ASSESSMENT OF PHYTOPLANKTON DIVERSITY IN TWO LAKES FROM THE NORTHEASTERN ALGERIAN SAHARA

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Abstract. Plankton is the basis of many food webs and is the main food of aquatic trophic chains. The primary productivity achieved by phytoplankton depends on the availability of nutriments. Phytoplankton biodiversity of two natural connecting lakes (Lella Fatma and Zerzaim) in the region of Megarine in South East of Algeria was studied during the period from January 2016 to December 2016. The relationships between the biomass of phytoplankton and the physicochemical properties of water were assessed in 28 genera of phytoplankton belonging to five classes (Mediophyceae, Coscinodiscophyceae, Bacillariophyceae, Euglenophyceae and Cyanophyceae). The statistical analysis performed during this study clearly shows that there is a strong correlation between differing physicochemical water parameters of the studied lakes and the influence on the phytoplankton population diversity.
Keywords: *phytoplankton, Megarine, lakes, diversity, nutriments*

Introduction

Natural lakes in arid areas constitute an important source to both ecological equilibrium and economical uses and in this ecosystem, biotic and abiotic components interact with them and determine the ecological statue of ecosystem (Awah, 2008). Population growth and the economic development are responsible for major modifications of water and the aquatic cycles are often perturbed by the excessive contributions in nourishing elements (Flandroy et al., 2018).

In addition to enriched nutrient content, these inputs induce an enhanced vegetation growth leading to an anarchic algal development, which propagate the unsightly appearance of water plans, emanation of unpleasant odors, death of aquatic species (Benredjeb and Romdhane, 2002; Brient et al., 2001). This has a detrimental effect on valuable ecosystem services, such as water supply, production, recreation, aesthetics, and more importantly the availability in sufficient quantity and quality that contributes to the maintenance of health. Enhanced anthropogenic activities deteriorate water quality (Chukwu et al., 2008) and impair their basic use through the process of pollution (Hur and Jung., 2009; Wu et al., 2005; Zhang et al., 2009).

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Algae are widely present in environments, such as streams, lakes and rivers and although relatively inconspicuous, they have a major importance, in terms of ecology and in relation to human use of natural resources. The maximum production of phytoplankton is obtained when the physicochemical factors are at optimum level (Muhammad et al., 2005).

The relation between the biodiversity and the functioning of the ecosystems is a fundamental ecological question and it is essential to know the potential effect of various abiotic and biotic elements (Zhang et al., 2018).

Phytoplanktons are highly diverse group of photoautotrophic organisms with unicellular reproductive structures, which are important for aquatic habitats (Ariyadej et al., 2004; Welker, 2008). They are important primary producers in the base of the food chain, constitute a vital link and an important biological indicator of the water quality (Laskar and Gupta, 2009). Maintenance of a healthy aquatic ecosystem depends on the biotic properties of water and the biological diversity of the ecosystem (Hillebrand et al., 2017).

In order to visualize the state of lakes in the Saharan region of Algeria, we have studied the spatiotemporal distribution of phytoplankton of two Saharan lakes during the year 2016, to determine the phytoplankton diversity and the abiotic factors responsible for their distribution.

The main objectives of the present study were (i) to measure the physicochemical factors of both lakes, (ii) to establish the inventories of phytoplanktons and (iii) to determine the spatiotemporal variations.

Material and methods

Study site

Megarine (Arabic: المقارين) is a town and commune in Ouargla province Algeria, it is located just North of Touggourt city. The region is made up of a large area of palm plantations surrounding an oasis network that extends from Sidi Slimane beyond Touggourt through to Balidat Ameur. Beyond the oases is the arid and barren landscape of the Sahara, featuring areas of sand dunes (ergs) and flat rocky plains (regs). The region of Megarine is approximately 285 km² (Dubost, 2002) in area and is located in the center of Touggourt region which is limited to the North by Sidi Slimane, to the South by Meggar and on the West by el Alia. The approximate meteorological conditions of the area are a mean annual precipitation 35.05 mm, temperature 23.3 °C, relative humidity 42.8%, visibility 12 km and wind speed is 12.4 km/h (ONMT, 2016) and the climate is hyper-arid, with a long dry season.

