopsis curvata* Fritsch and Rich, 1930			+	+	+	+
24	*Spirulina princeps* West and West, 1902					+	+
	Bacillariophyta						
25	*Cyclotella comta* (Ehrenberg) Kützing, 1849	+	+	+	+		+
26	*Cyclotella* sp1.	+	+	+	+	+	+
27	*Cyclotella* sp2.	+	+	+	+	+	+
28	*Gomphonema* sp.	+	+		+		+
29	*Gyrosigmas* sp.	+	+	+	+	+	+
30	*Melosira granulata* (Ehrenberg) Ralfs, 1861	+	+	+	+	+	+
31	*Melosira* sp.	+	+	+	+	+	+
32	*Naviculla* sp.	+	+	+	+	+	+
33	*Nitzschia closterium* (Ehrenberg) W. Smith, 1853	+		+	+	+	+
34	*Nitzschia* sp.	+	+	+	+	+	+
35	*Pinularia* sp.	+	+		+		+
36	*Surirella tenera* Gregory, 1856			+	+	+	+
37	*Synedra ulna* (Nitzsch) Ehrenberg, 1832	+	+	+	+	+	+
38	*Synedra* sp.	+	+	+		+	+
	Chlorophyta						
39	*Actinastrum hantzschii* Lagerheim, 1882	+	+	+	+	+	+
40	*Ankistrodesmus acicularis* (Braun) Korshikov, 1953	+	+	+	+	+	+
41	*Ankistrodesmus arcuatus* Korshikov, 1953	+	+	+	+	+	+
42	*Ankistrodesmus falcatus* (Corda) Ralfs, 1848					+	+
43	*Ankistrodesmus gracilis* (Reinsch) Korshikov, 1953	+	+	+	+	+	+
44	*Ankistrodesmus longissimus* (Lemmermann) Wille, 1909	+	+	+	+	+	+
45	*Chlamydomonas* sp.	+	+	+	+	+	+
46	*Chlorella* sp.	+	+	+	+	+	+
47	*Closterium gracile* Brébisson ex Ralfs, 1848		+	+	+	+	+
48	*Closterium* sp.	+	+	+	+	+	+
49	*Coelastrum sphaericum* Nägeli, 1849	+	+	+	+	+	+
50	*Coelastrum microporum* Nägeli, 1855	+	+	+	+	+	+
51	*Crucigenia lauterbornii* Schmidle, 1900	+	+	+	+	+	+
52	*Crucigeniella rectangularis* (Nägeli) Komárek, 1974	+	+	+	+	+	+
53	*Dictyosphaerium ehrenbergianum* Nägeli, 1849		+	+	+	+	+
54	*Eudorina elegans* Ehrenberg, 1832	+		+	+	+	+
55	*Gonium quadratum* Pringsheim ex Nozaki, 1990			+	+	+	+
56	*Micractinium pusillum* Fresenius, 1858		+	+	+	+	+
57	*Micractinium quadrisetum* (Lemmermann) Smith, 1916	+	+	+	+	+	+
58	*Oocystis borgei* J. Snow, 1903		+	+	+	+	+
59	*Pandorina morum* (Müller) Bory de Saint-Vincent, 1824	+	+	+	+	+	+

