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Relationship between Phytoplankton and Environmental Variables from Bien Ho and Lak Lakes in Central Highland of Vietnam

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Abstract

Being the primary producers of the food chain, phytoplankton including micro algae and cyanobacteria play a key role in freshwater ecosystems. This study aimed to investigate the seasonal variation of phytoplankton in relation to the environmental parameters such as temperature, pH, electric conductivity, transparency, turbidity, dissolved oxygen, biochemical oxygen demand, nutrients, trace metals in two natural lakes, Bien Ho and Lak lakes, from central highland of Vietnam. The cluster analysis revealed that the similarity of aquatic environmental parameters of Bien Ho Lake was clearly separated among the seasons and that of Lak Lake was overlap between the dry season and trans-season period. The results showed that the physical conditions and trace metal concentrations in surface water of the two lakes were comparable and favored the phytoplankton growth. Nutrients including nitrogen and phosphorus concentrations in Lak Lake were higher and advantageous for the development of phytoplankton whereas nitrogen concentration in Bien Ho seemed to limit the algal growth. From the monitoring, 98 and 312 species of phytoplankton in Bien Ho and Lak Lakes, respectively, which belong to green algae, Diatoms, golden algae, euglenoids, dinoflagellates and cyanobacteria. Phytoplankton densities were from 1 577 000 – 10 312 000 individuals/L in surface water from Bien Ho Lake and from 62 400 – 14 580 000 individuals/L in Lak Lake. The Canonical Correspondence Analysis showed that Bien Ho and Lak Lakes had similar characters of group distribution in each sampling time on the ordination plane. In Lak Lake, the parameters of pH, turbidity, chemical oxygen demand, iron, electric conductivity, and aluminum had a close correlation with the algal distribution. The transparency revealed the clearest correlation with the phytoplankton distribution in Bien Ho.

Keywords: Correlation, Environmental variables, Lentic waters, Phytoplankton, Seasonal variation

1. Introduction

Phytoplankton including algae and cyanobacteria play a key role in aquatic ecosystem because they are primary producers in water bodies. The coexistence of phytoplankton species is a conspicuous feature of aquatic ecosystems. In freshwater bodies, many environmental parameters regulate spatial and seasonal growth and succession of phytoplankton populations (Wetzel, 2001). Light intensity and temperature are major physical variables regulating the photosynthesis of phytoplankton in lakes and reservoirs (Wetzel, 2001), while other physical factors such as turbulence, pH and water circulation influence algal communities in water bodies (Findlay and Kasian, 1991; Zhang and Prepas, 1996; Wetzel, 2001). Nutrients including nitrogen and phosphorus compounds closely correlate with the development of phytoplankton, and different phytoplankton species have different nutrient requirements for their optimal growth (Sivonen, 1990; Wetzel, 2001; Sabour et al., 2009). Cyanobacteria with heterocytes can utilize atmospheric di-nitrogen as a nitrogen source, which enhances their competition over other phytoplankton species during the inorganic nitrogen depletion period in water bodies. For diatoms abundance, silica is the main controlling factor (Tilman et al., 1986). The ratio of total nitrogen to total phosphorus influences the phytoplankton structure as well (Smith, 1983). Furthermore, trace elements such as metals (e.g. iron, magnesium) and organic compounds (e.g. vitamins) are essential for growth and development of phytoplankton (Wetzel, 2001; Padisak, 2003). Generally, most investigations on phytoplankton structure, dynamics and ecology have been implemented in temperate region whereas the similar studies are less from tropical region, and especially limited from the Southeast Asian countries.

In Vietnam, taxonomy of freshwater phytoplankton including green algae, diatoms, euglenoids, dinoflagellates and cyanobacteria have been investigated for several decades (Shirota, 1966; Pham, 1969; Nguyen, 1983; Phung et al., 1992; Nguyen, 2003; Dao et al., 2010). However, investigations on correlation between freshwater phytoplankton and environmental variables are limited. Duong et al. (2013) noted the density of cyanobacteria was regulated by temperature and phosphate concentration in Nui Coc Reservoir in Northern Vietnam. The correlation between phytoplankton abundance and dissolved nitrogen and temperature in Tuyen Lam Reservoir was found by Tran et al. (2015). In Southern Vietnam, Dao and Bui (2016) reported the variation of phytoplankton and the correlation between species number, biodiversity and environmental parameters in Vam Co River. Recently, Dao et al. (2016) described that cyanobacterial biomass correlated to temperature, pH, biochemical oxygen demand (BOD_5) and inorganic nitrogen concentration in Tri An Reservoir.

Daklak and Gialai Provinces in central highland of Vietnam consist considerable wetlands with various shapes and origins (MOSTE, 2001). So far the aquatic flora especially phytoplankton from the Daklak and Gialai Provinces seem not to be uncovered. The previous investigations reported 73 and 93 phytoplankton species from Bien Ho Lake and Lak Lake, respectively (Dao, 1998; Le and Hoang, 2001). The same authors also noted the phytoplankton densities of 500 – 371 000 individuals/L from Bien Ho Lake and less than 1 000 000 individuals/L from Lak Lake. However, no investigation on interaction between phytoplankton and environmental parameters was implemented at central highland of

Vietnam. The aims of this study are to (1) investigate the spatial and temporal distribution of phytoplankton from Bien Ho and Lak Lakes and (2) study the correlation between phytoplankton and environmental variables from the two water bodies

2. Materials and methods

2.1 Study Area

Bien Ho Lake

Located by the national road number 14 and around 14 km Northern far from Pleiku City, Bien Ho Lake (Fig.1) is a volcanic water body with a square of about 2.4 km^2 and a volume of 23 million m^3. It has the position of 14°02’ – 14°06’ latitude, 107°99’ – 108°00’ longitude. The maximal depth of the lake is 23 m and the maximal gap of water level of the lake between rainy and dry seasons is 8 – 9 m (MOSTE, 2001). The annual rainfall within the lake area is about 2 000 mm which is mainly contributed (> 90% of total rainfall) during the rainy season. The average temperature and humidity are around 22°C and 85%, respectively (Le and Hoang, 2001). The water sources supplying water for the lake are mainly run off water and partly underground water. Bien Ho Lake is mainly used for drinking water supply, and partly for irrigation and tourism (MOSTE, 2001).