The lake of Megarine is divided into two small lakes namely Lella Fatma and Zerzaim (*Fig. 1*). Lella Fatma is located at latitude 33°12′21″ North and longitude 06°05′54″ East and Zerzaim lake is located at latitude 33°12′12″ North and longitude 06°05′50″ East. The two lakes are connected to each other by a natural trench but still distinct during the rainy period. The lakes are covered with *Juncus* and other macrophytes like *Phragmites*, *Tamaricaceae*, etc…

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Figure 1. *Photo shows the two lakes of the study Lella Fatma and Zerzaim*

Sampling sites and physicochemical analysis

Sample capturing used 0.5 l PVC bottles and were rinsed with distilled water and rinsed with sample water pre-sample collection. Samples were taken from a depth of 20 cm each month for one year (2016), at the five previously mentioned points of each lake (*Fig*. 2, *Table 1*).

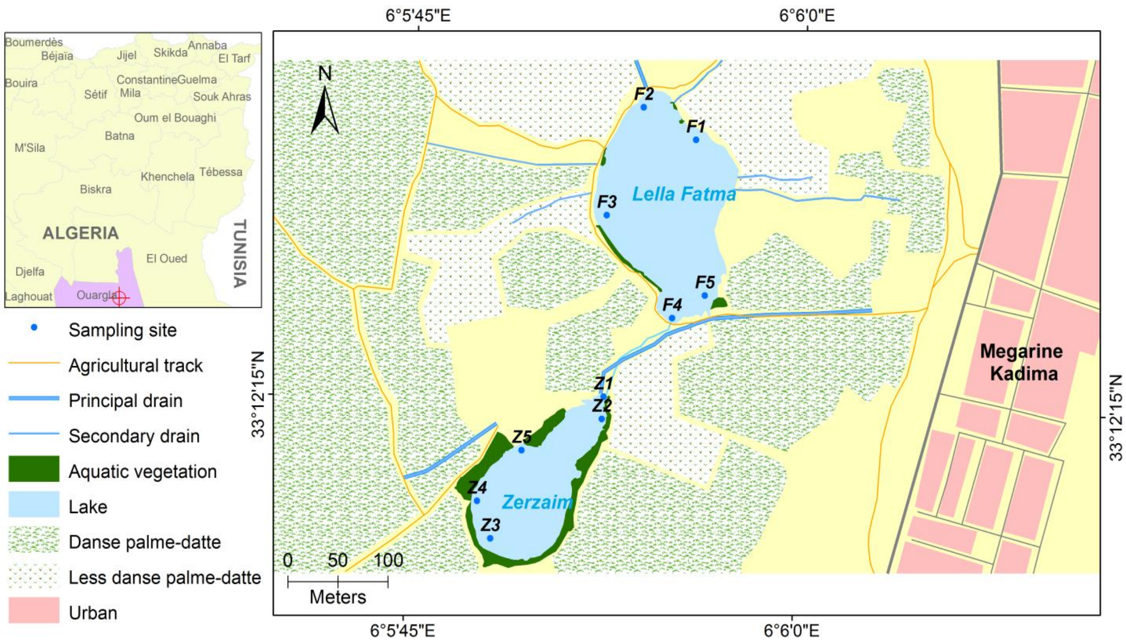

Figure 2. *The Location of Megarine lakes (Lella Fatma and Zerzaim) and the sampling points*

Table 1. *Characteristics of the sampling points of the two studied lakes*

Characteristics of LellaFatma lake sampling points		**Characteristics of Zerzaim lake sampling points**	
F1	Near a secondary drain	**Z1**	Connection point with LellaFatma Lake
F2	Evacuation point of a primary drain	**Z2**	Near a palm grove
F3	Near a palm grove	**Z3**	Near a palm grove
F4	Connection point with Zerzaim Lake	**Z4**	Presence of emerged plants
F5	Wastewater drainage point	**Z5**	Presence of salt crusts

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Some parameters are measured in situ, such as: temperature, electrical conductivity, pH and dissolved oxygen, using a multi-field parameter (Multi 350; SET5, Germany), while other parameters such as: nutrients (nitrogen compounds (NO_2^-, NO_3^-, NH_4^+) and PO_4^{3-} phosphates), were determined by using the standardized methods of Rodier (1996) using a spectrophotometer (60310) at the laboratory of the Scientific and Technical Research Centre for Arid Areas (CRSTRA), Biophysical Station, Touggourt, Algeria.

Simultaneously, to the abiotic data, phytoplankton samples were taken at the same points using a conical net ending with a collector and the collected phytoplankton samples were preserved in small plastic containers in 4% formalin (Anderson et al., 2002; Cemagref, 2007). Water samples containing the algae were collected from between 20 and 40 cm depth, away from the shore in order to have all the ecological types of algae and several techniques have been used, pressing plants and other submerged substrates and scraping from submerged or simply wet stones, branches or debris (Bourrely, 1966; Iltis, 1980). The harvested samples were placed in opaque glass jars previously washed and labeled (date of harvest, name of the study station and sampling point).