60	*Pandorina* sp1.	+	+	+	+	+	+
61	*Pandorina* sp2.	+	+	+	+		
62	*Pediastrum biradiatum* Meyen, 1829	+	+	+		+	+
63	*Pediastrum duplex* Meyen, 1829	+	+	+	+	+	+
64	*Pediastrum simplex* Meyen, 1829					+	+
65	*Pediastrum tetras* (Ehrenberg) Ralfs, 1845	+	+	+	+	+	+
66	*Scenedesmus acuminatus* (Lagerheim) Chodat, 1902	+	+	+	+	+	+
67	*Scenedesmus arcuatus* (Lemmermann) Lemmermann 1899	+	+	+	+	+	+
68	*Scenedesmus bicaudatus* Dedusenko, 1925	+		+	+	+	+
69	*Scenedesmus curvatus* Bohlin, 1897	+	+	+			
70	*Scenedesmus denticulatus* Lagerheim, 1882	+	+	+	+	+	+
71	*Scenedesmus ellipsoideus* Chodat, 1926	+	+			+	+
72	*Scenedesmus obliquus* (Turpin) Kützing, 1833		+	+	+	+	+
73	*Scenedesmus perforatus* Lemmermann, 1903			+	+	+	+
74	*Scenedesmus protuberans* Fritsch and Rich, 1929	+	+	+	+	+	+
75	*Scenedesmus quadricauda* (Turpin) Brébisson, 1835	+	+	+	+	+	+
76	*Schroederia setigera* (Schröder) Lemmermann, 1898		+	+	+	+	+
77	*Staurastrum dickiei* Ralfs, 1848	+	+	+	+	+	+
78	*Staurastrum natator* West, 1892					+	+
79	*Tetraedron constrictum* Smith, 1916			+	+	+	+
80	*Tetraëdron incus* (Teiling) Smith, 1926	+	+	+	+	+	+
81	*Tetraëdron trigonum* (Nägeli) Hansgirg, 1888	+	+	+	+	+	+
82	*Tetrastrum heteracanthum* (Nordstedt) Chodat, 1895			+	+	+	+
83	*Treubaria triappendiculata* Bernard, 1908	+	+	+	+	+	+
	Euglenphyta						
84	*Euglena acus* Ehrenberg, 1830	+	+	+	+	+	+
85	*Euglena caudata* Hübner, 1886				+	+	+
86	*Euglena elongata* Schewiakoff, 1892	+			+	+	+
87	*Euglena gracilis* Klebs, 1883	+	+	+	+	+	+
88	*Euglena oxyuris* Schmarda, 1846	+	+	+	+	+	+
89	*Euglena rostrifera* Johnson, 1944	+	+	+	+	+	+
90	*Euglena sociabilis* Dangeard, 1902	+		+	+	+	+
91	*Euglena spirogyra* Ehrenberg, 1832	+	+	+	+		+
92	*Euglena viridis* Ehrenberg, 1830	+	+	+	+	+	+
93	*Lepocinclis fusiformis* (Carter) Lemmermann, 1901			+	+	+	+
94	*Lepocinclis ovum* (Ehrenberg) Lemmermann, 1901	+	+	+	+	+	+
95	*Lepocinclis reeuwykiana* Conrad, 1934				+	+	+
96	*Lepocinclis salina* Fritsch, 1914	+	+	+	+	+	+
97	*Phacus anomalus* Fritsch and Rich, 1929	+	+	+	+	+	+
98	*Phacus contortus* Bourrelly, 1952			+	+	+	+
99	*Phacus helikoides* Pochmann, 1942	+		+	+	+	+
100	*Phacus longicauda* (Ehrenberg) Dujardin, 1841	+	+	+	+	+	+
101	*Phacus orbicularis* Hübner,1886	+			+	+	+
102	*Phacus pleuronectes* (Müller) Dujardin, 1841	+	+	+	+	+	+
103	*Phacus* sp.	+	+	+	+	+	+
104	*Phacus tortus* (Lemmermann) Skvortzov, 1928	+	+	+	+	+	+
105	*Phacus trapezoides* Stawinski, 1969	+	+	+	+	+	+
106	*Strombomonas australica* (Playfair) Deflandre, 1930					+	
107	*Strombomonas longicauda* (Swirenko) Deflandre, 1930	+		+		+	+
108	*Strombomonas napiformis* (Playfair) Deflandre, 1930	+	+	+	+	+	+
109	*Trachelomonas armata* (Ehrenberg) Stein, 1878	+	+	+	+	+	+
110	*Trachelomonas intermedia* Dangeard, 1902	+	+	+	+	+	+
111	*Trachelomonas hispida* (Perty) Stein, 1878	+	+	+	+	+	+
112	*Trachelomonas nova* Drezepolski, 1925			+	+	+	+
113	*Trachelomonas ovalis* Daday, 1913	+	+	+	+	+	+
114	*Trachelomonas* sp.			+	+	+	+
	Cryptophyta						
115	*Cryptomonas* sp.	+	+	+	+	+	+
116	*Rhodomonas* sp.	+	+	+	+	+	+
	Dinophyta						
117	*Peridinium* sp.	+	+	+	+	+	+
	Total Species	**76**	**79**	**97**	**105**	**110**	**113**

