

## Cyanobacteria Dynamics in a Mediterranean Reservoir of the North East of Algeria: Vertical and Seasonal Variability

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### ABSTRACT

Harmful cyanobacterial efflorescence is of growing global concern and its prediction and management require a better understanding of the growth control factors and dominance of cyanobacteria. The Zit-Emba reservoir located in the North-East of Algeria, was constructed to provide drinking water, irrigation, and fishing. The vertical and seasonal distribution variation of cyanobacteria community associated with environmental factors was comprehensively investigated from April 2016 to December 2016 at five depths, based on a seasonal sampling. The cyanobacteria communities of this reservoir are composed of seven genera belonging to five orders. The average proportion of *Microcystis* to total cyanobacteria population was 43%, followed by *Woronichinia* 21%, *Planktothrix* 16%, *Dolichospermum* 13%, *Oscillatoria* 5%, and the remainder (*Merismopedia*, *Spirulina*) 2%. The average cyanobacterial abundance was 2702 cells/mL, ranging from 360 to 65 795 cells/mL and this abundance exceeds the alert level 1 throughout the year. The most recurrent periods of increase took place from spring to summer and autumn. However, the vertical distributions of cyanobacteria displayed a similar profile each season, and abundances tended to decrease with depth. The results of the statistical analysis suggested that the most abundant of cyanobacterial genera were positively related to chlorophyll-a and water temperature and negatively with the concentrations of  $\text{NO}_3\text{-N}$ ,  $\text{NH}_4\text{-N}$ , and  $\text{NO}_2\text{-N}$ . This demonstration of toxigenic cyanobacteria in this drinking water production dam involves regular monitoring of the cyanobacterial communities and cyanotoxins in raw water.

**Keywords:** Cyanobacteria community, Zit-Emba reservoir; environmental variables; dynamics; Algeria.

### INTRODUCTION

In recent years, eutrophication has become the most important worldwide environmental issue regarding reservoirs and many other types of aquatic ecosystems [Sanchez-Carrillo et al., 2007]; severe eutrophication in freshwater reservoirs can cause the increasing appearance of harmful algal blooms, especially of cyanobacteria (Cyano-Habs) [Paerl, 2008; Codd, 2005]. However, cyanobacteria (commonly known as blue-green algae) are an ancient group of prokaryotic organisms found in all terrestrial and aquatic ecosystems around the world [Whitton and Potts, 2000]. They are important primary producers and play a key role in the ecosystem functioning and biodiversity [Mur et al., 1999]. In addition, some species of cyanobacteria produce secondary me-

tabolites that include hepatotoxic (microcystins), neurotoxic (anatoxins and saxitoxins) and cytotoxic (cylindrospermopsin) or dermatotoxic effects [Chorus, 2001]. These cyanotoxins have been associated with the decreased water quality and negative effects on higher trophic levels [Ferrão-Filho et al., 2009], as well as risks to human health (Paerl, 2008), and animal mortality and diseases [Jacoby and Kann, 2007; Nasri et al., 2008]. Moreover, several studies showed that different environmental factors influence the cyanobacterial bloom dynamics and toxin production. These include the abiotic factors such as temperature, pH, light availability, nutrients and hydrodynamics [Renaud et al., 2011; Elliott, 2012] but also the biotic interactions [Walsby et al., 2005; Ger et al., 2010]. Scientific research, preliminary studies and ongoing monitoring in many coun-

tries provide a general overview of the extent of cyanobacteria and cyanotoxins [Chorus and Bartram, 1999; Chorus, 2001; Quiblier et al., 2008; Joung et al., 2011]. In Algeria, the climate change and water degradation provided ecological conditions for the development of cyanobacteria in many aquatic ecosystems. However, a monitoring of the environmental conditions and phytoplankton assemblages was carried out in several freshwater reservoirs and lakes from which problems of eutrophication and harmful algal blooms were reported [Nasri et al., 2008; Ouarts et al., 2011; Djabourabi et al., 2014; Boussadia et al., 2015; Saoudi et al., 2015; Bidi-Akli et al., 2017; Saoudi et al., 2017; Guellati et al., 2017]. The Zit-Emba reservoir, located in the northeastern region of Algeria, was built to provide drinking water supplies and agricultural irrigation. In the last few years, parallel with the rapid development of the local economy and the intensive use of water resources, the water quality of this reservoir were significantly degraded due to untreated inputs of agricultural, industrial and domestic wastewater from the catchment area. The reservoir requires an effective biomonitoring program, but at present, there is no information on the diversity of phytoplankton and cyanobacteria in this water body.

This study aims, at a first step, to characterize the waters of the Zit-Emba reservoir by assaying the physicochemical parameters, to identify and count the cyanobacteria of this water body, and then to investigate the influence of some environmental parameters on the vertical and seasonal dynamics of cyanobacteria community through the application of statistical tests. These results will be used in evaluating the pollution level and developing a water monitoring program in the reservoir.

## MATERIALS AND METHODS

### Study site

The Zit-Emba reservoir (36°41'00.68"N, 7°18'07.68"E) is located in the North East of Algeria (Figure 1). This water body receives water from two rivers: El Hammam and El Mouguer; it has a surface area of 8.1km<sup>2</sup> with a capacity of 120 million m<sup>3</sup> and a maximum depth of 41 m [Belhadj, 2007]. It was built to supply drinking water to the city of Skikda, and it is used for irrigation, fishing and nautical activities.

### Sampling procedure

The sampling was conducted seasonally, in April, July, October and December 2016 at five depths (0 m, 5 m, 10 m, 15 m and 20 m) in the deepest zone of the dam (Figure 1). The water samples for the physicochemical analysis, chlorophyll-a (Chl-a) and cyanobacteria enumeration were collected with a Ruttner water sampler (1.000 ml, Hydrobios®, Germany). The sampling water for the cyanobacterial identification was concentrated using a plankton net (20 µm mesh size, Hydro-Bios®, Kiel, Germany) and the filtrate was immediately fixed with formaldehyde 4% final (v/v).

### Field measurement and water analysis methods

The physical and chemical variables, including water temperature, pH, dissolved oxygen, and conductivity were measured in situ using a multi-parameter probe (Multi 340i/SET-82362, WTW®, Germany). The water transparency was estimated with a Secchi disc (diameter 25 cm). The water samples for nutrient determinations Nitrates (NO<sub>3</sub>-N), nitrites (NO<sub>2</sub>-N), ammonium (NH<sub>4</sub>-N) and orthophosphate (PO<sub>4</sub>-P) were analyzed using a spectrophotometer method according to the previous reports [ISO, 1994; Aminot and Chaussepied, 1983]. Suspended Solids (SS) concentrations were determined gravimetrically by filtering 200–400 ml of water sample through combusted, pre-rinsed and pre-weighed glass microfiber filter of 0.45-µm porosity (Whatman GF/C™, GE Healthcare Ltd.) [Aminot and Chaussepied, 1983]. On the other hand, the water samples for chlorophyll-a determination were filtered through the same glass microfiber filters. Pigments were extracted in 90% aqueous acetone and measured by spectrophotometry (Shimadzu UV-1700 Pharma Spec UV-VIS) [Parsons, 1966]. The resulted water filtrates from Chl-a and SS samples filtration were kept in polypropylene sampling containers at 4°C in darkness until nutrient analysis and analyzed as soon as possible.