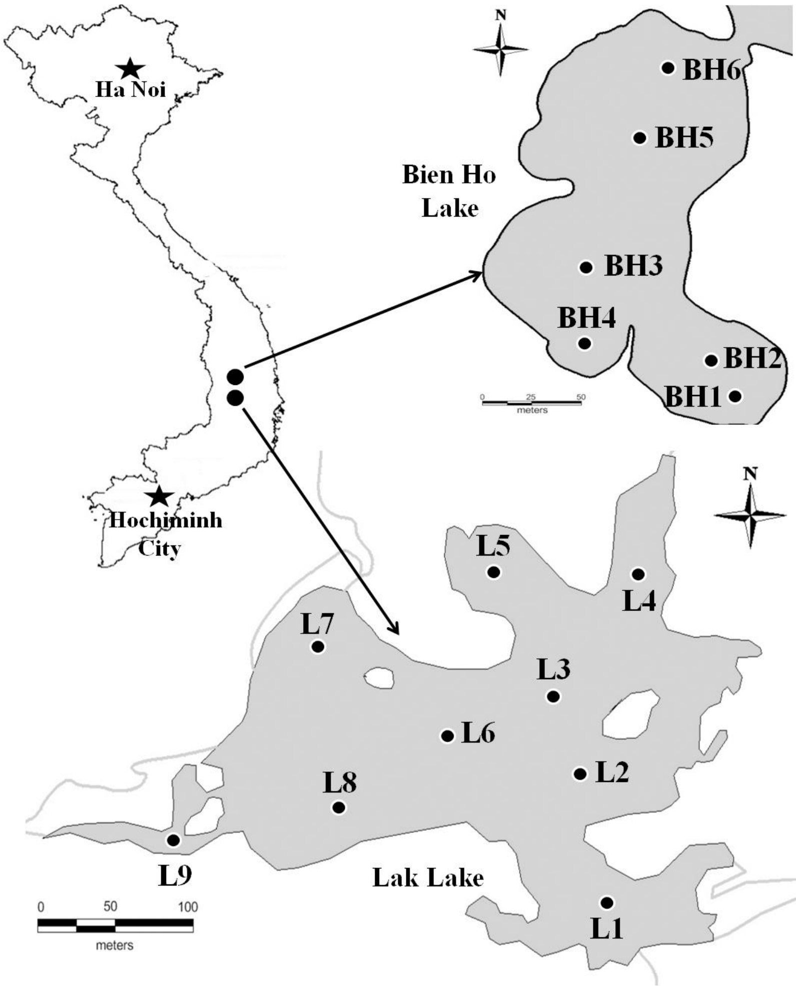

Figure 1. Maps of Bien Ho (BH) and Lak (L) Lakes with sampling sites (black round dots)

Lak Lake

The Lak Lake has the position of 12°24' – 12°27 latitude and 108°09' – 108°12' longitude. The lake originates from a curve of the Krongana River. Lak Lake (Fig. 1) has an area of about 6 km^2 and a maximal depth of 8 m (MOSTE, 2001). The annual rainfall within the lake area is about 1 900 mm mainly contributed during the rainy season (90% of the annual rainfall). The average temperature and humidity are around 24°C and 82%, respectively (Dao, 1998). This lake is used for flood control, fisheries, irrigation and tourism.

2.2 Sample Collection

The monitoring was implemented in September 2002 (middle of rainy season), December 2002 (end of rainy season and beginning of dry season which could be considered as trans-season period) and April 2003 (middle of dry season). Samples were collected at 6 sites in Bien Ho Lake and 9 sites in Lak Lake (Fig. 1). The sites were chosen based on the natural characters of the two lakes like the depth, in-coming and out let water between the lakes and connected streams.

Physical and chemical parameters

The physical and chemical parameters of surface water including pH, electric conductivity (EC), turbidity, temperature, transparency (Secchi disc) and dissolved oxygen (DO) were measured *in situ*. In addition, surface water samples for other chemical parameter analysis were also taken, kept on ice in the field and brought to the laboratory in the same day for chemical characterization. The monitored chemical parameters were total nitrogen, total phosphate, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total iron, sulfate, calcium (Ca^{2+}), magnesium (Mg^{2+}), bicarbonate (HCO_3^-), aluminum (Al^{3+}), silicate (SiO_2), sodium (Na^+), potassium (K^+), Chlor (Cl^-) and carbonate (CO_3^{2-}). All these parameters were analyzed according to the APHA (1998).

Phytoplankton

Qualitative samples were collected with a conical net with the mesh size of 20 µm. Quantitative samples were taken with a water sampler at the depth of 0.5 – 1 m. Net samples were fixed with formaldehyde while quantitative samples were fixed with neutral Lugol solution (Sournia, 1978). The phytoplankton were observed at the 400 – 1 000 × magnification (Olympus BX41) and morphologically identified according to many taxonomic books (e.g. West and West, 1904; Smith, 1924; Prescott, 1951; Gojdics, 1953; Bourrelly, 1970; Blomqvist and Olsin, 1981; Yamagishi and Akiyama, 1994a, 1994b, 1995; Komarek and Anagnostidis, 1989, 1999). The counting of phytoplankton was conducted on an inverted microscope with a Sedgewick Rafter counting chamber (Sournia, 1978).

2.3 Statistical Analysis

Cluster analysis was used for investigation on the similarity of environmental parameters between the sampling sites. Canonical correspondence analysis (CCA) was applied for analysis the correlation between phytoplankton and environmental parameters in the two lakes

3. Results

3.1 Environmental Parameters

The results showed that temperature of surface water from Bien Ho Lake was quite stable spatially. It was higher in the dry and rainy seasons (28 °C) and lower in the trans-season period (24 °C) (Table 1). pH of the Bien Ho water was alkali in dry season, ranging from 7.45 – 7.89 but became slightly acid in rainy season and trans-season period (6.47 – 6.6). The electric conductivity (EC) of the water was not so high and it was quite stable in the three surveys. EC had the values of from 24.1 – 27.3 µs/cm (Table 1). The Bien Ho water was quite transparent and the transparency was similar among the sampling sites. This characteristic was also reflected by the water turbidity (less than 8.9 NTU). The transparency in dry season was lowest among the three sampling times (1.1 – 1.4 m in dry season, 1.6 – 2 m in the other sampling times; Table 1). Water temperature from Lak Lake was lowest at the trans-season period (23 – 24 °C) while it was higher than in dry and rainy season (28 °C). The temperature of Lak water did not vary among the sampling sites. pH in the water body increased from rainy to dry seasons, from low acid to neutral character in rainy season (6.66 – 6.89), from neutral to slightly alkali (7.24 – 7.68) at trans-season period and seemed to be completely alkali in dry season (6.81 – 8.37). The electric conductivity slightly changed among the sampling sites and tended to increase from rainy season (42.7 – 52.9 µs/cm) to trans-season period (50.1 – 59.5 µs/cm), and to dry season (49.9 – 69.7 µs/cm). The water transparency from Lak Lake was quite higher in rainy season (1.1 – 1.8 m) when the lake had its highest water level. However, during the other time in year the transparency strongly decreased, 0.2 – 0.8 m at trans-season period, and 0.2 – 0.5 m in dry season, due to the water level decreasing and strong wind. This character was supported by the turbidity values recorded in the three sampling times (Table 2).