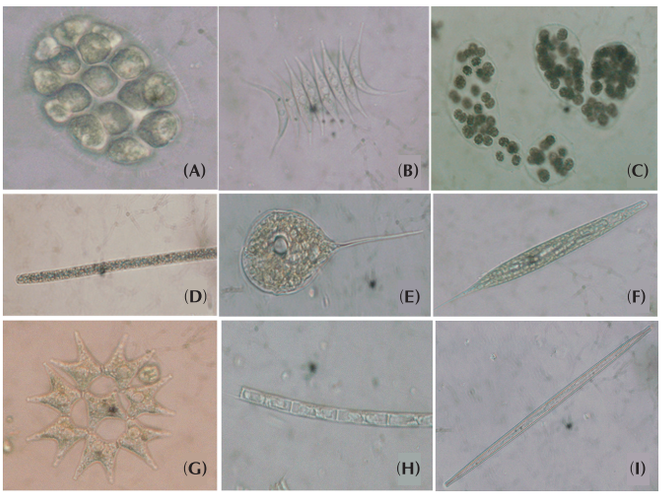

Fig. 2. Some widespread genera of algae in Nhu Y river. (A) *Pandorina*, **(B)** *Scenedesmus*, **(C)** *Microcystis*, **(D)** *Oscillatoria*, **(E)** *Phacus*, **(F)** *Euglena*, **(G)** *Pediastrum*; **(H)** *Melosira*; **(I)** *Synedra*. Scale bars = 20 μm.

Phytoplankton densities were high, ranging from 110,146 to 5,964x10^3 individuals/litre, and the values were the highest at the sampling site 2 (Vi Da bridge) and lowest at the site 8 (Thuy Thanh commune) (Fig. 3). The dominant species in the zone of study were *Oscillatoria agardhii, Arthrospira platensis, Jaaginema* sp., *Microcystis wesenbergii*, *Pandorina* sp2., *Cryptomonas* sp., *Rhodomona* sp. Among the dominant species, *Oscillatoria agardhii* occurred in most of the studied area.

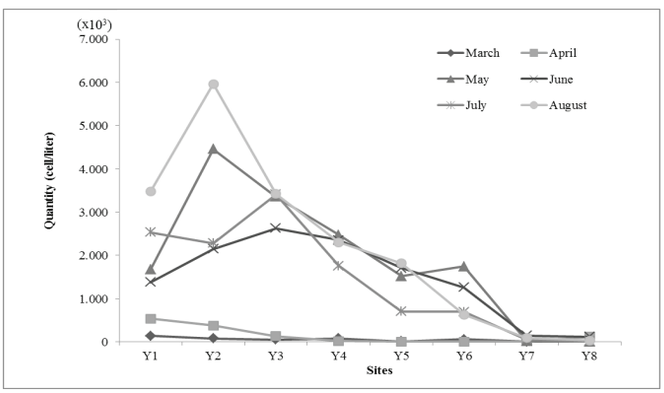

Fig. 3. Phytoplankton density in Nhu Y river during period of study.

Application of bio-indexes to assess the water quality in Nhu Y river

Palmer index:

Eighteen of the 20 genera in Palmer's algal genus list were present in Nhu Y river at the six monitoring times (Table 5). Many genera, such as *Ankistrodesmus, Chlamydomonas, Chlorella, Cyclotela, Melosira, Euglena, Oscillatoria, Pandorina, Phacus,* and *Scenedesmus* appeared on all six occasions.

Table 5. Algal genus tolerant of organic pollution in Nhu Y river.