The identification of cyanobacteria is based on the observation of morpho-anatomical characteristics using a light microscope (Carl Zeiss, Axiostar plus 1169–149, Germany) and according to the following taxonomic literature [Komárek and Anagnostidis, 1999; Komárek and Anagnostidis, 2005; Komárek et al., 2014].

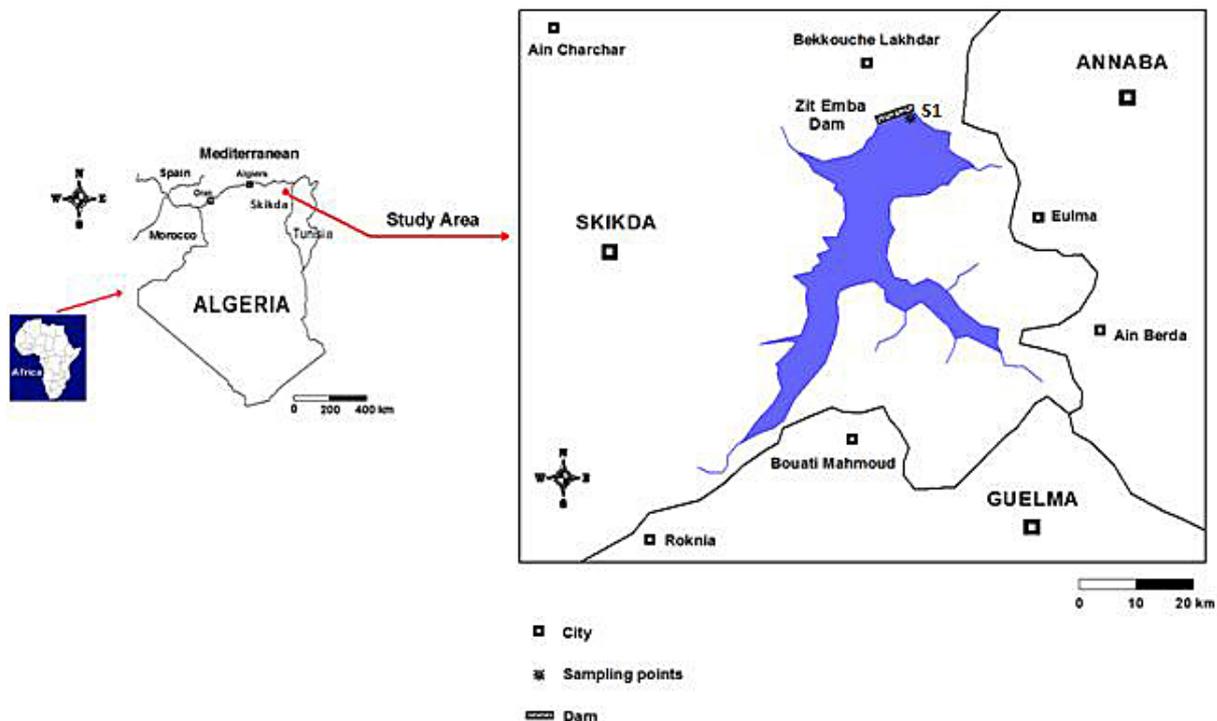


Fig. 1. Geographical position of the Zit-Emba reservoir and the location of the sampling station.

The enumeration of cells was carried out by a Nageotte cell and an optical microscope, as described in [Brient et al., 2008].

### Statistical analysis

The statistical analyses were performed under R software (3.1.2). First of all, the normality condition of the sample distributions was checked before by applying the Shapiro-Wilk test. Then, the inter-seasons and inter-depths comparisons were performed using the non-parametric Kruskal-Wallis test. In addition, the principal component analysis (PCA) was carried out using the R package FactoMineR. Finally, the correlations in our set of data were evaluated by the non-parametric Spearman correlation coefficient to analyze the intensity of relations between variables.

## RESULTS

### Physical and chemical variables

The means and ranges of environmental parameters at five depths are summarized in Table 1. The stratification events appeared in spring and lasted until autumn, whereas the water column was well-mixed in winter. During the stratification period, three different layers were clearly identi-

fied in the Zit-Emba reservoir: epilimnion (water depth from 0 to 5 m), metalimnion (5–15 m) and hypolimnion (from 15 m to the bottom). The water temperature showed a seasonal variation, the highest values being observed in summer at the surface and the lowest values in winter at the surface layer and also in the lower layer (Figure 2a). The dissolved oxygen concentrations decreased with depth in spring and summer, although the difference was more pronounced in summer (Figure 2b). The pH of water samples was alkaline (Figure 2c). The lowest values of conductivity were observed in spring and summer, with significant declines at the depth of 15 m (Figure 2d). Transparency oscillated in a small range, the lowest value was recorded in winter and the largest in spring (Table 1).

As far the nutrient concentrations (ammonium, nitrite, nitrate and orthophosphate) are concerned, they fluctuated with season and depth, but showing no clear trend. The highest concentrations of nitrate were found in the spring at 20 m depth, whereas the lowest concentrations were observed in summer at the surface (Figure 2e). The highest concentrations of nitrite appeared in winter at the depth of 20 m, while the lowest concentrations were detected in summer at 5 m (Figure 2f). The highest concentrations of ammonium were found in winter at the bottom waters, while the lowest concentrations were observed in the

**Table 1.** Environmental variables recorded in the reservoir Zit-Emba from April 2016 to December 2016

Parameters	Mean±sd	Min	Median	Max	C.V
WT (°C)	12.14	4.10	9.51	30.30	0.60
pH	8.28	7.46	8.350	8.79	0.03
DO (mg/L)	8.37	2.91	8.40	10.64	0.26
Cond (Us/cm)	647.10	568	654	702	0.04
Trans (cm)	107.50	70	115	130	0.24
SS (mg/L)	21.18	8	20.05	44.70	0.44
NH <sub>4</sub> -N (mg/L)	0.33	0.24	0.300	0.49	0.24
NO <sub>2</sub> -N (mg/L)	0.06	0.04	0.060	0.08	0.14
NO <sub>3</sub> -N (mg/L)	4.95	3.89	4.670	7.82	0.17
PO <sub>4</sub> -P (mg/L)	0.22	0.09	0.180	0.55	0.61
Chl-a (µg/L)	7.09	1.06	4.58	31.24	0.95

