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Research Article

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Temporal variation of phytoplankton community structure in Lake Mohicap, San Pablo City, Laguna, Philippines

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ABSTRACT

San Pablo City in Laguna province (Luzon Island) is known *for its seven freshwater lakes, one of which, Lake Mohicap, is of major use for aquaculture. This year-round study (April, 2013-March, 2014) involving biweekly water sampling evaluated the phytoplankton community structure in the lake in terms of occurrence of dominance by phylum of major groups and their succession by season and the relationship between water quality parameters. In terms of cell density, Bacillariophyta (Ba) showed the highest abundance, followed in decreasing order by the Cyanophyta (Cy), Chlorophyta (Ch), and both Euglenophyta and Dinophyta. Ba and Cy co-dominated in the rainy season (June-Nov), Ba, Cy and Ch in cool dry season (Dec-Feb), and, again, Ba and Cy in hot dry season (Mar-May). Results of Pearson's correlation coefficient (r) between phytoplankton densities by phylum and the water quality parameters were consistently negatively significant. Cyanophyta was not correlated with all considered parameters. Dinophyta was correlated negatively significant with nitrate (n) and conductivity (c), as did Euglenophyta with temperature (te), phosphate (p), n, and dissolved oxygen (DO), and Chlorophyta with transparency (tr), te, p, n, and DO. Only Bacillariophyta gave significant positive correlations with te, p, n, DO and chlorophyll a, but it still was with significant negative correlation with tr. Overall, Mohicap is a small lake and its phytoplankton community exhibited temporal (seasonal) but not spatial fluctuations in physico-chemical water parameters. Its use in aquaculture is in jeopardy making its water quality in critical level.*

***Keywords**: Lake Mohicap (Philippines), phytoplankton, temporal variation, physico-chemical parameters*

INTRODUCTION

Aquatic ecosystems are highly susceptible to spatial and temporal changes, their component phytoplankton community included[4]. The phytoplankton is an assemblage of primary producers occurring mainly in the upper stratum of the water. In this assemblage prokaryotic (blue-green algae or cyanobacteria) and eukaryotic organisms (algae in different phyla) vary widely in size and growth organization at the microscopic level[3], hence constitute the all-important foundation of the food web in the ecosystem[7,5,38].

In freshwater lakes in the tropics, the phytoplankton community serves as a long-term gauge of potential total productivity, energy flow and fish yield, and likewise of the trophic status of the lakes[26]. Alterations in species composition, biomass and primary production have a major impact in the environment[29,36].

These correlate with seasonal changes in the physico-chemical properties of the water such as levels of pH, temperature[6], transparency, dissolved oxygen[24], phosphate, nitrogen[23] and zooplankton grazing[15].

San Pablo City in Laguna province (Luzon Island) is known for its seven lakes, one of which, Lake Mohicap, is of major use for aquaculture. Global Nature Fund (GNF) has pronounced Lake Sampaloc and the six other lakes, that includes Lake Mohicap as the "Threatened Lake of the Year 2014" because of the deterioration of water quality resulting from proliferation of fish cages, aquaculture malpractices (e.g., overstocking and overfeeding), illegal physical constructions along the shoreline, pollution and other anthropogenic activities[12]. The Environmental and Research Division of the Laguna Lake Development Authority (LLDA) have been monitoring the phytoplankton community in Lake Mohicap since mid 1990's. Categorized into phyla, Cyanophyta and Chlorophyta dominated from 1996 to 2005, Chlorophyta in 2006 to 2008, Cyanophyta and Chrysophyta in 2010 and 2011, and Chrysophyta and Cyanophyta in 2012[19,20,21,22]. However, there is no detailed information on both the temporal and spatial variations of the phytoplankton community in relation to changes in the physico-chemical parameters of the water. It is this aspect that the present study is focused on Lake Mohicap from April, 2013 to March, 2014.