The determination of the different taxa that we concentrated by a net, was made in the laboratory under a microscope; for the systematic study, a series of specialized books of determination were consulted (Germain, 1981; Komàrek and Anagnostidis, 1994, 1997; Krammer and Lange-Bertalot, 1991, 1986).

Statistical analyses

Relative abundance and frequency were realized in order to evaluate the importance, the place and influence of species within a stand. Statistical analysis (correlation and correspondence analysis) was performed using Statistica 10 software, to remove the effects between the abiotic and biotic components.

Results

Physicochemical characteristics

During the study period, the region was characterized by: an air temperature average of 23.3°C (max = 33.5 °C in July and min = 12.7 °C in January), the annual rainfall of 49.6 mm with highest value in January (20.55 mm) and lowest in July (0 mm), and the average annual wind speed of 12.4 km/h (O.N.M.T., 2016).

Physicochemical characteristics of our lakes showed that: water temperature average ranged from 22.86 °C in Lella Fatma lake and 22.37 °C in Zerzaim lake. The temperature of water trace a seasonal evolution (*Fig. 3a*) relatively related to air temperature, which increases in summer (El Haouati et al., 2015). The minimum values are found in the winter with typical 16 °C in January for two lakes, and the maximum during August with 30 °C in Lella Fatma Lake and 29 °C to the Zerzaim Lake. The temperature augmentation is due to the absorption of the Sun's rays (Zheng et al., 2015).

In general the change in pH in the two lakes has a trend that varies between 7.46 and 8.6. For both lakes, these values are close to neutral (over 7). This deviation in the alkalinity was due to a good photosynthetic activity and also to the nature of the ground (Parinet et al., 2004). Aquatic plants consume dissolved CO_2 (by respiration) and

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displace the calcium-carbon balance, this tends to decrease the concentration of H^+ ions caused by the increase in pH, which is a good indicator of photosynthesis (Nagaraju et al., 2018). The pH value indicates the trophic state of a lake: an acidic water surface is oligotrophic, a neutral water surface is mesotrophic and an alkaline water surface is eutrophic (Stager et al., 2018).

The electric conductivity average value was 43.8 mS/cm in Lella Fatma Lake and 38.86 mS/cm in Zerzaim Lake, these results obtained showed a fluctuation in the interval of 11.4 and 76.8 mS/cm, which is higher in summer (*Fig. 3b*). The electrical conductivity is proportional to the amount of dissolved ionisable salts, it is a good indicator of the degree of mineralization of water, in our case the mineralization was high (S.E.E.E., 1996).

Dissolved oxygen variation is related to several factors, mainly temperature and salinity (Franco, 2017). The mean values of dissolved oxygen during the study period were 2.56% (min: 0.13%, max: 13.84%) for Lella Fatma Lake and 2.63% (min: 0.12%, max: 11.07 mg/l) for Lake Zerzaim. The high values of dissolved oxygen were found in the month of May and the autumn season; this elevation was due to the air movement (wind) (*Fig. 3c*).

Phosphorus and nitrogen are the two main nutrients essential for plant growth and are naturally present in soil, rock and vegetation. An accelerated load of phosphorus and nitrogen from anthropogenic sources can cause harmful algal blooms and is one of the biggest problems facing many countries around the world.

Nutrients observed during the study had an average of nitrogen components of 7.97 mg/l in total within Lella Fatma lake and 9.85 mg/l in Zerzaim lake (*Fig. 3d*).