No.	Genus	Sampling sites							
		Y1	*Y2*	*Y3*	*Y4*	*Y5*	*Y6*	*Y7*	*Y8*
1	*Anacystis*	-	-	-	-	-	-	-	-
2	*Ankistrodesmus*	A	A	A	A	A	A	A	A
3	*Chlamydomonas*	A	A	A	A	A	A	A	B
4	*Chlorella*	A	A	A	A	A	A	A	B
5	*Closterium*	D	C	C	B	B	C	A	A
6	*Cyclotella*	A	A	A	A	A	A	A	A
7	*Euglena*	A	A	A	A	A	A	A	A
8	*Gomphonema*	-	E	D	E	D	B	B	A
9	*Lepocinclis*	B	B	A	B	B	A	A	A
10	*Melosira*	A	A	A	A	A	A	A	A
11	*Micractinium*	A	B	A	B	B	B	D	D
12	*Navicula*	D	B	B	C	D	B	A	A
13	*Nitzschia*	B	B	B	B	A	A	A	A
14	*Oscillatoria*	A	A	A	A	A	A	A	A
15	*Pandorina*	A	A	A	A	A	A	A	A
16	*Phacus*	A	A	A	A	A	A	A	A
17	*Phormidium*	E	F	F	E	C	E	D	D
18	*Scenedesmus*	A	A	A	A	A	A	A	A
19	*Stigeoclonium*	-	-	-	-	-	-	-	-
20	*Synedra*	B	B	B	B	A	A	A	A

Note: (-): species were not present; (A): species were present during all six monitoring periods; (B): species were present during five monitoring periods; (C): species were present during four monitoring periods; (D): species were present during three monitoring periods; (E): species were present during two monitoring periods; (F): species were present during one monitoring period.

The value of algal genus pollution index during the monitoring in 2011 was relatively high, ranging from 30 to 41. In Nhu Y river, the Palmer's index value was generally higher in April and August than in March, May, June and July. Furthermore, the index value was the highest (41) at sites Y5 and Y6 (in April) and at Y3, Y7, and Y8 (in August) (Table 6).

Shannon-Weiner diversity index:

The phytoplankton diversity index values in this survey fluctuated from 0.66 to 2.92 (Table 6). In Nhu Y river, the diversity index values of all sites were less than 1 in May (except at Y7 and Y8), while the index value of all sites ranged from 1 to 2 in July and August (except at Y7 and Y8 in July, and Y8 in August). In addition, the values of the algal diversity index were greater than 2 at all sites in March, April (except Y8), and June.

Diatomeae index:

The values of the Diatomeae index in this study are presented in Table 6. In general, the Diatomeae index values were greater than 0.2 at most stations during the survey period.

Table 6. The values of the Palmer pollution index, Shannon-Wiener diversity index (H'), and Diatomeae index of phytoplankton in Nhu Y river.

Sites	Mar	Apr	May	Jun	Jul	Aug
			Palmer index			
Y1	31	38	38	39	36	36
Y2	34	39	36	39	38	39
Y3	33	40	38	39	36	41
Y4	30	39	35	39	37	40
Y5	36	41	39	39	37	38
Y6	40	41	39	38	38	40
Y7	39	40	35	39	41	41
Y8	39	40	39	37	37	41
			Shannon-Wiener index (H')			
Y1	2.51	2.46	0.88	2.49	1.60	1.70
Y2	2.52	2.31	0.97	2.53	1.64	1.67
Y3	2.60	2.57	0.66	2.36	1.78	1.61
Y4	2.84	2.19	0.76	2.39	1.67	1.18
Y5	2.90	2.93	0.86	2.47	1.83	1.67
Y6	2.16	2.88	0.79	2.47	1.90	1.92
Y7	2.79	2.65	2.87	2.83	2.30	1.69
Y8	2.30	1.54	2.74	2.65	2.79	2.92
			Diatomeae index			
Y1	-	1.3	1.0	1.7	2.0	1.0
Y2	2.5	1.3	1.3	1.3	0.8	1.0
Y3	5	1.3	1.3	1.0	1.0	0.8
Y4	-	1.3	1.0	1.3	1.5	0.8
Y5	1.3	0.6	0.6	1.7	1.0	1.0
Y6	1.0	0.8	1.0	1.0	0.6	0.6
Y7	0.6	0.6	0.4	0.8	0.4	0.8
Y8	0.2	1.0	0.6	0.6	0.3	0.6