MATERIALS AND METHODS

Study Area

Lake Mohicap (N 14˚ 07.330', E 121˚ 20.078'), one of the famed seven lakes in San Pablo City, is located in Barangay San Buenaventura (Fig. 1.). Its surface area is 22.89 ha, and maximum depth of 39.2m[19]. It is of volcanic origin, as are its six sister lakes, formed by the eruption of distant Mt. San Cristobal nearby Mt. Banahao. Lava from the eruption intersected with the groundwater forming concentric depressions which then eventually filled with water. These lakes are natural resting places of migratory birds coming from China and Japan in winter[31]. The LLDA by virtue of Republic Act 4850 in 1966 has jurisdiction over Lake Mohicap. It is responsible for the development, environmental management and control, preservation of the ecological systems, and prevention of the deterioration and pollution of the lake. Lake Mohicap water is "Class C" type of inland water, i.e., suitable for growth and propagation of aquatic resources, recreation and industrial use [Dept. of Environmental & Natural Resources (DENR) Administrative Order No. 34, Series of 1990][8]. Philippines experiences two alternating seasons each year. The *rainy season* starts in June and ends in November and the *dry season* begins in December and extends till May. Philippine Atmospheric, Geophysical & Astronomical Services Administration (PAGASA) further subdivides the dry season into *cool dry* (December-February) and *hot dry* (March-May) seasons[27]. This 3-season-year calendar was adopted in this study.

Water Sampling

Lake Mohicap was cross-transected into four approximately equal-sized sections for even collection of samples. Three marked linear sampling stations equidistant to each other were then established diagonal to each section. Water sampling was done biweekly each month from April, 2013 to March, 2014, between 11:30 am and 4:00 pm. A 3-L customized Plexi glass water sampler was used for three hauls each from the surface, middle and bottom of the water column at each sampling station. The total amount of samples was then pooled or integrated into one sample. From the latter, 1 L was quickly fixed *in situ* by the addition of a few drops of 70% Lugol's iodine solution, then sealed in plastic bottle; this was used in *ex situ* determination of phytoplankton composition and density. Another 1 L was untreated, placed and sealed in plastic bottle, kept cool during transport, and frozen in the refrigerator in the laboratory for later use in *ex situ* determination of chlorophyll *a*, nitrates and phosphates.

Water Physico-chemical Parameters

For physical parameters, water temperature, water transparency and rainfall were included. Xplorer GLX was used for temperature and, for transparency, a 30-cm Secchi disk was used and determined *in situ*. For rainfall data, it was obtained from a government institution (PAGASA). For chemical parameters, these include chlorophyll *a*, nitrates, phosphates, pH, conductivity and dissolved oxygen. Recommended method of American Public Health Association (APHA) 2000 was followed for chlorophyll *a* determination[1].

Nitrates and phosphates were measured using a HACH DREL 2800 Complete Water Quality Lab Equipment. Dissolved oxygen, conductivity and pH were evaluated *in situ* using Xplorer GLX water sensor. When this was not available for field use, however, Lutron PDO-520 and Hach Water Quality Test Strips were substituted for DO, temperature and pH, respectively.

Phytoplankton Density

The protocol of Martinez *et al.*, was followed. Ten-mL aliquots from iodine-fixed water samples were centrifuged (20,000 rpm) for 10 minutes and appropriate amounts were loaded in Neubauer Counting Chamber for density determination as viewed using Olympus CH20 compound light microscope[25].

Statistical Analyses

Normality of the data for the physico-chemical parameters and phytoplankton abundance in four sampling sections was tested using Shapiro-Wilk test. Results showed that these were not normally distributed. Non-parametric Kruskal-Wallis test was then used for further analysis. Results showed that there was no significant difference between the physico-chemical water parameters and phytoplankton abundance by phylum among the four sampling sections. This may be attributed to the relative small size of the lake. To determine the relationship between the phytoplankton groups (phyla) and physico-chemical parameters, Pearson's Correlation Coefficient (r) was used.