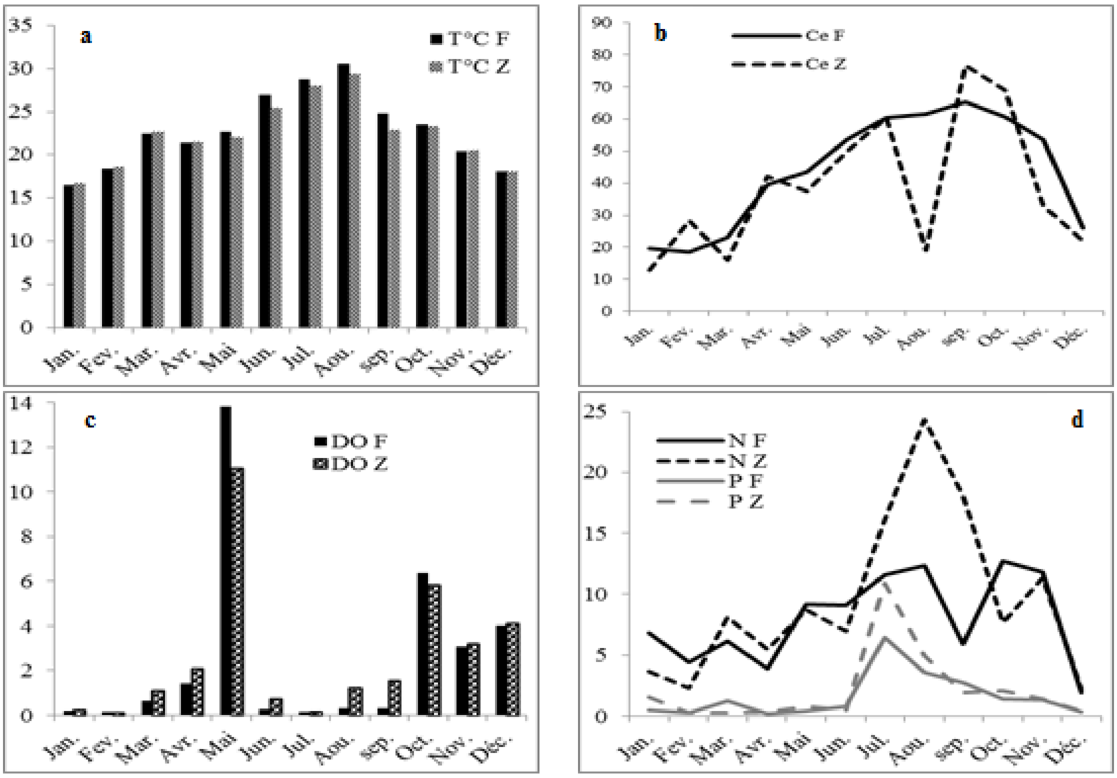

Figure 3. *Annual variation of the physicochemical parameters of the two lakes.* ***a.*** *Water temperature,* ***b.*** *electrical behavior,* ***c.*** *dissolved oxygen,* ***d.*** *nutriments N & P*

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The N/P ratio (Redfield, 1963) of ambient concentrations may indicate the limiting nutrient. N/P ratio < 16/1 indicates nitrogen limitation, while phosphorus limitation occurs when N/P 16/1 (Goman et al., 2017).

The graphs in *Figure 3d* demonstrate that the values of nitrogen in totality are higher than phosphorus' values.

To determine whether it is phosphorus or nitrogen that limits the development of algal biomass, the most frequently used method is to compare the value of the total nitrogen/total phosphorus (N/P) ratio measured in water with that measured in a non-deficient algal population. If results show that an N/P ratio is above 7.2 it indicates a phosphorus limitation and an N/P ratio of less than 7.2 is due to nitrogen limitation (Goman et al., 2017). The application of this criterion indicates that phosphorus is the limiting factor in the lakes, where it was found that the N/P ratio averaged at 4.98 for Lella Fatma lake and 4.58 for Zerzaim lake.

Phytoplankton biodiversity

Diversity, abundance and dominance of phytoplankton community of lakes were studied during January 2015 to December 2015 with a total of 58 spices belonging to 20 family, 14 orders, 5 classes and to 3 phylums (Bcillariophyta, Euglenophyta and Cyanobacteria) being observed. A total of 23 species of Cyanophyceae, 21 species of Bacillariophyceae, 12 species of Mediophyceae, 1 species of Coscinodiscophyceae, and 1 species of Euglenophyceae (*Table 2*).