WT – water temperature, °C; DO – dissolved oxygen, mg/L; Cond – Conductivity, µS/cm; Trans – transparency, cm; NH<sub>4</sub> – Ammonium, mg/L; NO<sub>2</sub> – Nitrite, mg/L; NO<sub>3</sub> – Nitrate, (mg/L); PO<sub>4</sub> – Orthophosphate, mg/L; SS – suspended solids, mg/L; Chl-a – Chlorophyll a, µg/L; (Standard deviation – sd; coefficient of variation – C.V).

summer and the autumn at the surface (Figure 2g). The highest concentrations of orthophosphates were recorded in summer at the depth of 20 m, while the lowest concentrations were reported in autumn at the surface (Figure 2h). The concentrations of suspended solids showed significant declines at 10 m depth during four seasons, while the highest values were recorded in winter and the lowest values in spring (Figure 2i). During the study period, the chlorophyll-a concentrations decreased steadily from the surface to bottom, with the lowest values recorded in winter at the depth of 20 m and the highest values in summer at the surface (Figure 2j).

The Kruskal–Wallis test detected significant differences among depths for Chl-a and SS. However, significant differences between seasons were found with regards to WT, DO, Cond, NO<sub>3</sub>-N and PO<sub>4</sub>-P ( $p < 0.05$ ) (Table 2).

#### Diversity of cyanobacteria community in the reservoir zit-emba

A total of 5 orders, 7 families and 7 genera were determined from the water samples (Table 3). The proportion of the community composition was *Microcystis* 43%, *Woronichinia* 21%, *Planktothrix* 16%, *Dolichospermum* 13%, *Oscillatoria* 5%, and the remainder (*Merismopedia*, *Spirulina*) 2%. The estimation of the occurrence frequency shows that among the 7 identified genera, only *Microcystis* was ubiquitous. In addition, it can be observed the constancy of *Woronichinia* and the regularity of *Planktothrix* and *Dolichospermum*, respectively. On the other hand, the genus *Oscillatoria* had an accessory frequency and the 2 ot-

ers genera belong to the incidental fraction of the cyanobacteria community (Table 4).

#### Variation in cyanobacteria abundance

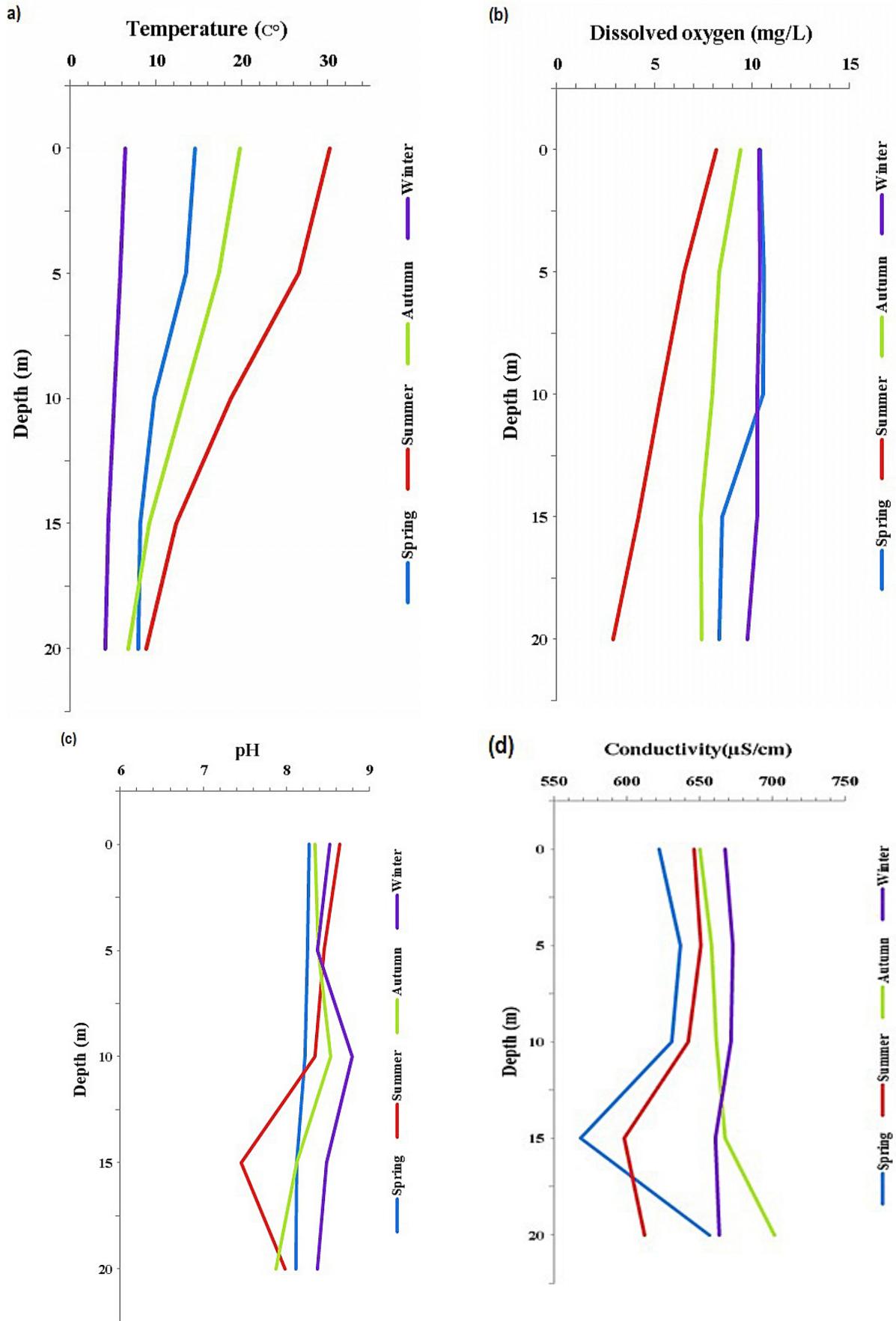
The total cyanobacteria abundance in the Zit-Emba reservoir (Figure 3) ranged from 360 in winter at a depth of 20 m to 65 795 cells/mL in summer at the surface. The most recurrent periods of increase took place from spring to summer and autumn, while winter was the period of the lowest abundance. However, the vertical distributions of cyanobacteria displayed a similar profile in each season, and the abundances tended to decrease with depth. The Kruskal–Wallis test detected significant differences among depths, but no significant differences between seasons ( $p < 0.05$ ).

#### SUCCESSION OF CYANOBACTERIA COMMUNITY

The vertical and seasonal succession of cyanobacteria community in the Zit-Emba reservoir is shown in Figure 4.