RESULTS AND DISCUSSIONS

Water Physico-chemical Parameters

Temperature was highest in May (30.0ºC) during the hot dry season and the lowest was in January (25.8ºC) during the cool dry season in the country (Table 1). Transparency was lowest in April (1.3 m) during the hot dry season and its highest was in September (4.1 m) during the rainy season. Nitrates content was highest in June (25.8 mg/L) during the onset of the rainy season and lowest in January (3.2 mg/L) during the cool dry season. From April to July 2013, the amount exceeded by about 1½ the allowable limit for Class C type of inland water set by the DAO 1990. Phosphates level recorded was highest in June (2.4 mg/L) and lowest in March (0.8 mg/L). The levels determined throughout the one-year water sampling were consistently way above the limit for fish aquaculture in lakes. The high amounts of nutrients in Lake Mohicap may be attributed to aquaculture malpractices and anthropogenic activities in the area[19,21,12]. Dissolved oxygen (DO) was highest in May (7.8 mg/L) towards the end of the hot dry season. This could be due to the presence of high density of phytoplankton that contributed DO thru photosynthesis. Rainfall in the country, according to PAGASA, peaks during the rainy season [417.6 (318.3-682.0)mm][28]. The lowest DO recorded was in February (3.3 mg/L) in the cold dry season. This coincided with the low density of phytoplankton and low rainfall. From the mid-January to mid-February 2014, the amount of DO was in critical value. It was below the set limit that can support good aquaculture in Class C type of water[8]. The pH value was maximum in April (7.9) and lowest in June (5.7). The pH values in June and July could have been due to the upwelling that occurred in mid-June. Upwelling increases the amount of nutrients in the water column. Fish kill was observed during that time. Also contributory to acidification were run-off water from surrounding areas and intense aquaculture. Conductivity reading was highest in January (560.4 µS/cm) and lowest in April (326.0 µS/cm). Range of conductivity that can support good mix of fisheries in freshwater ecosystem is from 150 to 500 µS/cm. Values outside this range can be harmful to some species of fish or macro invertebrates[10]. The high value of conductivity in January could be due to the upwelling that happened in the middle of the month causing nutrients from the bottom sediment to mix in the water column. Another fish kill was observed during this time. Highest amount of chlorophyll *a* was in the hot dry season in the month April (0.242 mg/L and its lowest was in the cool dry season, in the month of January (0.011 mg/L (Figure 3f). This observation was also supported by the evaluation of phytoplankton density.

Phytoplankton Density

Direct cell counts by phylum with the use of Neubauer Counting Chamber[25] and transformed to cell density clearly showed the diatoms as the most numerous, followed in decreasing order by the cyanophytes, chlorophytes, and both the euglenophytes and dinophytes.

The occurrence of nearly all the phytoplankton species in the different phyla exhibited remarkable fluctuations throughout the year. Highest and lowest cell densities for diatoms were 4.036×10^5cells/mL in April and 0.007×10^5cells/mL in January (Fig. 2b). *Aulacoseira granulata*, *Synedra ulna*, *Cyclotella menegheniana, Nitzschia amphibia, and Navicula accomoda* were the most abundant and dominant species of diatoms in the entire sampling period. *A. granulata* and *S. ulna* were frequently accounted at all sampling times. For the chlorophytes, highest and lowest densities recorded were 0.380×10^5cells/mL in February and 0.007×10^5cells/mL in December (Fig. 2a). Among the green algae, of *Chlorella* sp., *Kirchneriella* sp., *Crucigenia* sp., *Closterium* sp. and *Staurastrum* sp. were dominant during the rainy months and dry cool months, while *Pediastrum* sp. and *Ankistrodesmus* sp. appeared rare except during summer months. Cyanophytes were abundant the whole year with peak counts at 1.348×10^5cells/mL in March, 1.065×10^5cells/mL in May and 1.057×10^5cells/mL in October (Fig. 2c). For the blue-greens, *Merismopedia glauca, Anabaena catenula, Oscillatoria* sp., *Synechocystis* sp. and *Lyngbya* sp. were quite common during the dry season. Euglenophytes and dinophytes were encountered respectively in nearly all sampling months and in July-January, but cell densities were very low, highest at 0.009×10^5cells/mL for the former and less than 0.005×10^5cells/mL for the latter (Figs. 2d & 2e).