Table 2. *Various species found during the period of study*

Phylum	Class	Order	Family	Species	Lella Fatma	Zerzaim
Bcillariophyta	Mediophyceae	Thalassiophysales	Catenulaceae	*Amphora coffeaformis* Kützing	75.0	75.0
				Amphora ovalis Kützing	33.3	41.7
				Amphora lineolata Ehrenberg	50.0	41.7
		Naviculales	Amphipleuraceae	*Amphiprora sp* Ehrenberg	0.0	25.0
				Frustulia rhomboides Ehrenberg	8.3	8.3
			Brachysiraceae	*Brachysira aponina* Kützing	16.7	33.3
			Naviculaceae	*Navicula halophila* Grunow	25.0	41.7
				Navicula *margalithie* Lange-Bertalot	16.7	41.7
			Pleurosigmataceae	*Pleurosigma angulatum* W.Smith	25.0	41.7
		Cocconeidales	Cocconeidaceae	*Cocconeis placentula* Ehrenberg	83.3	100.0
		Stephanodiscales	Stephanodiscaceae	*Cyclotella menighiniana* Kützing	66.7	66.7
				Cyclotella striata Kützing	41.7	50.0
	Coscinodiscophyceae	Melosirales	Melosiraceae	*Melosira dickiei* Kützing	0.0	33.3
	Bacillariophyceae	Cymbellales	Cymbellaceae	*Cymbella pusilla* Grunow	50.0	66.7
			Gomphonemataceae	*Gomphonema angustatum* Kützing	25.0	41.7
		Fragilariales	Fragilariaceae	*Fragilaria tenera* W.Smith	50.0	66.7
				Fragilaria fasciculta C.Agardh	8.3	16.7
		Mastogloiales	Achnanthaceae	*Achnanthes minutissima* Kützing	75.0	83.3
			Mastogloiaceae	*Mastogloia braunii* Grunow	58.3	83.3
				Mastogloia elliptica C.Agardh	58.3	66.7
		Bacillariales	Bacillariaceae	*Denticula kuetzingii* Grunow	58.3	66.7

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				Hantzschia elogantula Grunow	8.3	16.7
				Nitzschia constricta Kützing	41.7	41.7
				Nitzschia fonticola romana Grunow	58.3	58.3
				Nitzschia vitrea G.Norman	16.7	33.3
				Nitzschia geitleri Hustedt C	8.3	16.7
				Nitzschia tubicola Grunow	8.3	16.7
				Nitzschia palea Kützing	33.3	50.0
				Nitzschia obtusa W.Smith	25.0	41.7
				Nitzschia recta Grunow	41.7	66.7
				Nitzschia sigmoidea W.Smith	25.0	25.0
		Surirellales	Surirellaceae	*Campylodiscus clypeus* Kützing	8.3	16.7
				Surirella striatula Turpin	33.3	41.7
				Surirella ovata var. *pinnata* W.Smith	8.3	25.0
Euglenophyta	Euglenophyceae	Euglenales	Phacaceae	*Phacus orbicularis* K.Hübner	8.3	25.0
Cyanobacteria	Cyanophyceae	Chroococcales	Chroococcaceae	*Chroococcus minutus* Kützing	66.7	66.7
				Chroococcus turgidus Kützing	33.3	41.7
				Chroococcus lemnticus Lemmermann	41.7	50.0
			Cyanobacteriaceae	*Cyanothece major* Komárek	8.3	0.0
			Microcystaceae	*Gloeocapsa sp* Kützing	16.7	25.0
				Microcystis sp Kützing	8.3	0.0
			Gomphosphaeriaceae	*Gomphosphaeria salina* Komárek	25.0	33.3
		Oscillatoriales	Oscillatoriaceae	*Oscillatoria chalybea* Mertens	33.3	58.3
			Phormidiaceae	*Phormidium chalybeum* Anag. & Komá.	16.7	25.0
			Coelosphaeriaceae	*Coelomoron pusillum* Komárek	33.3	50
				Coelosphareium sp Nägeli	16.7	8.3
				Woronichinia karelica Komá. & Legn	41.7	75
				Woronichinian aegeliana Elenkin	0.0	16.7
			Merismopediaceae	*Merismopedia warmingiana* Lagerheim	33.3	16.7
			Leptolyngbyaceae	*Leptolyngbya granulifera* Anagnostidis	33.3	58.3
				Planktolyngbya sp Anag. & Komá.	25.0	33.3
			Romeriaceae	*Romeria sp* Koczwara	25.0	333
			Pseudanabaenaceae	*Jaaginema subtilissimum* Anag. & Komá.	8.3	16.7
				Pseudanabaena recta Komá. & Cronb.	25.0	33.3
				Pseudanabaena galeata Böcher	8.3	8.3
				Pseudanabaen amucicola Naum. & Hube.	33.3	58.3
				Pseudanabaena papillaterminata Kisselev	16.7	8.3
		Spirulinales	Spirulinaceae	*Spirulina tenuior* Lagerheim	8.3	33.3

F = 100%: ubiquitous species
F = 100-75: constant species
F = 75-50: frequent species
F = 50-25: common species
F = 25-5: accessory species
F ≤ 5: rare species

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Frequency and spatiotemporal distribution of phytoplankton species

According to the calculation of the relative abundance that is based on the number of individuals observed under the microscope, phytoplankton populations exhibit fluctuations in abundance as a function of time and space. This spatiotemporal variation (*Fig. 4*) differs from one species to another, and in this study was as follows:

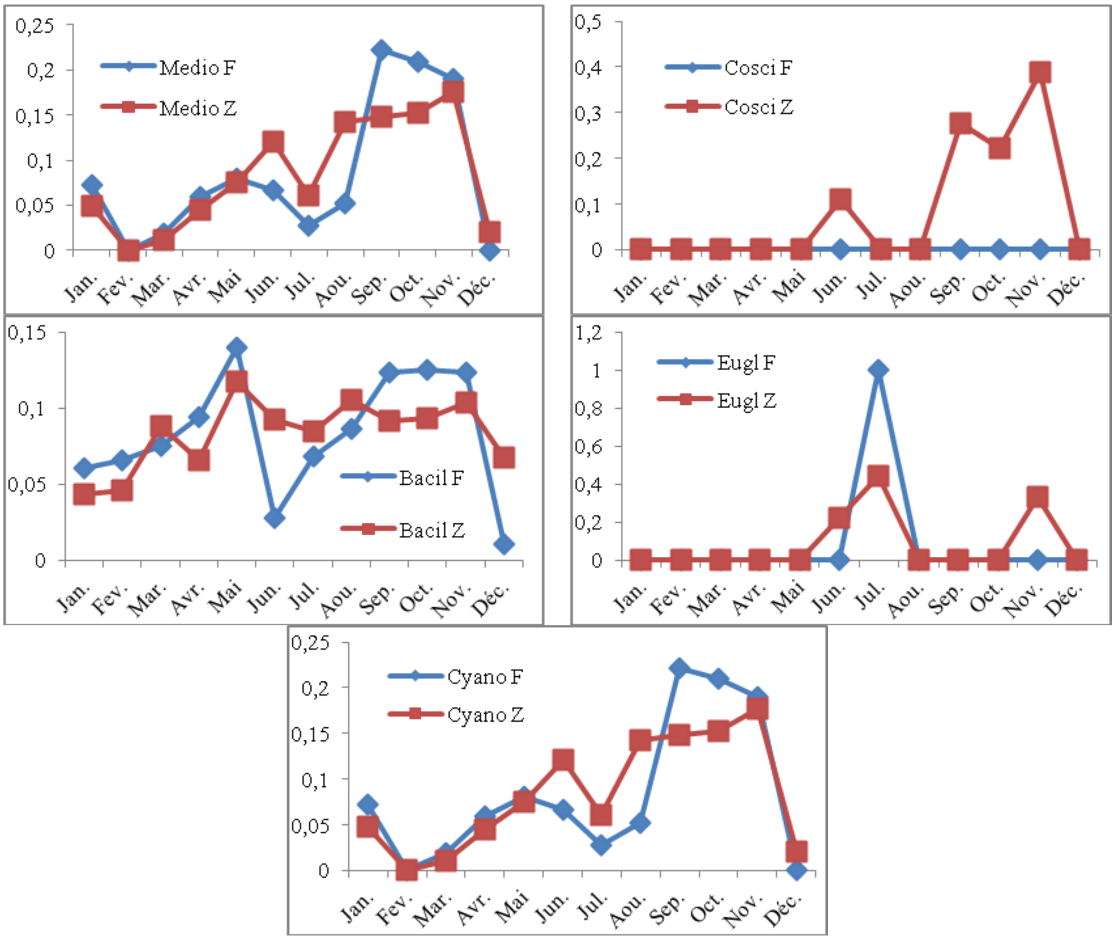

Figure 4. *Spatiotemporal variation in relative abundance of phytoplankton in lakes (Lella Fatma & Zerzaim) (2016). (Cyano: Cyanophyceae, Bacil: Bacillariophyceae, Medio: Mediophyceae, Cosci: Coscinodiscophyceae, Eugl: Euglenophyceae)*

Cyanophyceae forms the most dominant group with 23 species, or 39.7% of the total phytoplankton community andare represented in the majority by the genus Chroococcus.

Bacillariophyceae forms the most diverse group, with 21 taxa, or 36.2% of the entire population, the representative species of the group are: *Achnanthes minutissima*, *Fragilaria, Mastogloia and Nitzschia.*

Mediophyceae, this class contains 12 species, with a proportion of 20.7%, dominated by genre *Amphora* and species *Cocconeis placentula*.

The two final groups **Coscinodiscophyceae** and **Euglenophyceae** are represented by only one species respectively: *Melosira dickiei* in Zerzaim Lake only and *Phacus orbicularis*in both lakes.