In spring (Figure 4a), three genera of cyanobacteria were observed: *Planktothrix*, *Microcystis* and *Woronichinia*. In addition, this season was characterized by high densities of the *Planktothrix* genus throughout the water column compared to other genera recorded, with an average density of 3 398 cells/mL.

In summer (Figure 4b), two genera *Dolichospermum* and *Oscillatoria* were added to those encountered in spring (*Planktothrix*, *Microcystis* and *Woronichinia*). The densities decreased with



**Fig. 2.** Vertical and seasonal variations of environmental variables in Zit-Emba reservoir from April 2016 to December 2016: (a) water temperature; (b) dissolved oxygen; (c) pH; (d) conductivity

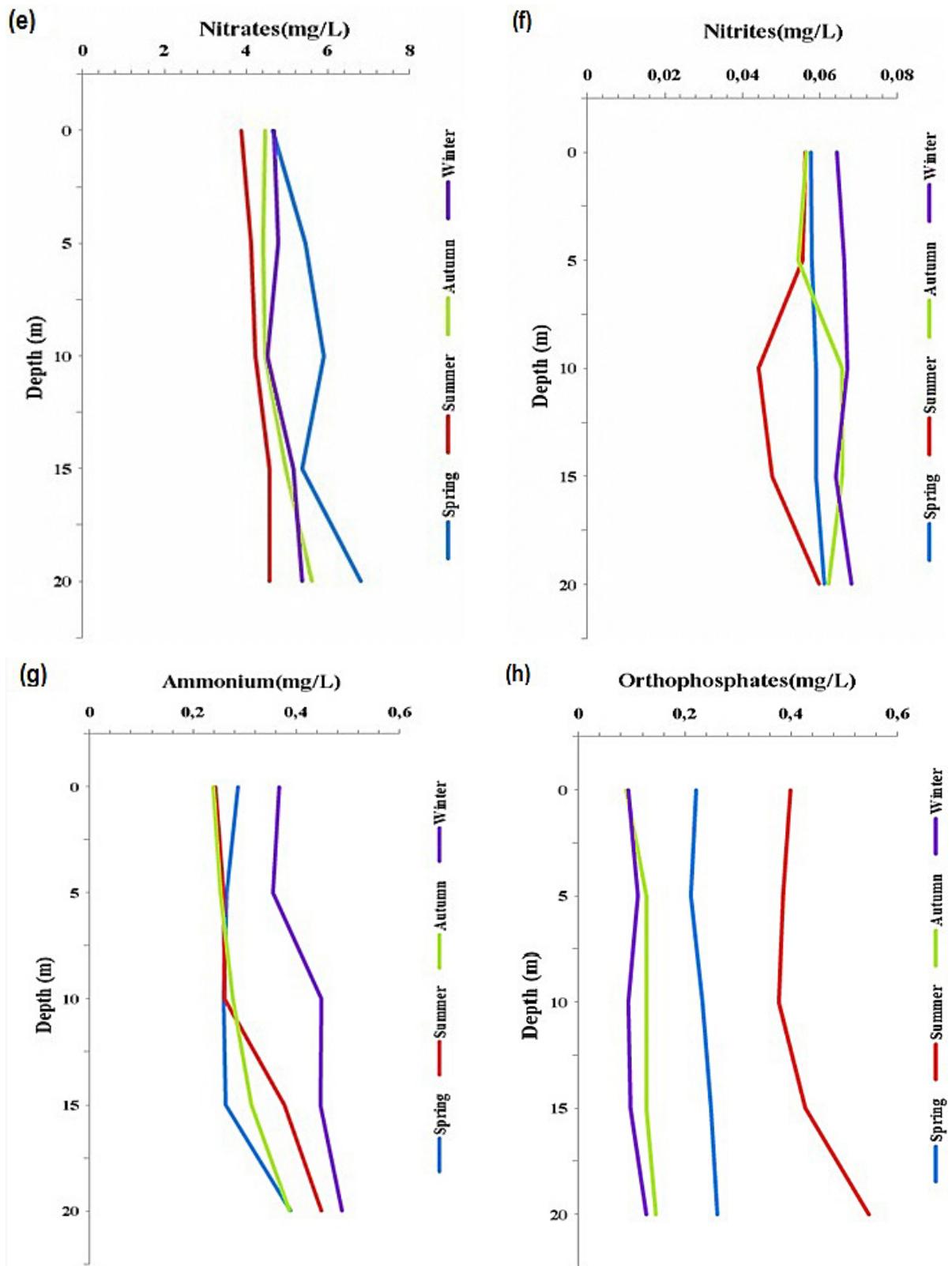


Fig. 2. Vertical and seasonal variations of environmental variables in Zit-Emba reservoir from April 2016 to December 2016: (e) Nitrates; (f) Nitrites; (g) Ammonium; (h) Orthophosphate