Seasonal variation of phytoplankton community

Overall, all five groups (phyla) of phytoplankton were present but with oscillations in cell counts throughout the year (Fig. 2). When counts for the groups were totalled, expressed in percentages, and clustered into the three seasons qualified by PAGASA[27], the relative proportions of each group in the total community per season became clear (Fig.3). During the rainy season (Jun-Nov), the phytoplankton community in Mohicap was dominated by Bacillariophyta (55%) and Cyanophyta (41%). Chlorophyta was at a low 3%. Come cool dry season (Dec-Feb), however, there was a near complete reversal in abundance among these three groups. Cyanophyta (45%) and Chlorophyta (36%) outnumbered Bacillariophyta (18%). Advent of the hot dry season (Mar-May) completed the cycle; overall relative proportions of the groups resembled those in the rainy season. Chlorophyta was down again to 3%. Bacillariophyta (74%) increased by about 20%, as much as did Cyanophyta (22%) decrease its abundance in the phytoplankton community. Euglenophyta and Dinophyta, each with two genera and two species occurred during the rainy season till the following cool dry season but only as minor components of the phytoplankton community in the lake (Figs. 2d & 2e). Their relative composition is less than 1% and was not included in Fig.3. Since all five groups co-occurred year-round in the water, blending of their intrinsic visible colorations was expected. Thus, when Bacillariophyta and Cyanophyta were dominant during the wet and hot dry seasons, water in Lake Mohicap appeared turbid and bluish-brown. But when both co-occurred with Chlorophyta during the cool dry season, lake water turned bright dark green.

Pearson's Correlation Coefficient

Pearson's Correlation Coefficient (r) was used to determine possible direct positive or negative relationships between the set of water physico-chemical parameters and phytoplankton densities by phylum. Chlorophyta was negatively correlated with transparency (p=0.001), temperature (p=0.000), phosphates (p=0.000), nitrates (p=0.020) and dissolved oxygen (p=0.000). These green algae occur in lakes with a wide range of trophic conditions, from oligotrophic to hypereutrophic. They become dominant or co-dominant in early summer or during clear water phase[2]. The results suggested that high density of Chlorophyta in Lake Mohicap occurred in the month of January during the cool dry season extending to March during the early hot dry season. Bacillariophyta was negatively correlated with transparency (p=0.016), but positively correlated with temperature (p=0.001) phosphates (p=0.000) nitrates (p=0.000), dissolved oxygen (p=0.001) and chlorophyll *a* content (p=0.000). The results showed that Bacillariophyta (diatoms) highly dominated in the months of April to June 2013 when phytoplankton densities, phosphates and nitrates were highest. These nutrients are the limiting factors in the productivity in freshwater environment, the former in temperate lakes and the latter in tropical lakes[30]. When nitrogen supply is high, diatoms dominate because of their enhanced storage capacity for the element[18]. Moreover, it is a well-known fact that the diatoms have a more efficient nutrient uptake system[34] as reflected by their higher intrinsic growth rates.

They occur in a wide range of trophic conditions but are normally abundant in eutrophic environment[2] hence, serve as a good indicator of acidification, eutrophication and climate change[37,14]. Phytoplankton generally plays an important role in the regulation of global climate system. They produce compounds, e.g., organic sulfur, as a defense from the harmful effects of sunlight and ultraviolet radiation[9]. Cyanophyta (blue-green algae) showed no correlation with all the physico-chemical parameters of water quality. In tropical and subtropical countries, blue-green algae may dominate at any time and their dominance may continuously persist in the entire year[13]. In the present study, densities of these prokaryotes fluctuated all year round and, compared to other groups, were highest in all three seasons. They are present in oligotrophic to eutrophic waters[2], can tolerate high pH and low CO_2 concentrations[35], survive and reproduce even in a low nitrate and phosphate environment[33,2] and have depth regulation buoyancy[35]. Zooplankton and even macro invertebrates in most scenarios cannot effectively prey on filamentous blue-green algae (e.g., *Oscillatoria, Anabaena* and *Lyngbya*) which are generally inedible[32] and grazer-resistant[18]. Euglenophyta was negatively correlated with temperature (p=0.015) phosphates (p=0.014), nitrates (p=0.026) and dissolved oxygen (p=0.002). The euglenoids are not useful as biological indicators. They are abundant in enriched decaying organic environment and can thrive even in very low pH[2]. In this study densities of euglenoids were abundant in the months of July-August and February-March. These were the months after the upwelling and fish kill had occurred. Dinophyta has a significant negative correlation with nitrates (p=0.016) and conductivity (p=0.002). These dinoflagellates appeared in July, 2013 after the bloom of diatoms and onwards in January 2014. Their growth is favored after depletion of some inorganic substances[17] and in environments with high concentrations of calcium ions[2]. Phytoplankton density was negatively correlated with transparency (p=0.17) but positively correlated with temperature (p=002), phosphates (p=0.000), nitrates (p=0.000), dissolved oxygen (p=0.005) and chlorophyll a (p=0.000). It was highest during the hot dry season when water quality was not good. High temperature favors the growth of the phytoplankton and increases the biological activities and chemical processes[16].