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The influence of environmental variables on the distribution of phytoplankton groups in the Megarine lakes' was assessed using PCA analysis (*Fig. 5*).

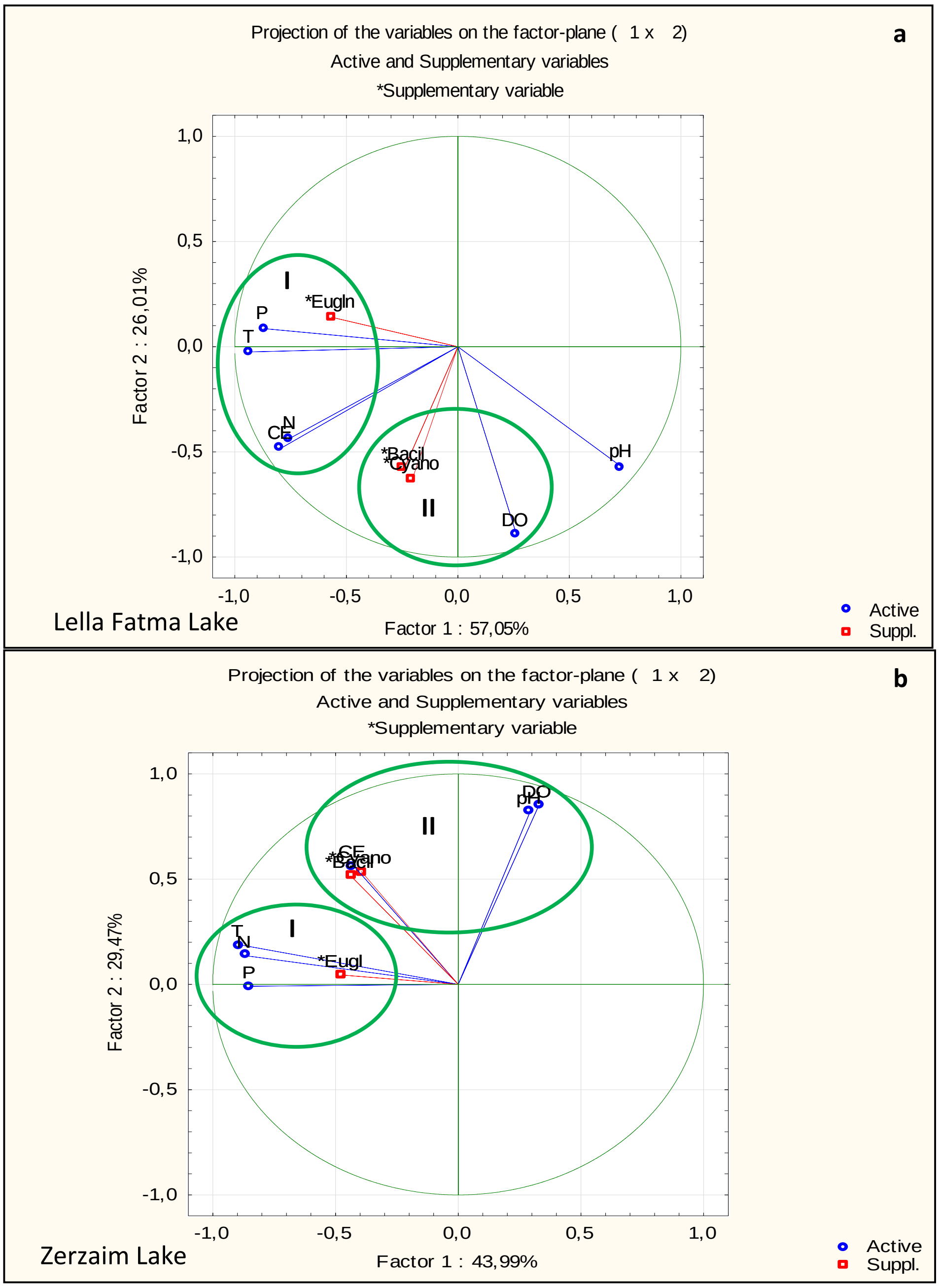

Figure 5. *Principal components and Classification Analysis diagram of environmental variables and phytoplankton groups in lakes (Lella Fatma & Zezeim) during period study (2016). (T: water temperature, pH: hydrogen potential, CE: Electric conductivity, DO: Dissolved Oxygen, P: Phosphate, N: nitrogen elements, Bacil: Class Bacillariophyta, Eugle: Euglenophyta, Cyano: Cyanobacteria)*

The PCA of the biotic and abiotic parameters, in the two studied lakes, showed that the first two axes F1 and F2 contain most of the data since they present 83.06% of the total inertia for the Lake Lella Fatma and 73.46% for Lake Zerzaim. Examining the

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correlations between the axes and the different components makes it possible to explain the meaning of each axis in the structured distribution of the variables clouds.