Table 1. Environmental parameters (minimum-maximum (mean) values) of surface water from Bien Ho Lake (BH1-BH6). BOD_5, biochemical oxygen demand; COD, chemical oxygen demand; EC, electric conductivity; DO, dissolved oxygen; N, nitrogen; P, phosphorus

Parameters	**BH1**	**BH2**	**BH3**	**BH4**	**BH5**	**BH6**
pH	6.5-7.9 (7.0)	6.4-7.8 (6.9)	6.5-7.7 (6.9)	6.5-7.6 (6.8)	6.5-7.5 (6.9)	6.5-7.5 (6.9)
Temperature (°C)	24-28 (26.7)	24-28 (26.7)	24-28 (26.7)	24-28 (26.7)	24-28 (26.7)	24-28 (26.7)
EC (µs/cm)	24-27 (26)	25-27 (26)	24-27 (26)	24-27 (26)	25-27 (26)	26-27 (26.8)
Turbidity (NTU)	3-6 (4)	3-8 (5)	3-8 (5)	3-9 (5)	3-8 (5)	3-9 (5)
Transparency (m)	1.4-2 (1.7)	1.2-2 (1.6)	1.2-1.9 (1.6)	1.4-1.9 (1.7)	1.3-2 (1.6)	1.1-1.9 (1.5)
DO (mg/L)	4.9-7 (6.2)	4.7-7 (5.9)	4.9-7 (6)	5.1-6.7 (6)	4.7-6.7 (5.9)	5.5-6.8 (6.3)
BOD_5 (mg oxygen/L)	0.5-1 (0.7)	0.5-1 (0.8)	0.5-0.5	0.5-1 (0.7)	0.5-1 (0.7)	0.5-1.5 (1)

COD (mg oxygen/L)	1-2 (1.5)	1-2 (1.6)	0.8-1.7 (1.1)	1-2 (1.5)	0.7-2 (1.4)	1-3.5 (2.1)
Total N (mg/L)	0-0.069 (0.03)	0-0.069 (0.032)	0-0.28 (0.12)	0-0.16 (0.08)	0-0.32 (0.13)	0-0.07 (0.04)
Total P (mg/L)	0.003-0.01 (0.005)	0.002-0.01 (0.005)	0.003-0.01 (0.005)	0.003-0.01 (0.005)	0.002-0.01 (0.005)	0.003-0.01 (0.005)
Fe (mg/L)	0.24-0.33 (0.29)	0.24-0.28 (0.26)	0.21-0.44 (0.33)	0.25-0.3 (0.27)	0.18-0.36 (0.3)	0.25-0.34 (0.28)
SO_4 (mg/L)	0.21-8.16 (3.56)	0.17-8.16 (3.6)	0.21-6.19 (2.97)	0.13-6.19 (3.01)	0.17-8.16 (3.64)	0.13-8.16 (3.71)
Ca (mg/L)	1.3-3.28 (2.22)	1.62-2.3 (1.95)	1.3-2.3 (1.9)	0.6-1.6 (1.3)	0.9-2.6 (1.7)	0.6-2.3 (1.7)
Mg (mg/L)	0.98-2.16 (1.69)	1.08-2.95 (1.95)	0.98-2.56 (1.82)	0.97-2.36 (1.59)	1.34-2.16 (1.8)	0.97-2.16 (1.4)
HCO_3 (mg/L)	10.8-13.7 (12.3)	7.5-10.4 (9.4)	4.9-12.3 (9.1)	10.4-13.6 (12.2)	4.7-12.3 (9.2)	5.3-12.3 (9.4)
SiO_2 (mg/L)	0.4-5.1 (3.5)	0.4-5.6 (3.7)	0.4-5.7 (3.8)	0.4-5.5 (3.7)	0.4-5.7 (3.60	0.38-5.89 (3.75)
Al (mg/L)	0.05-0.95 (0.37)	0.08-0.92 (0.38)	0.03-0.81 (0.31)	0.05-0.78 (0.31)	0.04-0.66 (0.4)	0.04-0.77 (0.28)

Table 2. Environmental parameters (minimum-maximum (mean) values) of surface water from Lak Lake (L1-L9). Abbreviations as in Table 1.

Parameters	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**
pH	6.7-8.2 (7.4)	6.7-8.4 (7.4)	6.7-8.2 (7.4)	6.7-8.2 (7.4)	6.8-8.2 (7.4)	6.7-8.3 (7.5)	6.8-8.1 (7.4)	6.9-8.2 (7.3)	6.8-7.3 (6.9)
Temperature (°C)	23-28 (26)	23-28 (26)	23-28 (26)	23-28 (26)	23-28 (26)	23-28 (26)	23-28 (26)	23-28 (26)	23-28 (26)
EC (µs/Cm)	51-70 (58)	43-69 (55)	49-69 (59)	45-69 (55)	44-69 (55)	43-69 (54)	43-66 (54)	43-59 (51)	50-50 (50)
Turbidity (NTU)	12-63 (36)	8-34 (21)	9-37 (21)	5-33 (18)	4-27 (17)	4-36 (22)	3-59 (25)	7-160 (94)	13-117 (71)
Transparency (m)	0.3-1 (0.60	0.4-1.6 (0.8)	0.3-1.2 (0.6)	0.4-1.4 (0.8)	0.4-1.6 (0.9)	0.4-1.8 (0.9)	0.4-1.6 (0.9)	0.2-1.3 (0.6)	0.2-1.1 (0.5)
DO (mg/L)	4.9-7.8 (6)	5-7.6 (6)	5.2-7.2 (6)	5.1-7.4 (6)	5.2-7.1 (5.9)	5.2-7.6 (6)	5.3-7.6 (6.1)	5.1-8.4 (6.3)	5.1-7.8 (6.1)
BOD_5 (mg oxygen/L)	1-2 (1.7)	1-2 (1.7)	1-2 (1.7)	1-3 (1.3)	1-5 (2.3)	1-2 (1.3)	1-5 (3)	1-2 (1.7)	1-2 (1.3)
COD (mg oxygen/L)	4.5-13 (8.6)	2.8-13 (6.7)	3.5-13 (8)	2.8-13 (6.8)	2.9-12 (7.2)	2.9-13 (7)	3.5-12 (8.6)	2.8-12 (8.4)	4.3-12 (7)
Total N	0.006-0	0.01-0.	0.01-0.	0.01-0.	0-0.028	0.01-0.	0.01-0.	0.01-0.	0.01-1.

(mg/L)	.051 (0.022)	04 (0.02)	03 (0.02)	03 (0.02)	(0.012)	086 (0.038)	35 (0.125)	063 (0.037)	12 (0.393)
Total P (mg/L)	0.004-0.034 (0.019)	0.003-0.02 (0.012)	0.004-0.04 (0.016)	0.004-0.03 (0.014)	0.003-0.03 (0.015)	0.003-0.05 (0.023)	0.003-0.04 (0.017)	0.003-0.05 (0.024)	0.003-0.052 (0.025)
Fe (mg/L)	0.8-3.2 (1.9)	1.3-1.9 (1.6)	0.8-4.2 (2.3)	0.5-2 (1.4)	0.5-4 (1.9)	0.7-2.3 (1.6)	0.6-1.9 (1.2)	0.6-5.2 (3.4)	0.9-4.2 (2.7)
SO_4 (mg/L)	0.13-6.2 (3.7)	0.17-6.2 (3.6)	0.11-6.2 (3)	0.17-6.2 (3.1)	0.11-5.3 (2)	0.08-6.2 (4.2)	0.11-5.3 (3)	0.08-31 (12.3)	0.11-4.2 (2)
Ca (mg/L)	2.9-6.9 (4.4)	2.9-5.9 (4.1)	3.7-4.9 (4.4)	2.6-5.5 (3.6)	2.6-5.5 (3.7)	2.6-4.9 (3.5)	2.6-3.4 (2.9)	2.4-3.3 (2.7)	2.4-5.5 (3.6)
Mg (mg/L)	2.2-2.7 (2.4)	1.3-2.4 (1.7)	2.3-3.1 (2.7)	2.1-2.9 (2.6)	1.1-2.7 (1.9)	1.8-3.3 (2.5)	1.2-4.3 (2.4)	1.5-4.5 (2.6)	1.7-3.9 (3)
HCO_3 (mg/L)	18-24 (21)	19-24 (21)	19-27 (23)	19-24 (22)	16-23 (19)	16-23 (21)	15-23 (20)	16-22 (20)	15-22 (20)
SiO_2 (mg/L)	0.45-6.6 (4.5)	0.47-8.5 (5.7)	0.47-7.8 (5)	0.47-11 (5.5)	0.47-6 (3.9)	0.46-6.4 (4.2)	0.44-5.9 (3.7)	0.77-6.5 (4.4)	0.73-7.3 (4.5)
Al (mg/L)	0.46-1.1 (0.8)	0.36-1.9 (0.9)	0.25-0.74 (0.4)	0.27-0.85 (0.5)	0.31-2 (0.9)	0.22-1.5 (0.7)	0.08-1.4 (0.7)	1-1.5 (1.2)	0.51-1.5 (1.1)