Lake Mohicap: Trophic Conditions Then and Now

Lake Mohicap in 1996-2012 was in eutrophic condition based on the level of chlorophyll *a* assessed by LLDA[21]. Some three months thereafter until the end of water sampling in this study (April, 2013-March, 2014), trophic conditions of the lake varied from mesotrophic to hypereutrophic based on the lake trophic states by Fuller *et al.*,[11]. It was mesotrophic at best based on the average annual Secchi disk transmittance but hypereutrophic at worst on account of the average annual readings for chlorophyll *a* and phosphates. Phosphates level throughout the study period was multiple times above the limit set by DAO 1990. Degradation of water quality leading to high phytoplankton density especially during the hot dry season (March-June) could be due to the inflow of domestic effluent from communities residing nearby and also to aquaculture malpractices by fish cage operators[19,21]. Summing up, water quality in Lake Mohicap remains in a critical state, just as it was in LLDA's report of 2012. Moreover, it gives credence to GNF's 2014 inclusion of Mohicap with Lake Sampaloc and the other five sister lakes in San Pablo City as the "Threatened Lake of the Year 2014".

Table 1. Lake Mohicap, April, 2013-March, 2014: Water parameters (means and ranges) by season

Parameters	Rainy Season (Jun - Nov)	Cool Dry Season (Dec-Feb)	Hot Dry Season (Mar – May)
Rainfall* (mm)	417.6 (318.3-682)	81.1 (30-192)	75.2 (2-132.6)
Conductivity (µS/cm)	471.5 (391.8-560.3)	469.8 (358.5-560.4)	458.8 (326-506.8)
pH	6.8 (5.7-7.6)	7.4 (7.1-7.6)	7.6 (7.2-7.9)
Temperature (ºC)	28.3 (27.8-29.2)	26.8 (25.8-27.7)	28.6 (26.8-30)
Transparency (m)	2.9 (2.0-4.1)	2.1 (1.5-4.0)	1.9 (1.48-2.4)
Dissolved oxygen (mg/L)	6.4 (5.3-7.6)	4.6 (3.3-5.8)	6.4 (5.8-7.8)
Phosphates (mg/L)	1.5 (1.1-2.4)	1.0 (0.8-1.2)	1.3 (0.8-1.9)
Nitrates (mg/L)	10.1 (3.3-25.8)	3.6 (3.2-4.0)	16.1 (4.0-25.0)
Chlorophyll *a* (mg/L)	0.041 (0.020-0.147)	0.030 (0.016-0.075)	0.123 (0.044 - 0.242)

*Rainfall data from Tayabas (Quezon) PAGASA Station, obtained from Climate & Agromet Data Section, Climatology and Agro Meteorology Division, PAGASA-DOST, Quezon City.

Table 2. Lake Mohicap, April, 2013-March, 2014: Pearson's correlation coefficients (*r*) between phytoplankton densities by phylum and physico-chemical water quality parameters

		Trans	Temp	pH	Phos	Nit	Cond	DO	Chlo *a*
Chloro-phyta	Pearson's Correlation	-.390	-.518	.103	-.420	-.273	.192	-.458	-.191
	Sig. (2-ailed)	.001	.000	.384	.000	.020	.103	.000	.105
Bacillario-phyta	Pearson's Correlation	-.282	.383	-.060	.570	.809	.030	.371	.842
	Sig. (2-tailed)	.016	.001	.615	.000	.000	.802	.001	.000
Cyano-phyta	Pearson's Correlation	.077	.044	.091	-.139	-.126	-.036	-.022	-.148
	Sig. (2-tailed)	.515	.711	.445	.242	.286	.764	.855	.211
Eugleno-phyta	Pearson's Correlation	.038	-.285	.121	-.286	-.261	.162	-.354	-.101
	Sig. (2-tailed)	.751	.015	.307	.014	.026	.172	.002	.397
Dinophyta	Pearson's Correlation	.073	.056	-.001	.022	-.282	-.356	.108	.021
	Sig. (2-tailed)	.541	.638	.990	.852	.016	.002	.361	.860
Total Density	Pearson's Correlation	-.279	.361	-.009	.472	.729	.029	.323	.760
	Sig. (2-tailed)	.017	.002	.938	.000	.000	.807	.005	.000

r in red, significant (p>0.05) and, in blue, highly significant (p>0.01).