"Lella Fatma" Lake: The F1 axis (57.05% of total inertia) is mainly correlated with temperature, electrical conductivity and nutrients (nitrogen and phosphorus), as long as the F2 axis (26.01% total inertia) is mainly bound with dissolved oxygen (*Fig. 5a*). The PCA allows for discrimination of the two groups:

Group I contains the Euglenophyta, directly proportional to the presence of nutrients, water temperature and electrical conductivity and from this a conclusion can be made that the axis represents organic matter mineralization phenomenon.

Group II, the Bacillariophyta and Cyanobacteria prefer well-oxygenated waters, therefore this axis relates to eutrophication.

"Zerzaim" Lake: The F1 axis (43.99% of total inertia) is correlated in particular with temperature and nutrients (nitrogen and phosphorus), as long as the axis F2 (29.47% of total inertia) is bound with dissolved oxygen (*Fig. 5b*).

Group I contains the Euglenophyta, always remains directly proportional to the presence of nutrients and the temperature of the water, it is therefore the mineralization of organic matter that takes place at this level.

Group II, Bacillariophyta and Cyanobacteria have a relationship proportional to the oxygen level, the potential of hydrogen and the electrical conductivity, so the presence of the phenomenon of eutrophication is noted

Discussion

An annual evolution in phytoplankton community with regard to physicochemical properties was evident in this study, and monitoring of the phytoplankton compartment in both lakes highlights that it is directly influenced by the fluctuation of abiotic parameters (Wetzel, 2001).

The phytoplankton populations in Lake Zerzaim were denser and more diversified in relation to the environmental parameters and more favorable than in Lake Lella Fatma, especially with the contribution of nitrogen and phosphorus.

Cyanobacteria perform photosynthesis with release of oxygen, and it is beneficial to find them in abundance within the lakes.

Cyanobacteria were also known to produce a variety of bioactive compounds of which some have toxic effects and are called cyanotoxins**.** The effects of some harmful algal blooms were not related to toxin production, but they were involved in depletion of dissolved oxygen concentration caused by algal proliferation, death and decay or night respiration (Shaista, 2008)**.**

Several freshwater, brackish water and marine cyanobacterial produce hepatotoxins (Welker, 2008) and in this study, it highlights: the genera of Microcystis that may produce linear and cyclic peptide (Ploutno et al., 2005), Oscillatoriamay produce toxins, aplysiatoxins which may cause skin problems in swimmers (Shaista, 2008).

Phytoplankton require nitrogen as a basic element in protein anabolism (Forsberg, 1977), and the nutritional role of phosphorus is assumed to be responsible for the rapid eutrophication of water bodies (Griffith et al., 2009), which was the case for the study.

Finally in the Megarine region lakes the development of phytoplankton populations was obviously caused by nutrients (nitrogen and phosphorus); and has caused a migration of micro-algae towards the deeper depths of lakes (Serizawa H et al., 2008).

The remarkable difference between the two lakes in terms of phytoplankton density was due to human activity, because the road to the Lake Lella Fatma is accessible and easy for people and even vehicles. For this reason, the lake is a place of tourist events in each summer. Unlike the Zerzaim lake, which characterized by the absence of clear pathways and surrounded only by palm trees and other plants on each side.

Physicochemical and phytoplankton data obtained in this study could be used as a baseline and reference point when assessing further changes caused by nature or man, since there has not been published information or data on these lakes.

Subsequent studies should allow a more precise approach to the interactions existing between the phytoplankton compartment and the adjacent levels of the food web and the impact of the abiotic parameters of the lakes. The rapid evolution of phytoplankton communities in response to environmental changes reinforces the importance of their ecological monitoring because of the importance of these lakes.

Conclusion

The study of some physicochemical parameters of Megarine lakes made it possible to characterize the general state of water during the year 2016. The results obtained showed that the lakes suffer from an agricultural pollution and shows that these lakes were favorable ecosystems to microalgae proliferation. The succession of phytoplankton populations was therefore conditioned by abiotic parameters. Phytoplankton represents a remarkable compartment by the role it plays, not only in the aquatic environment but also in all areas of our life: environmental quality (oxygen), food (fish and seafood), well-being (health, beauty), industrial resource, therefore it is imperative to monitor them in the global ecosystems.

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