During the three sampling times, the dissolved oxygen (DO) of Bien Ho water valued from 4.7 – 7 mg/L (Table 1) and was lowest in dry season. The COD and BOD_5 values of surface water from Bien Ho were low (COD < 3.5 mg/L and BOD < 1.5 mg/L). Concentrations of total nitrogen were not very high in the lake water, generally. In rainy season (Sep. 2002) the concentrations of nitrogen were a little higher than those in trans-season period (Jan. 2003). However, the nitrogen concentrations in dry season (Apr. 2003) were so low or under detection level. During the three sampling times, the concentrations of phosphorus from Bien Ho water were similar among the sampling sites and ranged from 0.01 – 0.04 mg/L (Table 1). In Lak Lake, the values of dissolved oxygen (DO) from Lak water were quite similar among the sites in each sampling time, from 5.3 – 5.6 mg/L in rainy season, 4.9 – 5.3 mg/L in dry one, and 7.1 – 8.4 mg/L at trans-season period (Table 1). The values of BOD_5 in Lak water slightly changed among the sites, from 1 – 3 mg/L, excepting that at the site 7 at trans-season period, BOD_5 was 5 mg/L. The values of COD in the water were widely varied via the three sampling times. They were lowest in rainy season (3 – 5 mg/L) and highest in dry one (> 12 mg/L at most sites). Generally, the concentrations of total nitrogen at the sites in Lak Lake via three monitorings were not high (< 0.09 mg/L) but at the site 9 in dry season (1.12 mg/L) (Table 2). The total phosphorus concentrations valued from 0.003 – 0.052 mg/L (Table 2) and quite similar among the site in each season. However, the phosphorus concentrations were lowest in rainy season and highest in dry one.

Generally, the concentrations of total iron in surface water of Bien Ho Lake slightly altered among the sampling sites, ranging from 0.18 – 0.36 mg/L. The aluminum concentrations seemed to be constant among the sites within each sampling time but they varied between the sampling times. The aluminum concentrations were highest in rainy season (0.66 – 0.95 mg/L), and lowest at trans-season period (0.03 – 0.08 mg/L). The silicate concentrations were spatially stable among the sampling sites and slightly changed from rainy season to trans-season period (4.83 – 5.89 mg/L), but strongly decreased in dry season (0.36 – 0.4 mg/L) (Table 1). The sulfate concentrations were quite similar among the sampling sites. The remarkable difference was the big gap between sulfate concentrations in rainy season (6.19 – 8.16 mg/L) and trans-season period (0.13 – 0.21 mg/L). The concentrations of carbonate in dry season were similar to those in rainy one of which they strongly varied among the sampling sites (Table 1). In general, total calcium and magnesium concentrations were lowest in rainy season and similar between the dry season and trans-season period.

During the three surveys, the iron (Fe) concentrations in Lak water were from 0.48 – 5.22 mg/L (Table 2) and lowest in rainy season. The Fe concentrations were not only varied between the sampling times but among the sampling sites as well. The changing tendency of aluminum concentrations was similar to that of Fe. The silicate concentrations in Lak water were strongly varied between the sampling times. They were highest at the trans-season period (5.99 – 10.84 mg/L) and lowest in dry season (0.44 – 0.77 mg/L; Table 1). The results also indicated that the concentrations of sulfate were highest in rainy season (4.18 – 6.19 mg/L) and lowest at trans-season period (0.08 – 0.17 mg/L). Generally, they did not change so much among the sampling sites in each season. Similar situation occurred to the carbonate concentrations in the water body. The carbonate concentrations were lowest in rainy season (14.95 – 19.52 mg/L) and were similar during the other surveys (18.61 – 24.26 mg/L). Concentrations of magnesium and calcium in the Lak Lake were slightly different among the three sampling times (Table 2).

In each monitoring time, water characteristics of Bien Ho Lake were quite similar among the sampling sites (similarity > 95%). However, the similarity of aquatic environmental parameters of Bien Ho Lake was clearly separated among the seasons (Fig. 2). The similarity between rainy season and trans-season period was nearly 90%. However, the similarity of all studied parameters between dry season and the remaining time in the water body was lower, around 80% (Fig. 2). Besides, the cluster analysis of environmental parameters in Lak Lake showed that the water characters were highly similar among the sampling sites in rainy season, more than 90% (Fig. 2). However, they were quite varied among the sites in the other times of sampling, ranging from 50-85%. Additionally, aquatic physical and chemical characters of some sampling sites were strongly separated from other sites in dry and/or trans-season period. Furthermore, conditions of aquatic environment was around 63% similar between Bien Ho Lake (3 surveys) and Lak Lake (rainy season). Interestingly, there was almost separated in environmental characteristics between the two water bodies during dry season and trans-season period (Fig. 2).

3.2 Phytoplankton

Species composition of phytoplankton

From the three surveys, 98 species of phytoplankton belonging to green algae, diatoms, golden algae, euglenoids, dinoflagellates and cyanobacteria were recorded from Bien Ho

Lake. The phytoplankton species number were mainly contributed by green algae (58 species, gaining 59.2% of total species number) followed by diatoms (17 species, 17.3%), cyanobacteria, euglenoids. In addition, the contribution of the other algal groups (golden algae and dinoflagellates) was minor (Table 3).