Fig.1: Location map and photo of the study site (Lake Mohicap)

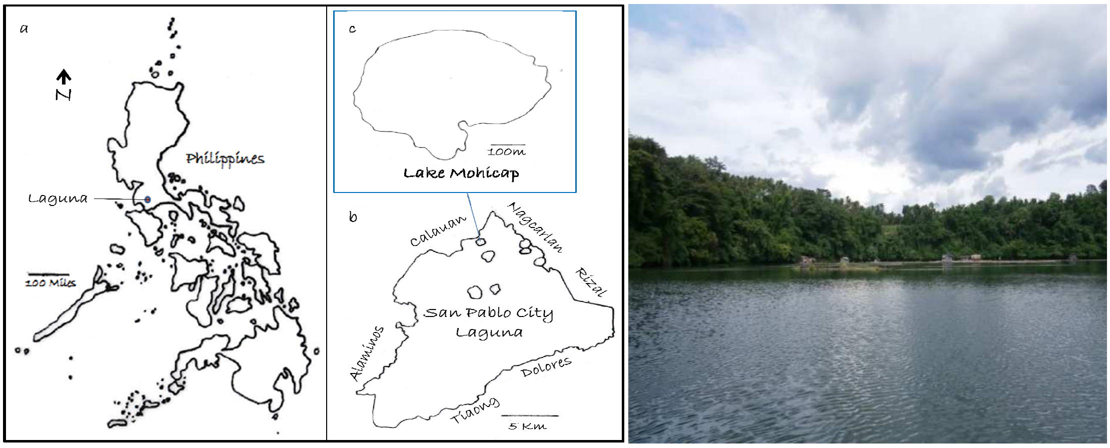
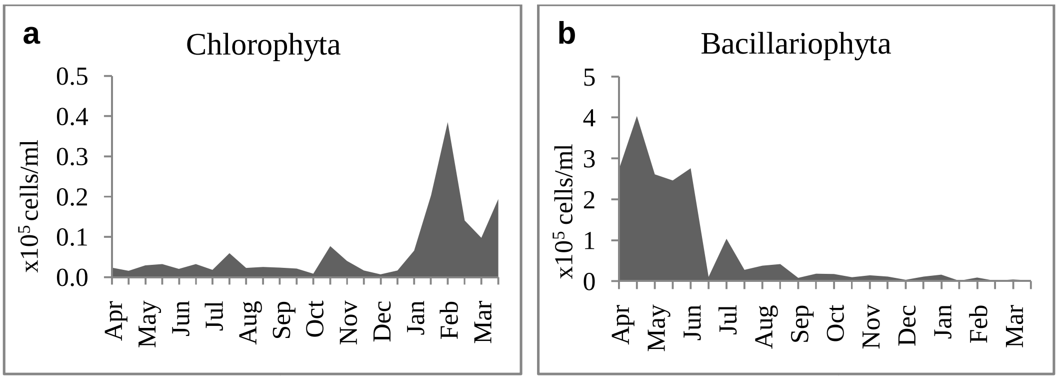


Fig. 2: Lake Mohicap, April 2013 – March, 2014: Biweekly densities of phytoplankton by phylum