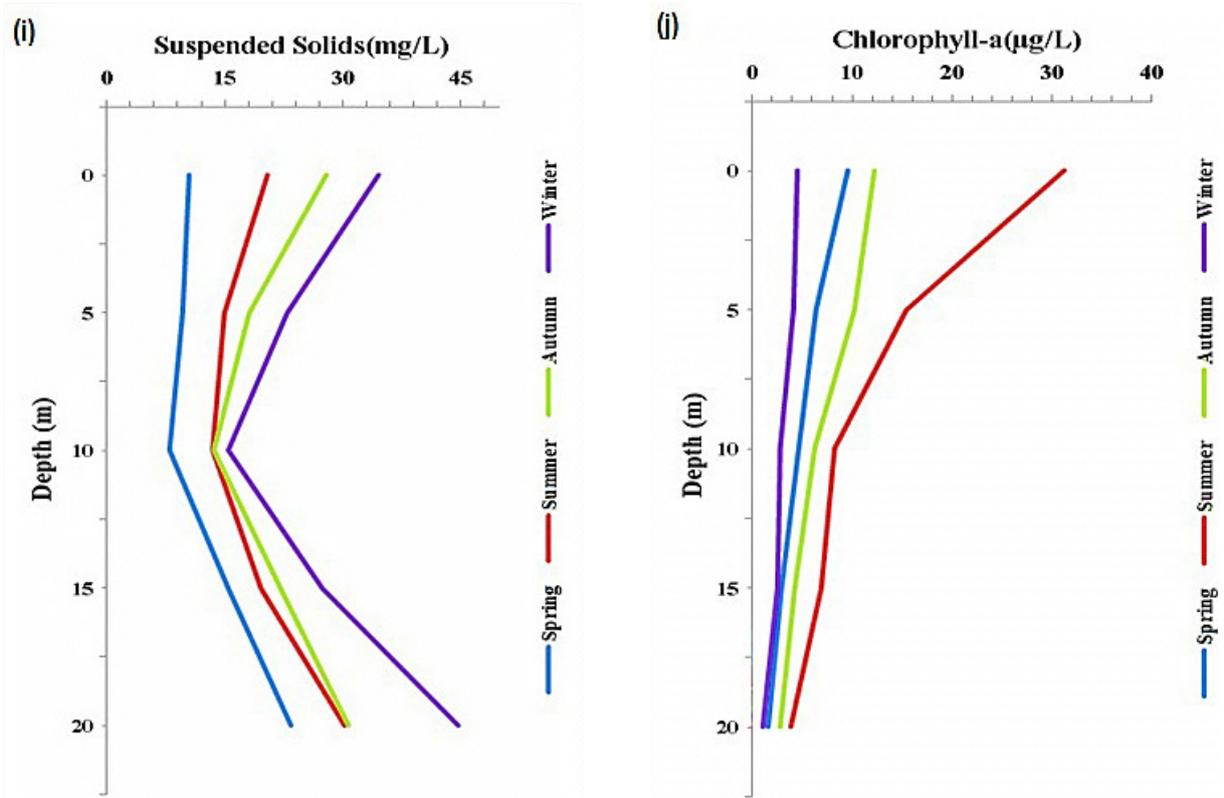


Fig. 2. Vertical and seasonal variations of environmental variables in Zit-Emba reservoir from April 2016 to December 2016: (i) Suspended Solids; (j) Chlorophyll-a.

Table 2. The inter-seasons and inter-depths comparison of median values of physico-chemical parameters and cyanobacteria density in the Zit-Emba reservoir

Parameters	Inter-depths			Inter-Saisons		
	$\chi^2$ value	p- value	df	$\chi^2$ value	p- value	df
WT (°C)	6.01	0.19	4	12.13	0,00	3
pH	7.25	0.12	4	6.44	0.09	3
DO (mg/L)	3.40	0.49	4	14.01	0.00	3
Cond (Us/cm)	1.34	0.85	4	13.48	0.00	3
Trans (cm)	3,00	0,39	4	//	//	//
SS (mg/L)	10.92	0.02	4	6.77	0.07	3
NH <sub>4</sub> -N (mg/L)	8.86	0.06	4	6.43	0.09	3
NO <sub>2</sub> -N (mg/L)	2.75	0.60	4	5.65	0.12	3
NO <sub>3</sub> -N (mg/L)	5.65	0.22	4	10.31	0.01	3
PO <sub>4</sub> -P (mg/L)	1.40	0.84	4	16.80	0.00	3
Chl-a (µg/L)	11.38	0.02	4	7.04	0.07	3
DC (cells/mL)	14.42	0.00	4	4.00	0.26	3

$\chi^2$  – chi-squared value; df – degrees of freedom; p-value – probability value; (p<0.05).

the increasing depth and only the genera *Microcystis* and *planktothrix* were present at the depth of 20 m. However, *Microcystis* was the dominant genus, with an average density of 9 663 cells/mL.

In autumn (Figure 4c), six cyanobacterial genera were recorded with the appearance of two genera *Merismopedia* and *Spirulina*, but at low densities and the absence of the *planktothrix* ge-

nus for the first time, whereas at the surface and 5 m depth we noted the presence of all genera identified in this season, with the dominance of *Microcystis* and *Woronichinia* with mean densities of 6 778 cells/mL and 4036 cells/mL, respectively.

In winter (Figure 4d), we observed the same five genera found in summer, but with low densities. *Microcystis* and *Woronichinia* were domi-

**Table 3.** List of Cyanobacteria Genera identified in Zit-Emba reservoir from April 2016 to December 2016

Orders	Family	Genera
Chroococcales	Microcystaceae	<i>Microcystis</i>
Synechococcales	Coelosphaeriaceae	<i>Woronichinia</i>
	Merismopediaceae	<i>Merismopedia</i>
Nostocales	Aphanizomenonaceae	<i>Dolichospermum</i>
Oscillatoriales	Oscillatoriaceae	<i>Oscillatoria</i>
	Microcoleaceae	<i>Planktothrix</i>
Spirulinales	Spirulinaceae	<i>Spirulina</i>

**Table 4.** The frequency of generic occurrence of the cyanobacterial community in the Zit-Emba reservoir from April 2016 to December 2016

Genera	Frequency of occurrence (F %)	Observation
<i>Microcystis</i>	100	omnipresent
<i>Woronichinia</i>	75	constant
<i>Planktothrix</i>	65	regular
<i>Oscillatoria</i>	60	regular
<i>Dolichospermum</i>	45	accessory
<i>Merismopedia</i>	10	incidental
<i>Spirulina</i>	10	incidental

nant at the depth of 10 m and *Planktothrix* at 15 m; only *Microcystis* was present at 20 m. However, the highest mean density in this season did not exceed 1 000 cells/mL and was recorded by the genus *Microcystis*.

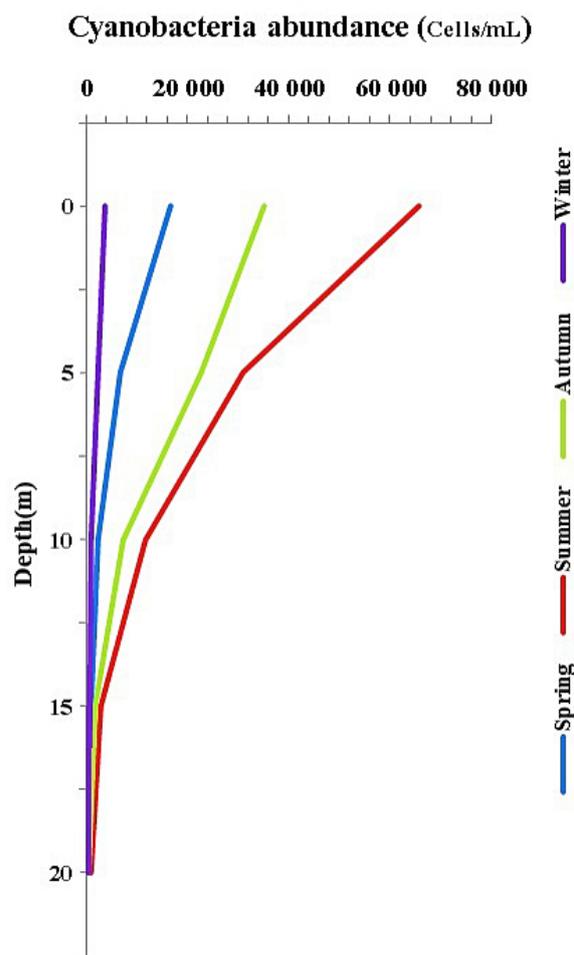
**Relation between abiotic and biotic variables**

The principal component analysis showed that the eigenvalues of the two first principal components represent up to 58.78% of the total variance (Figure 5).