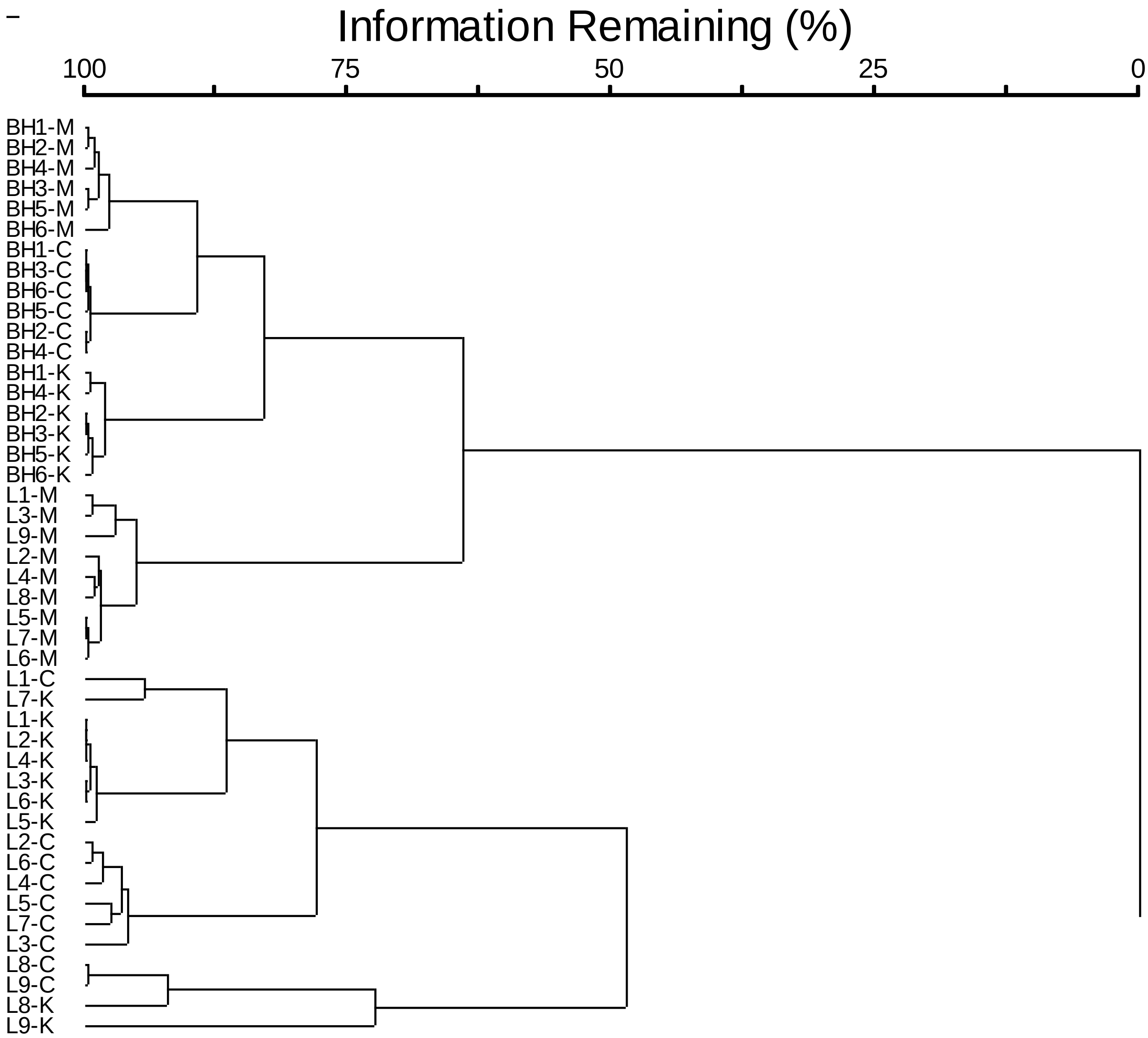

Figure 2. Cluster analysis of environmental parameters from Bien Ho and Lak Lakes. BH1-BH6, sampling sites in Bien Ho Lake; L1-L9, sampling sites in Lak Lake; M, rainy season; C, trans-season period; K, dry season.

Table 3. Phytoplankton community structure from Bien Ho and Lak Lakes

Phytoplankton groups	Bien Ho Lake		Lak Lake	
	Species number	%	Species number	%
Cyanobacteria	11	11.3	29	9.3
Yellow algae	1	1	1	0.4
Golden algae	2	2	6	1.9
Diatoms	17	17.3	57	18.3

Green algae	58	59.2	132	42.3
Euglenoids	7	7.2	80	25.6
Dinoflagellates	2	2	7	2.2
Total	**98**	**100**	**312**	**100**

In the Lak Lake, 312 phytoplankton species belonging to green algae, diatoms, golden algae, euglenoids, dinoflagellates and cyanobacteria were recorded during the three sampling times. The species number of phytoplankton were mainly contributed by green algae (132 species, gaining 42.3% of total species number) followed by euglenoids (80 species, 25.6%), diatoms (57 species, 18.3%) and cyanobacteria (29 species, 9.3%) whilst the remaining algal groups (e.g. yellow, golden algae and dinoflagellates) were minor contribution to the total species number (Table 3).

In Bien Ho Lake, the species number of phytoplankton was highest in trans-season period (75 species) and lowest in dry season (44 species). The species number at each site ranged from 21 – 36 species in rainy season, 21 – 28 species in dry season and 42 – 52 in trans-season period (Table 3). The species number of phytoplankton from Lak Lake was lowest in dry season (180 species) and highest in trans-season period (272 species). At each sampling site, species number was from 70 – 123 species in rainy season, 91-159 species in trans-season period and 76-108 species in dry season (Table 4).

Table 4. Species number of phytoplankton from Bien Ho and Lak Lakes during the sampling times. BH1-BH6, sampling sites in Bien Ho Lake; L1-L9, sampling sites in Lak Lake.

Sampling times	**BH1**	**BH2**	**BH3**	**BH4**	**BH5**	**BH6**			
Sep. 2002	21	32	29	28	25	36			
Jan. 2003	42	52	42	44	42	42			
Apr. 2003	23	21	28	21	24	25			
Sampling times	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**
Sep. 2002	82	85	114	86	70	123	79	106	91
Jan. 2003	134	148	125	159	134	136	113	91	98
Apr. 2003	87	93	95	85	87	84	76	108	105

The results also showed that the species number at each sampling site from Lak Lake were much higher than those from Bien Ho Lake (Tables 4). Consequently, the biodiversity of phytoplankton from Lak Lake (312 species) was much higher than that from Bien Ho Lake (98 species). This difference was mainly contributed by the four phytoplankton groups, green algae, euglenoids, diatoms and cyanobacteria (Table 2). The majority phytoplankton families occurred in Lak Lake but could not be found in Bien Ho Lake were *Hydrodictyaceae* (e.g. *Pediastrum*), *Desmidiaceae* (e.g. *Closterium, Cosmarium, Euastrum, Micrasterias*) (green algae), *Euglenaceae* (e.g. *Euglena, Phacus, Lepocinclis, Trachelomonas, Strombomonas*) (euglenoids), *Eunotiaceae* (e.g. *Eunotia*), *Naviculaceae* (e.g. *Navicula, Pinnularia, Cymbella*), *Nitzschiaceae* (e.g. *Nitzschia*) (diatoms), *Chroococcaceae* (e.g. *Microcystis, Chroococcus*), *Oscillatoriaceae* (e.g. *Oscillatoria*) and *Rivulariaceae* (e.g. *Gloeotrichia*, *Calothrix*) (cyanobacteria) (Fig. 3).