Discussion

Some investigations of phytoplankton in rivers of Vietnam have been performed and published. Luong and Phan (2014) [6] recorded 280 species of phytoplankton in Huong river systems in which Chlorophyta contributed the highest number of species. In a study of phytoplankton in La Nga river, 202 algae species were identified of which Chlorophyta were also the greatest number [18]. In Thi Vai river, 98 taxa were recorded, of which Bacillariophyta contributed the greatest number [19]. During the monitoring of the current study, Chlorophyta were dominant in terms of species numbers. The distribution of the number of species in Nhu Y river (117 taxa recorded) is considered average compared to some other rivers. However, the structure of phytoplankton communities in the rivers cited and in Nhu Y river comprised similar algal phyla, such as Cyanobacteria, Chlorophyta, Bacillariophyta, Euglenophyta, and Dinophyta.

Generally, the phytoplankton densities in this survey were very high, with over 10^6 individuals/litre, with strong growth of the *Oscillatoria agardhii* species. In addition, Nhu Y river was experiencing eutrophication during the

monitoring because it was affected by domestic wastewater, construction, irrigation, and agricultural activities.

According to Palmer (1969) [7], the quality of the water in Nhu Y river was characterised by highly organically polluted conditions because the index values were over 20 at all sites during the monitoring in 2011. Genera such as *Anabaena*, *Microcystis, Oscillatoria, Euglena, Phacus, Scenedesmus, Chlamydomonas, Navicula, Chlorella, Nitzschia* and *Ankistrodesmus* were found in organically polluted water, an assertion that was supported by Ratnasabapathy (1975) [20]; Gunale and Balakrishnan (1981) [21]; Jafari and Gunale (2006) [22]; Shams, et al. (2012) [23]; and Shams and Karimian (2017) [24]. Similar genera were recorded in the present investigation. *Oscillatoria* species, which were found to be the most active participants at all stations, may be good indicators of contaminated water bodies as similar observations were recorded by Sanjib, et al. (2007) [25] and Rai, et al. (2008) [26].

The Shannon-Wiener diversity index has been widely applied Wilhm (1975) [8] proposed three water quality categories for the Shannon-Weiner diversity index. A high H' value suggests a more vigorous ecosystem and, in contrast, a low H' value suggests meagre diversity in a structured community and a less healthy ecosystem. In the current study, the range of the H' value in Nhu Y river was 0.66-2.92 (Table 6). Nhu Y water sources can only be classified into categories II and III, indicating moderate and heavy pollution, respectively [8]. Similar results were recorded at the Mae Moh power plant [27] and the two waterbodies at Tiruvannamalai [28].

According to Nguyen (2003) [9], the values of the Diatomeae index at the survey sites in the Nhu Y river during the period of study were greater than 0.2, indicating that the water quality there was eutrophic.

Conclusions

During the survey period of March to August in 2011, 117 algal species belonging to six phyla were recorded in Nhu Y river, including Cyanobacteria, Chlorophyta, Bacillariophyta, Euglenophyta, Cryptophyta, and Dinophyta, of which the Chlorophyta and Euglenophyta phyla were dominant in terms of species numbers. In general, the algal density recorded in the present study was very high and reached millions of individuals/litre.

We identified 18 algal genera in Palmer's list (1969) [7] that are tolerant of organic pollution. The values of the Palmer index, the Shannon-Weiner diversity index and the Diatomeae index reflect the organic pollution and the eutrophic condition of Nhu Y river. Studies of phytoplankton are very important because in their habitat phytoplankton play a crucial role as primary producers in the food web. Apart from physicochemical methods, phytoplankton indexes such as the Palmer, algal biodiversity, and Diatomeae indexes are useful tools for assessing the water quality of Nhu Y river.

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