The first axis accounted for 36.76% of the variation which was due to the positive loading of NH<sub>4</sub>-N (r = 0.71), NO<sub>2</sub>-N (r = 0.69), NO<sub>3</sub>-N (r = 0.58) and SS (r = 0.57) and negative loading of WT (r = -0.87), Chl-a (r = -0.75), PO<sub>4</sub>-P (r = -0.65), Trans (r = -0.36), Mcs (r = -0.62), Doli (r = -0.61), Plank (r = -0.56), Worn (r = -0.55) and Osci (r = -0.40).

The second axis contributed for 22.02% of the variation found to be positively loaded by pH (r = 0.86), DO (r = 0.68) and Cond (r = 0.51).

Additionally, The PCA plot showed that the first principal component reflected the seasonal gradient and the mixing regime (Figure 5). On



**Fig. 3.** Vertical and seasonal variation of the total Cyanobacteria abundance in Zit-Emba reservoir from April 2016 to December 2016.

the negative side of axis 1, the sampling units of spring, summer and mid-autumn seasons correlated with the strong stratification and higher values of water temperature, chlorophyll-a and were also characterized by high abundances of cyanobacteria. On its positive side, the sampling units of winter correlated with mixing and, accordingly, higher dissolved nutrient concentrations and concentrations of suspended solids. However, this axis allowed us to reveal the separation between two different layers in the water epilimnion and metalimnion column (negative side of the axis), to the other layer hypolimnion (on the positive side of the axis).

The results of Spearman’s rank correlation analysis between cyanobacterial genera and environmental variables are shown in Table 5.

In terms of the correlation coefficients, it is obvious that most abundance of cyanobacterial genera in the Zit-Emba reservoir was strongly re-

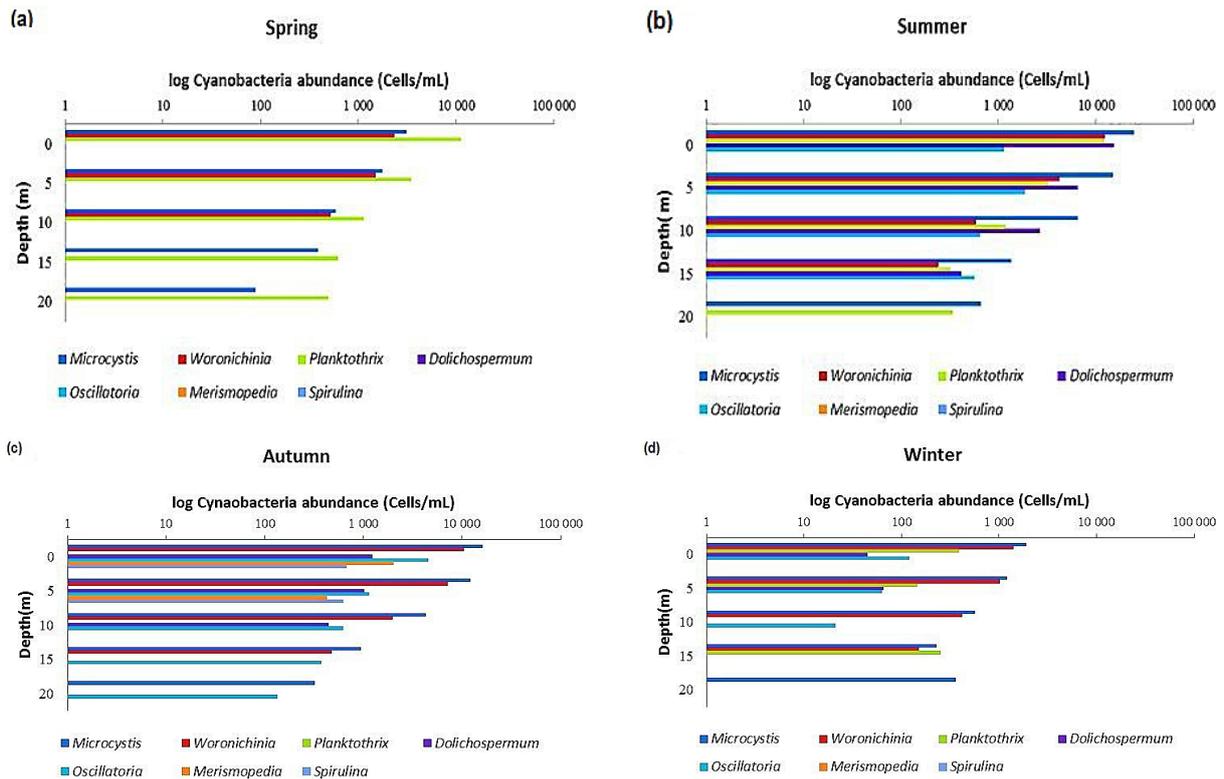


Fig. 4. Vertical and seasonal succession Cyanobacteria community in the Zit-Emba reservoir from April 2016 to December 2016. (a) in spring; (b) in summer; (c) in autumn; (d) in winter.

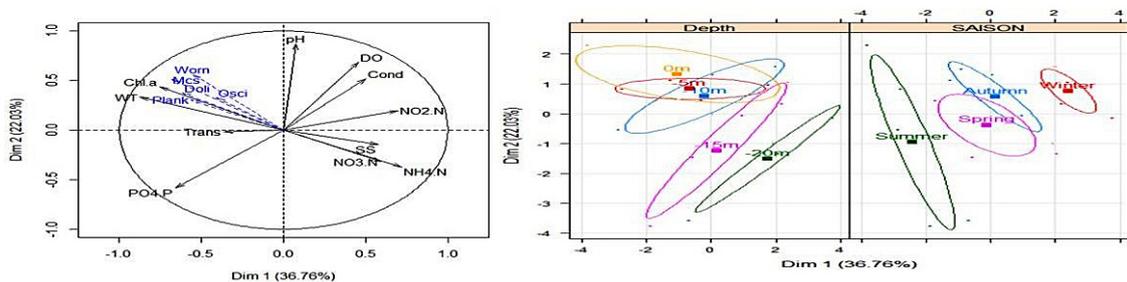


Fig. 5. Principal component analysis (PCA) based on biotic and abiotic variables during the period of April 2016 to December 2016 in the Zit-Emba reservoir at depths and seasonal sampling. Abbreviations for domains: WT – water temperature; DO – dissolved oxygen; pH; Cond – conductivity;  $\text{NO}_3\text{-N}$  – Nitrates;  $\text{NO}_2\text{-N}$  – Nitrites;  $\text{NH}_4\text{-N}$  – Ammonium;  $\text{PO}_4\text{-P}$  – Orthophosphate; Chl-*a* – Chlorophyll *a*; SS – Suspended Solids; Trans – Transparency; Mcs – Microcystis; Worn – Woronichinia; Plank – Planktothrix; Doli – Dolichospermum; Osci – Oscillatoria. Cell abundances as supplemental variables

lated to Chl-*a* and WT which was in accordance with the PCA analysis. The abundance variation of *Microcystis*, *Dolichospermum*, *Woronichinia* and *Oscillatoria* were negatively correlated with  $\text{NO}_3\text{-N}$ ,  $\text{NH}_4\text{-N}$  and  $\text{NO}_2\text{-N}$ ; *Planktothrix* has an abundance positively correlated with  $\text{PO}_4\text{-P}$  and negatively correlated with Cond and SS. The *Woronichinia* abundance showed significant positive correlation with pH. Besides, the variables Chl-*a*, WT,  $\text{NO}_3\text{-N}$ ,  $\text{NH}_4\text{-N}$ ,  $\text{NO}_2\text{-N}$  and SS significantly correlated with each other.