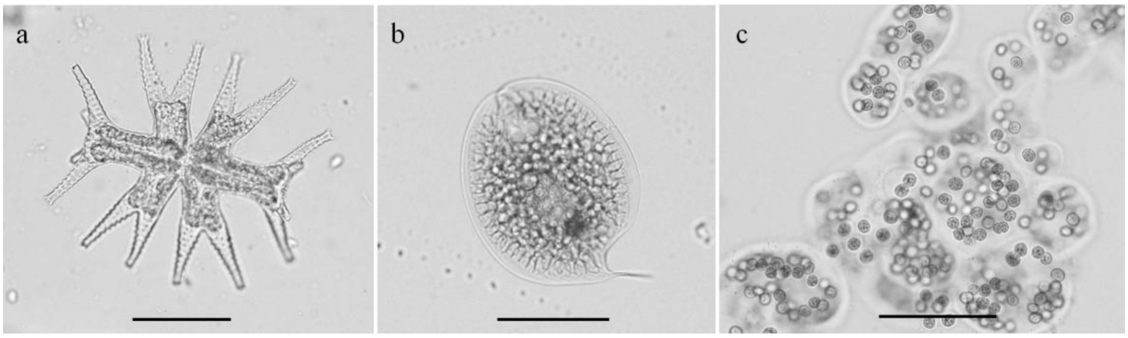

Figure 3. The common algal genera found in Lak Lake but not found in Bien Ho Lake. a, *Micrasterias*; b, *Phacus* and c, *Microcystis*; scale bars = 50 µm

Phytoplankton abundance

Phytoplankton densities in surface water from Bien Ho Lake were from 1 577 000 – 2 351 000, 2 555 000 – 4 701 000 and 6 832 000 – 10 312 000 individuals/L in rainy season, trans-season period and dry season, respectively (Fig. 4a, b, c). The results showed that phytoplankton densities increased around 3 - 4 folds from rainy to dry seasons.

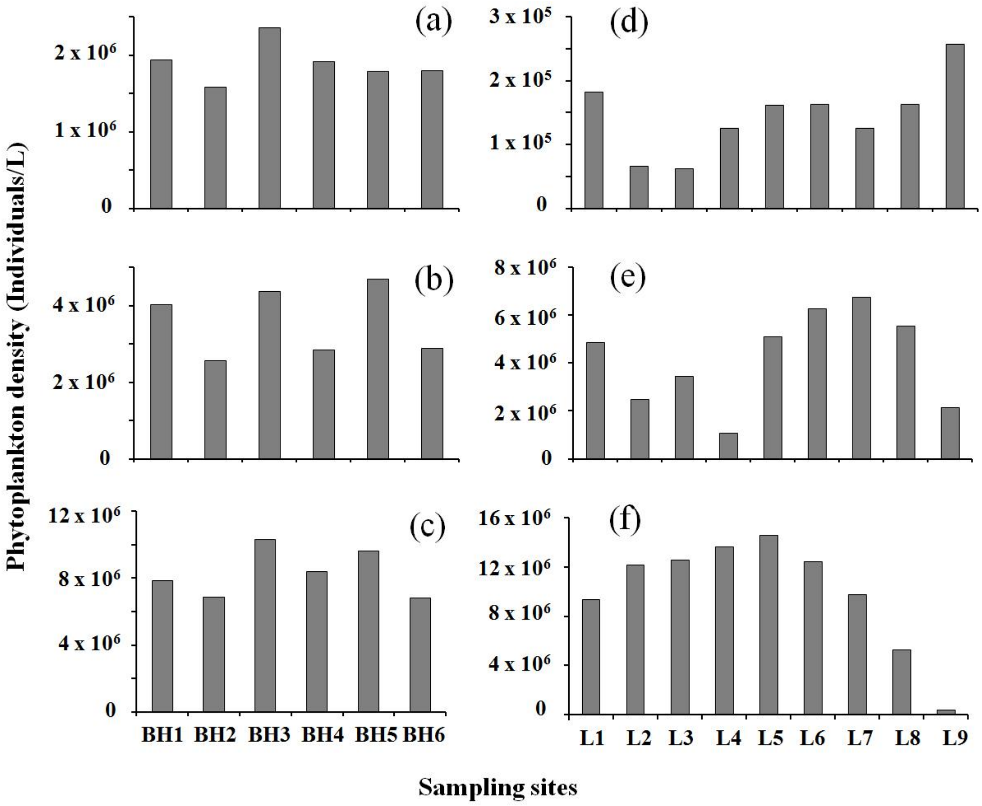

Figure 4. Phytoplankton densities from Bien Ho (BH1 – BH6) and Lak (L1 – L9) Lakes during the monitoring. (a) and (d), rainy season; (b) and (e), trans-season period; (c) and (f), dry season.

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From Lak Lake, phytoplankton densities ranged from 62.400 – 256 800, 1 057 000 – 6 750 000 and 362 000 – 14 580 000 individuals/L in rainy season, trans-season period and dry season, respectively (Fig. 4d, e, f). The phytoplankton densities were comparable between the two water bodies in dry season and trans-season period (Fig. 4b, c, e, f). However, in rainy season they were much lower in Lak Lake than in Bien Ho Lake (Fig. 4a, d). In addition, the only dominant species of phytoplankton densities in Bien Ho Lake at all sampling sites and sampling times was *Planktolyngbya limnetica*. However, there were several species dominant in quantitative samples at different sites and times of sampling in Lak Lake such as *Aulacoseira granulata*, *Trachelomonas volvocina v. derephora*, *Planktolyngbya limnetica*, *Achnanthes* cf. *gracillima*, *Dictyosphaerium pulchellum* of which *Planktolyngbya limnetica* was dominant at all sites in dry season and at several sites in the other sampling times, rainy season and trans-season period.

3.3 Relationship between Phytoplankton and Environmental Parameters

The Canonical Correspondence Analysis (CCA) of the environment parameters and phytoplankton (Fig. 5) showed that there were three groups of sampling sites of the three sampling times. Species composition of phytoplankton was strongly different among the sampling times. Positions of the sampling sites at trans-season period were closed to each other on the ordination plane reflecting the highly similar phytoplankton characters among the sites. This happened again in dry season except the sampling site 6 which was separated from the other sites. In rainy season, the sites 1 and 2 separated from the others.

The CCA result showed Bien Ho and Lak Lakes had similar characters of group distribution in each sampling time on the ordination plane (Fig. 5). Phytoplankton communities were different in each season at the two lakes. Besides, the two groups of site distribution of Bien Ho and Lak Lakes were completely separated. The environmental variables BOD_5, N, DO, SO_4, Mg had little correlation with the species composition distribution of phytoplankton at the two lakes. In Lak Lake, the parameters pH, turbidity (DD), COD, Fe, EC, Al had a directly close correlation with the algal distribution. The vector direction of the above parameters was opposite to that of transparency (DT) of which the latter was the only factor playing the clearest correlation with the phytoplankton distribution in Bien Ho Lake (Fig. 5).