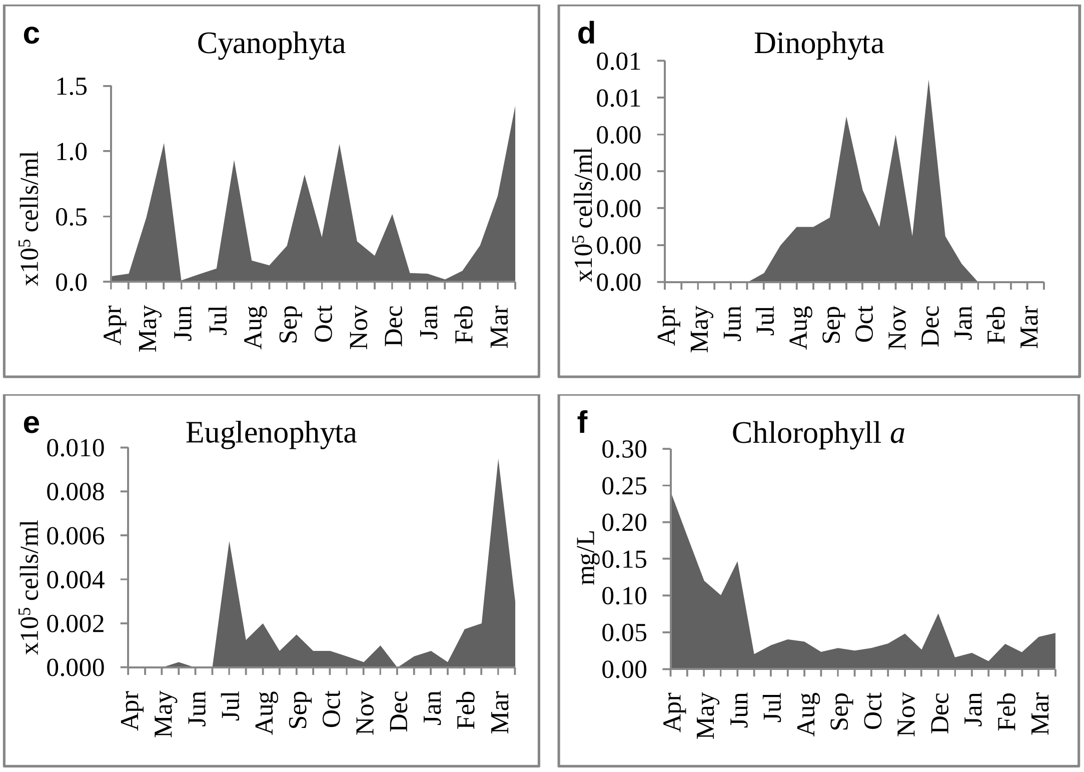
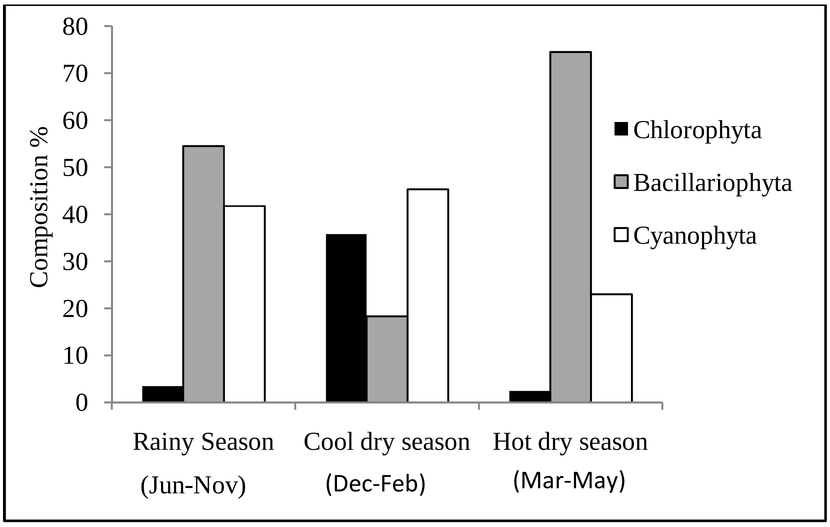


Fig. 3: Lake Mohicap, April 2013 – March 2014: Relative composition of the three major phytoplankton phyla by season



CONCLUSION

Lake Mohicap is only a small lake and its phytoplankton community exhibited temporal (seasonal) but not spatial fluctuations in physico-chemical water parameters which are generally with significant negative correlations with densities of the dominant Bacillariophyta, Cyanophyta and Chlorophyta. The dominance of the Bacillariophyta, Chlorophyta and Cyanophyta in this study tallied with the analyses done in 1996-2012, in these reports Bacillariophyta was given as Chrysophyta. It appears, thus, that the composition of the phytoplankton community in Lake Mohicap has not changed in nearly two decades (18 years, 1996 to 2014).

However, its continued utility in aquaculture is in jeopardy because of the critical state of its water, especially with the phosphate load far exceeding year-round the limit defined in DAO 1990.

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