## DISCUSSION

The Zit-Emba reservoir is used by humans for several activities, including the recreational ones and the supply of drinking water, which makes the monitoring of cyanobacteria in such ecosystems of particular importance, especially as part of the assessment of the health risks linked to cyanobacterial blooms and their toxins [Codd *et al.*, 2005].

The most important physical gradient in the Zit-Emba reservoir was the thermal-density

**Table 5.** Spearman's rank correlation analysis between cyanobacterial genera and environmental variables

	WT	DO	Chl.a	Cond	pH	Trans	SS	NO <sub>2</sub> -N	NO <sub>3</sub> -N	PO <sub>4</sub> -P	NH <sub>4</sub> -N	Mcs	Worn	Plank	Osci	Doli
WT	1.00															
DO	-0.28	1.00														
Chl.a	0.92***	-0.12	1.00													
Cond	-0.49*	0.12	-0.37	1.00												
pH	0.01	0.30	0.20	0.41	1.00											
Trans	0.20	0.40	0.20	-0.80	-0.80	1.00										
SS	-0.51**	-0.18	-0.47*	0.45*	-0.04	-0.80	1.00									
NO <sub>2</sub> -N	-0.56**	0.15	-0.58**	0.58**	0.22	-0.77	0.33	1.00								
NO <sub>3</sub> -N	-0.62**	0.43*	-0.71***	0.08	-0.51**	-0.20	0.17	0.33	1.00							
PO <sub>4</sub> -P	0.44*	-0.54**	0.25	-0.69***	-0.49*	0.21	-0.28	-0.39	-0.11	1.00						
NH <sub>4</sub> -N	-0.83***	-0.01	-0.81***	0.36	-0.13	-0.31	0.51*	0.43*	0.44*	-0.16	1.00					
Mcs	0.84***	-0.14	0.94***	0.94	0.37	0.20	-0.32	-0.43*	-0.81***	0.09	-0.75***	1.00				
Worn	0.74***	0.18	0.88***	-0.03	0.52**	0.20	-0.38	-0.30	-0.65***	-0.14	-0.74***	0.91***	1.00			
Plank	0.44*	0.13	0.40	-0.62**	-0.04	0.00	-0.49*	-0.44*	-0.05	0.61**	-0.36	0.26	0.24	1.00		
Osci	0.63*	-0.47*	0.69	0.17	0.29	-0.20	-0.00	-0.24	-0.76***	-0.02	-0.57**	0.76***	0.64**	-0.16	1.00	
Doli	0.68***	-0.04	0.76***	-0.04	0.41	-0.40	-0.11	-0.33	-0.82***	0.13	-0.63**	0.84***	0.71***	0.12	0.88***	1.00

WT – water temperature; DO – dissolved oxygen; Chl-a – Chlorophyll a; Cond – conductivity; pH; NO<sub>3</sub>-N – Nitrates; NO<sub>2</sub>-N – Nitrites; NH<sub>4</sub>-N – Ammonium; PO<sub>4</sub>-P – Orthophosphate; Trans – Transparency; SS – Suspended Solids; Mcs – Microcystis; Worn – Woronichinia; Plank – Planktothrix; Doli – Dolichospermum; Osci – Oscillatoria, \* p≤0.05; \*\* p≤0.01; \*\*\* p≤0.001.

stratification that was strongly coupled with the dissolved oxygen concentration gradient along the water column. Although the reservoir was completely oxic during the mixing period, an anoxic hypolimnion developed along the stratification. Accompanying with this gradient, we observe that the nutrients levels were greater in hypolimnetic waters than in epilimnetic ones, suggesting the presence of a vertical gradient in nutrient resources.

Higher ammonium concentrations on the bottom of this reservoir could result from ammonification of organic matter and dissimilatory nitrate reduction to ammonium, which is an important N-cycling pathway, approved by anaerobic bacteria in aquatic ecosystems [Pajares et al., 2017].

The high content of orthophosphates in summer and in depth of the Zit Emba water column can be explained by the recycling of this element from sediment and dead matter; according to [Gachter and Muller, 2003], the process depends on the physical, chemical and biological mechanisms. The relatively high and irregular values of pH during the whole period of study might be due to the photosynthetic activity of phytoplankton. The fluctuations in the electrical conductivity may be due to changes in the rate of decomposition of organic matter or the influx of seeps and nutrients from the watershed. Furthermore, high levels of suspended solids found in this reservoir can result from a large variety of sources, such as sediment

transported by storm water runoff, streambank and streambed erosion, decaying plant and animal matter, sewage, and industrial wastes.

The values of chlorophyll *a* and transparency observed during the study period indicate that the water body fluctuated between a mesotrophic and eutrophic status, according to the OECD (Organization for Economic Co-operation and Development) classification scheme [Vollenweider and Kerekes, 1982].

The total cyanobacteria abundance in the Zit-Emba reservoir, during the monitoring period, decreased along with depth; while the periods of increase occurred from spring to autumn. However, the chlorophyll-*a* concentration in the water column was highest in summer and decreased gradually in winter, similar to the abundance of the total cyanobacteria, which reached its maximum concentration during full stratification.

Referring to the guideline values admitted by WHO (cyanobacterial biomass <2000 cells/ml), the seasonal variation of the total cyanobacteria population recorded in the reservoir Zit-Emba shows that the abundances exceed the alert level 1 [Affsa/Afsset, 2006] throughout the year.

In the Zit Emba water body, *Microcystis*, *Woronichinia*, *Planktothrix* and *Dolichospermum* represented more than 90% of the global density of the collected cyanobacteria. According to [Huber et al. 2012], long periods of stable stratification are competitively advantageous for

gas-vacuolated cyanobacterial species (*Microcystis*, *Woronichinia*, *Planktothrix* and *Dolichospermum*); these genera are capable of making vertical movements by regulating their buoyancy in the water column through intracellular gas vacuoles. This mechanism gives this group the advantage of relocating to the optimum depth in a stable water column to obtain solar radiation in the surface water during the day and absorb enough nutrients in the lower layer at night [Walsby and Booker, 1980; Reynolds et al., 1987; Dokulil and Teubner, 2000]. These genera were reported to be the main CyanoHAB producers in the Mediterranean in the summer-autumn period [Carrasco et al., 2006]. In the Lake Alto Flumendosa of Sardinia, *Planktothrix rubescens* dominated between August 2011 and April 2012, alternating with *Woronichinia naegeliana* and *Microcystis botrys*; *Dolichospermum planctonicum* was always present at low densities [Stefanelli et al., 2017].