The curves in the Figure 6 showed the borders of the biodiversity index values. The results showed that the parameters of nitrogen, SiO_2, DO, Mg, total phosphorous, turbidity and pH seemed to have no relation with the alteration of biodiversity of phytoplankton from Bien Ho Lake. In contrast, the increasing direction of the parameters Al, SO_4, COD, BOD, EC, Ca, Fe and HCO_3 was parallel with that of algal biodiversity index values from Bien Ho Lake. The CCA results showed the parameters Mg, Ca and nitrogen had minor relation with the changes of algal biodiversity from Lak Lake (Fig. 6). The vector direction of DO and BOD was in line with the increase of algal biodiversity index values. However, transparency revealed the negative relation with the algal biodiversity from Lak Lake (Fig. 6).

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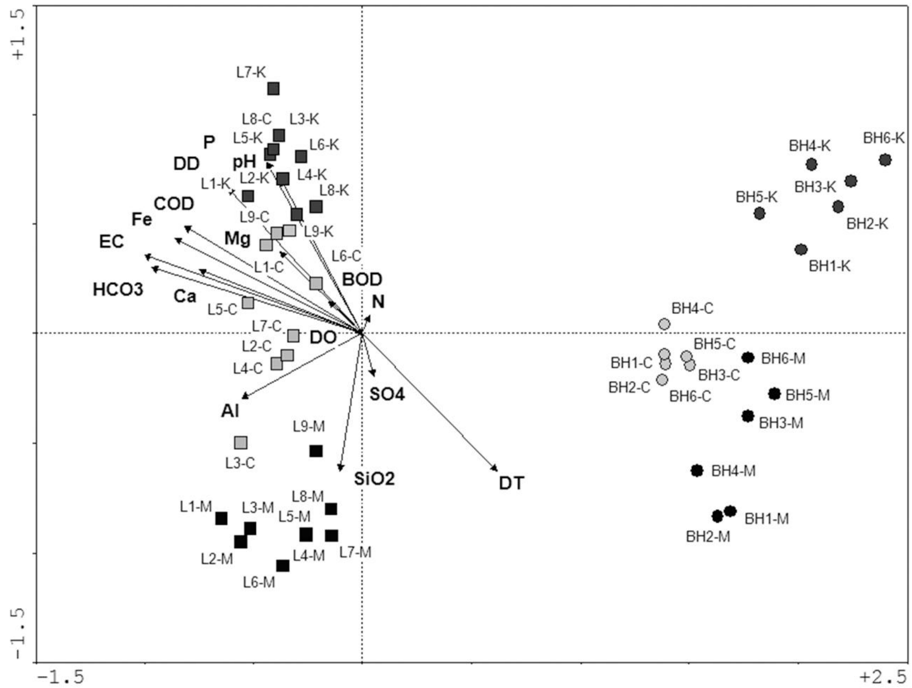

Figure 5. Relationship between phytoplankton and environmental parameters between the two lakes based on CCA. M, rainy season; C, trans-season period; K, dry season; DT = transparency; other abbreviations as in Table 1.

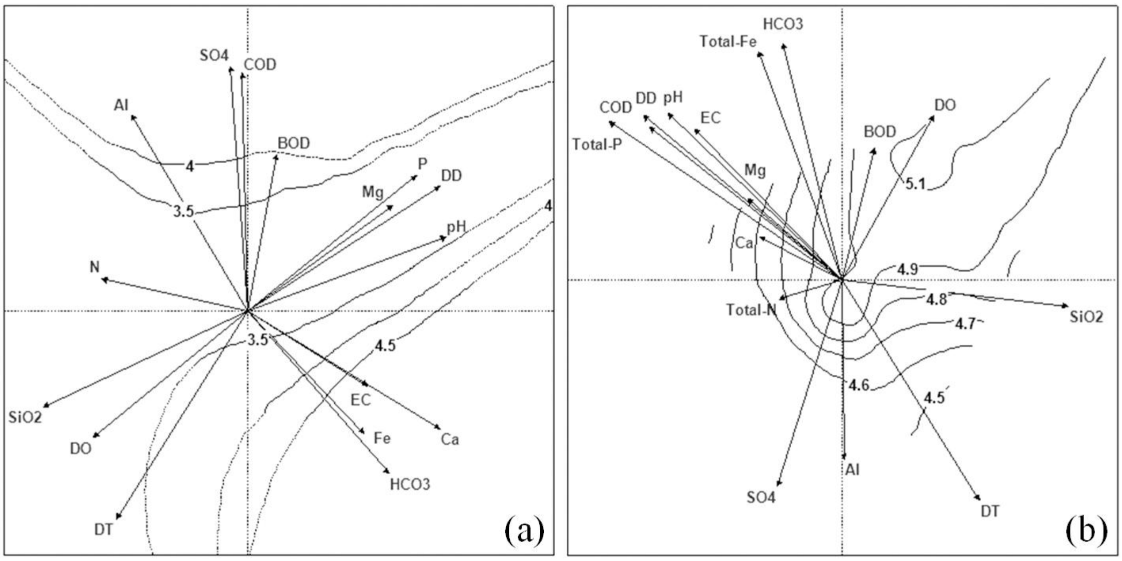

Figure 6. Relationship between algal biodiversity and environmental parameters in Bien Ho Lake (a) and Lak Lake (b) based on CCA. Abbreviations as in Table 1 and Figure 5.

4. Discussion

4.1 Environmental Parameters

Different water temperature was reported in rivers, lakes and reservoirs between the Northern (around 24 ℃) and Southern (28 – 32 ℃) regions in Vietnam (Dao et al., 2010; Duong et al., 2013; Dao and Bui, 2016). Interestingly, water temperature in Bien Ho and Lak Lakes in central highland ranged between that from the two regions of Vietnam, from 23 – 28 ℃ (Table 1, 2). This difference should be closely related to the geographical conditions in which the two lakes in this study are located at around 1 500 m above the sea level (MOST, 2001) whereas other water bodies in the previous investigations in the Northern and Southern Vietnam are in the delta regions or not more than 70 m above the sea level. The pH values in the two lakes of this study were comparable and had similar seasonal changing tendency. This may be that the two lakes share the similar annual precipitation and hydrology (e.g. run off water) of the central highland. In general, the pH of water in these two lakes were higher than that from several standing water bodies in Vietnam such as Tri An, Dau Tieng and Nui Coc Reservoirs (Dao et al., 2010; Duong et al., 2013; Pham et al., 2015). The temperature and pH in Bien Ho and Lak Lakes should offer favorable conditions for phytoplankton growth according to Wetzel (2001).

Turbidity or transparency reveals the photic conditions or layers of water bodies which is closely related to the photosynthesis and distribution of phytoplankton in water column. Lower turbidity and higher transparency in Bien Ho than Lake Lakes imply a higher advantage condition for seasonal photosynthesis in Bien Ho Lake which needs further *in situ* investigations to confirm.

The DO in water of deep water bodies could be enhanced by photosynthesis activity. However, in large and shallow lake like Lak Lake, the strong wind would be the main regulator for the DO increase. This might be the root for the higher DO concentration in Lak (4.9 – 8.4 mg/L) than in Bien Ho (4.7 – 7 mg/L) Lakes (Table 1, 2). Generally, the COD and BOD_5 values in Lak Lake were higher than in Bien Ho Lake which helps to explain the much higher nitrogen and phosphorus concentrations in Lak Lake compared to in Bien Ho Lake (Table 1, 2). The nitrogen concentrations in Bien Ho showed an un-favorable condition for phytoplankton growth (Horne and Goldman, 1994) and the phosphorus concentration in this lake characterized for mesotrophic condition (Reynolds, 2007). Differently, in Lak Lake the nutrients were favorable for the development of phytoplankton especially the phosphorus concentrations (0.003 – 0.052 mg/L, Table 2) revealed the mesotrophic to eutrophic condition of the water body according to Reynolds (2007).

Iron and magnesium are two important metals for many important activities of phytoplankton especially photosynthesis (Wetzel, 2001). Silicate is not used by green algae, dinoflagellates and cyanobacteria but is an essential chemical for diatoms and golden algae as it contribute to the cell structure and content inside the cells (Wetzel, 2001). Sulfur (S) is an important part in protein and enzyme structure in cells while carbonate offers the essential air chemical (CO_2) for photosynthesis of phytoplankton. In general, the concentrations of trace elements (Fe, Mg, Ca; Table 1) should favor the requirement of phytoplankton growth.

The cluster analysis based on the environmental parameters revealed a high homogeneous water conditions in Bien Ho Lake in every time of sampling (> 95% similarity; Fig. 2). However, the water characteristics in Bien Ho Lake were quite different seasonally. This might be related to the geographical conditions of Bien Ho Lake in which the lake is located on top on a volcanic mountain and water quality was slightly influenced by human activities. On the contrary, Lak Lake is larger than Bien Ho Lake, and located in a lowest position compared to the surrounding habitats and receives water from several streams, and impacted by many local human activities (agriculture, poultry and cattle raising, domestic waste...). Hence, water characteristics in Lak Lake were regulated and influenced by multi-factors consequently the similarity values were much varied temporally and spatially (Fig. 2). The variation of environmental variables in the two lakes should lead to the alteration of phytoplankton community structure and abundance seasonally.

4.2 Phytoplankton

In nature, many algal and cyanobacterial species coexist in the same water body (Wetzel 2001) which is supported by the results in the current study (Table 3). The two lakes in our study shared the same characteristic that green algae were dominant in phytoplankton species composition which is in line with previous investigations in the North, South and Central highland in Vietnam (Dao 2010; Duong et al. 2013; Tran et al. 2015). In addition, golden and yellow algae and dinoflagellates were less diverse groups in both Bien Ho and Lak Lakes which could be explained as the meso-eutrophic conditions of the lakes were not favorable for development of the algae found in the current study, *Dinobryon*, *Mallomonas*, and *Tribonema*, which are characterized for clean water or oligotrophic condition (APHA 1998; Wetzel 2001). Besides, that Diatoms in the two lakes was lower in species richness should relate to the lentic water characteristics of the Bien Ho and Lak Lakes which are not as suitable as running water conditions for Diatoms' growth (Dao and Bui 2016). Again, both Bien Ho and Lak Lakes had less species number in dry season and higher species number in trans-season period (Table 4). This could be explained as the water level in the lakes was lowest in dry season and the nutrients and trace elements were enriched and introduced into the lakes through the run-off water during the first rains of the trans-season period. However, the species richness in the two lakes (98 species in Bien Ho Lake and 312 species in Lak Lake) was much higher than that in previous studies (73 species in Bien Ho Lake and 93 species in Lak Lake; Dao 1998; Le and Hoang 2001). The much higher species richness of phytoplankton in Lak than Bien Ho Lakes should be related to (i) the larger area of Lak Lake than Bien Ho Lake, (ii) the shallower water body consequently more turbulence in Lak Lake compared to Bien Ho Lake and (iii) favorable nutrient concentrations in Lak Lake especially from the income springs and local anthropogenic activities. Generally, the species number or biodiversity of phytoplankton in Lak Lake were higher than those from other freshwater bodies in Northern (e.g. Nui Coc Reservoir) and Southern (e.g. Tri An Reservoir) in Vietnam (Dao 2010; Duong et al 2013).

The seasonal alteration of phytoplankton abundance was similar in both Bien Ho and Lak Lakes, lowest in rainy season and highest in dry season (Fig. 4). This should be related to the lower water transparency in rainy season (Table 1) which reduced the photosynthesis of phytoplankton in water bodies. However, the density of phytoplankton in the current study was much higher than that in previous investigations in the same lakes (Dao 1998; Le and Hoang 2001). Probably, this might be related to the nutrient enrichment to the lakes through several years enhanced the development of phytoplankton which needs further monitoring in the coming years to confirm. It was so interesting that the only cyanobacterium *Planktolyngbya limnetica* was dominant in Bien Ho Lake during the three monitorings. This might be explained as *P. limnetica* is a very small size species (not more than 2 µm in diameter) and cyanobacteria possess many advantage characteristics such as optimal growth in higher temperature, bouncy, nutrient uptake, adjustment their position in water column among others to overcome and out compete the micro algae in water bodies (Dao 2010). Differently, the environmental conditions were strongly varied in Lak Lake due to the lake size, water depth, high turbulence, local effects of human activities consequently the dominance in phytoplankton density in the current study was shared by different species of Diatoms, euglenoids, green algae and cyanobacteria.

4.3 Relationship between Phytoplankton and Environmental Parameters

The environmental parameters are the basic conditions for living and growing of phytoplankton. Hence, the seasonal changes of environmental conditions would lead to the alteration of phytoplankton. These are the roots for the group formation of both biotic and abiotic factors on the ordination plane from CCA. Duong et al. (2013) reported the correlation between phosphorus concentration and abundance of cyanobacteria. Dao and Bui (2016) noted the phytoplankton species richness positively correlated with temperature but negatively correlated with nitrate concentration. The same author showed the biodiversity positively correlated with temperature and species number, but negatively correlated with nitrate and phytoplankton abundance. However, in our study algal distribution positively correlated with pH, turbidity, COD, EC, aluminum and iron concentrations, especially the water transparency. Probably, different water bodies, environmental characteristics, eutrophic conditions and dominated phytoplankton groups would result in the different correlation between environmental variables and phytoplankton species and abundance.

5. Conclusion

The environmental parameters of surface water in Bien Ho and Lak Lakes were seasonally varied. The temperature and pH in both lakes were favorable for the development of phytoplankton. In Bien Ho Lake the nitrogen concentrations seemed to be limit where as the phosphorus concentration was advantageous for algal growth. However, in Lak Lake the nutrients, characterized for mesotrophic to eutrophic conditions, were favorable for the development of phytoplankton. Besides, the concentrations of trace elements (Fe, Mg, Ca) in two lakes should be within or higher the requirement of phytoplankton growth. Generally, the biodiversity and abundance of phytoplankton in Lak Lake were higher those in Bien Ho Lake. The cluster analysis revealed that the similarity of aquatic environmental parameters of Bien Ho Lake was clearly separated among the seasons and that of Lak Lake was overlap between the dry season and trans-season period. The seasonal variation of phytoplankton was similar from both lakes, higher in rainy season and lower in dry season. The distribution of phytoplankton positively correlated with pH, turbidity, COD, EC, aluminum and iron concentrations, especially the water transparency. The water transparency was the only factor playing the clearest correlation with the phytoplankton diversity in Bien Ho and Lak Lakes.

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