Nevertheless, the other genera, including *oscillatoria*, *Merismopedia* and *Spirulina* represent a small proportion of the total cyanobacterial community in the Zit-Emba reservoir. This low proportion was associated to the reconstitution of nutrients and the degradation of an effective light climate, but allowed the development of more competitive genera (*Microcystis*, *Woronichinia*, *Planktothrix* and *Dolichospermum*) in our water body [Paerl and Huisman, 2008].

Our results show that the most dominant genus of cyanobacteria was *Microcystis*; this genus is present throughout the water column and during the entire year. The dominance of this genus was also found in other Algerian reservoirs used for drinking water [Guellati et al., 2017; Nasri et al., 2007; Saoudi et al., 2015]. *Microcystis* blooms frequently occur in the ecosystems containing  $N_2$ -fixing cyanobacteria belonging to the genera *Aphanizomenon*, *Dolichospermum* and *Cylindrospermopsis* [Wu et al., 2010; Soares et al., 2012]. *Microcystis* sp. is known to have a worldwide distribution [Harke et al., 2016] and to proliferate mainly in the eutrophic and hypereutrophic ecosystems during the summer season [Mariani et al., 2015; Van Wichelen et al., 2016].

In the Hammam Debagh reservoir, unlike what has commonly been found in numerous water bodies in temperate areas [Harke et al., 2016; Pobel et al., 2011; Mc Donald and Lehman, 2013], *Microcystis* was not associated with *Dolichospermum* and *Aphanizomenon* [Guellati et al., 2017]. According to [Guellati et al., 2017], these two genera were only found in a restricted number

of samples, in which they have always displayed very low abundance in this water pond. In Mexa dam, [Saoudi et al., 2015] reported the constancy of *Microcystis* and the regularity of *Oscillatoria* but the presence of the genus *Dolichospermum* was not recorded in this water reservoir.

*Woronichinia* is a characteristic genus of cyanobacteria in standing-water ecosystems. According to [Wilk-Wozniak, 1996], this species was found as the accompanying species in water blooms caused by *Microcystis aeruginosa*. In our water body, *Woronichinia* was highly correlated with *Microcystis*; this genus was never dominant, but always present with an average proportion, 21% of the total cyanobacterial community. The strong presence of *Woronichinia* in summer and autumn is related to the water temperature.

Many studies reported that long-lasting stratification, with consequent high levels of nutrient enrichment of the hypolimnion, followed by mixing of the entire water column in late autumn, can significantly affect the cyanobacterial species composition, thus favoring *Planktothrix* blooms [Huber et al., 2012; Mariani et al., 2015]. This was the case for Zit Emba, which was subjected to a longer stratification period and the extensive growth of *Planktothrix* species from late autumn to spring during mixing. In the reservoir of Zit Emba, *Planktothrix* reaches 16% of the total cyanobacterial community; the maximum concentration of *Planktothrix* was observed in spring.

In Zit Emba, *Dolichospermum* showed a strong presence in summer and autumn; which was not surprising in the warmest season, as this genus prefers high summer temperatures and high water stability [Marchetto et al., 2009], with an extended distribution in areas with a temperate climate [Mariani et al., 2015; Padedda et al., 2017; Stefanelli et al., 2017].

In most studies, it was shown that interactive physical, chemical and biotic factors are involved in controlling the growth and dominance of bloom forming cyanobacteria [Aguilera et al., 2017; Paerl and Fulton, 2006; Thomas and Litchman, 2015; Guellati et al., 2017; Saoudi et al., 2015]. In the present study, the relationships between the environmental factors and Cyanobacteria communities were investigated by using Principal component analysis (PCA) and Spearman's rank correlation.

Our results indicated that the cyanobacterial genera in the Zit-Emba reservoir, including *Microcystis*, *Woronichinia*, *Planktothrix*, *Dolichospermum* and *Oscillatoria* were positively related

to Chl-a and WT, which indicated the influence of thermal stratification on their growth [Dokulil and Teubner, 2000]. However, we noted negative correlations between most of the cyanobacteria genera and the concentrations of  $\text{NO}_3\text{-N}$ ,  $\text{NH}_4\text{-N}$  and  $\text{NO}_2\text{-N}$ , while a positive correlation should be observed in this case. This opposite pattern noticed in our study could be related to the high growth of the cyanobacteria communities that leads to the nutrient depletion [Abrantes et al., 2006].

Furthermore, it should be reported the positive correlation between the Planktothrix abundance and the  $\text{PO}_4\text{-P}$  concentrations in this reservoir, revealing that high orthophosphates concentrations increase the growth rate of this genus. This corroborates the results found by previous studies of [Catherine et al., 2008 and Bidi-Akli et al., 2017]. The Woronichinia abundance showed a positive correlation with pH; this may not be surprising, because later studies revealed the presence of this genus in meso-eutrophic and eutrophic reservoirs [Nowicka-Krawczyk and Żelazna-Wieczorek, 2017].

Demonstration of toxigenic cyanobacteria in this drinking water production dam involves regular monitoring of the cyanobacterial communities and cyanotoxins in raw water [Codd, 2000]. The monitoring of the water body can be performed using simple tools such as phycocyanin probes, to estimate the biomass of cyanobacteria [Brient et al., 2008; Macario et al., 2015] and ELISA kits [Lawton and Edwards, 2008; Triantis et al., 2010] used for the detection of different families of cyanotoxins (microcystins and others...).

The installation of a monitoring protocol of water bodies will not only improve the treatment of drinking water, but also allow making recommendations for fish consumption due to the cyanotoxins bioaccumulation in their flesh [Jia et al., 2014]. Nevertheless, it would be wise to encourage the authorities in charge of this sector as well as its inhabitants to implement the measures to reduce nutrient loads [Jeppesen *et al.*, 2007] into the watershed through the establishment of a wastewater treatment plant before being discharged into the Wadi that supplies the dams.

## CONCLUSION

The factors causing the dominance of one or other group are often difficult to reveal because several interacting factors are usually involved, which are not necessarily the same in different

environments. Our study provided important evidence for the strong relationships among the trophic status, temperatures and cyanobacterial abundance. The phytoplankton responses to the nutrient variations cannot be separated from the responses to other, larger environmental changes occurring at the same time, such as global climate change. The progressive enlargement of the geographical distribution of harmful species, both in the Mediterranean area and globally, highlights the need for further detailed research on their ecology, toxicology, and genetics at the local scale.

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