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RESEARCH ARTICLE

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STUDIES ON SPATIO-TEMPORAL DYNAMICS OF PHYTOPLANKTON IN BURULLUS LAGOON, SOUTHERN MEDITERRANEAN COAST, EGYPT

ABSTRACT:

This work was carried out to shed light on the present status of the Burullus Lagoon's phytoplankton and the long-term changes that had resulted from phytoplankton abundance, community structure, dominant species and diversity indices. Phytoplankton dynamics were examined seasonally from summer 2013 to spring 2014 at twelve sampling stations represented by three basins (eastern, middle and western). Water was alkaline, well oxygenated and with an annual average salinity of 3.89 PSU. Nutrient concentrations were generally high. A total of 163 taxa from five classes were recorded; diatoms were the most diversified group. The three dominant classes: Chlorophyceae, Bacillariophyceae and Cyanobacteria had a progressively lower abundance from west to east, while species diversity showed the opposite trend. The results showed that Chlorophyceae was the dominant group in the three basins, followed by Bacillariophyceae in the eastern and western basins, while Cyanobacteria followed chlorophytes in the middle basin. Shannon-Wiener diversity index values were higher than those recorded during the previous years. Notable phytoplankton species recorded can be regarded as possible indicators for each basin. Providing evidence that phytoplankton abundance decreased from year to year and that a nuisance species such as *Geitlerinema amphibium* was evidently environmentally harmful, hence suggesting that a major improvement in water quality must be done.

KEY WORDS:

Phytoplankton, Species Indicators, Burullus Lagoon, Diversity Index

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INTRODUCTION:

Coastal lagoons of the Nile River of Egypt are the largest lagoons in the north of Africa (Saad, 2003). Burullus is the second largest of the Nile Delta coastal lagoons, occupying a central position along the Mediterranean Nile Delta coast of Egypt, at the eastern side of Rosetta Nile Branch. The lagoon is connected to the Mediterranean Sea by a canal in the north. There are eight drains discharging a mix of agricultural, fish farm drainage water and industrial and sewage wastes into the lagoon. Also, the lagoon receives fresh Nile water from Brimbal Canal (El-Adawy *et al.*, 2013).

The lagoon is characterized by having an extensive growth of hydrophytes (Phragmites and Typha) as *Phragmites australis* (Cav.) Trin. ex Steud. and *Typha domingensis* Pers., 1807 particularly along its southern shores beside the extensive patches of submerged *Potamogeton pectinatus*, which are important refuges for fish fry (Ramdani *et al.*, 2001). Approximately 75 islands are scattered in the lagoon. During the last two decades, Burullus Lagoon has become a more eutrophic ecosystem, owing to the remarkable increase in the amount of discharging agricultural drainage water that is loaded with nutrients. This increase in nutrient loading led to a significant influence on biodiversity and an abundance of phytoplankton where many sensitive marine species have completely disappeared. However, the significant change that the environment of Burullus Lagoon underwent during the last three decades has designated it as a protected area in 1998 (Nassar and Gharib, 2014).

From previous studies on phytoplankton of Burullus Lagoon, a large variation in the species composition and density that had occurred during the past two decades can be viewed. The first monitoring of phytoplankton populations of Burullus Lagoon was performed by El-Sherif (1983). There are more recent evaluations of the phytoplankton proved by Radwan (2002), Fathi and Abdelzahar (2004), Okbah and Hussein (2006), Ali and Khairy (2012) and recently, Nassar and Gharib (2014). According to these studies, the order of relative abundance between the major algal groups changed between 1980 and 2006. Bacillariophyceae made up about half of the phytoplankton species richness followed by Chlorophyceae and then Cyanobacteria came in third position, but the recent study which evaluated the phytoplankton during four years (2009-2012), recorded Chlorophyceae as the first, followed by Bacillariophyceae or Cyanobacteria (Nassar and Gharib, 2014).

So, the present investigation aims to shed light on the changes in phytoplankton community structures and diversity of Burullus Lagoon and to identify phytoplanktonic indicator species or community characteristics of the different basins along the lagoon.

MATERIAL AND METHODS:

Study area:

Burullus Lagoon is located between longitudes 30° 30' and 31° 10´ E, and latitudes 31° 21' and 31° 35’ N (Fig. 1). The lagoon has a length of about 47 km and its width varies between 6 and 16 km, with an average of about 11 km. It had lost about 62.5% of its area during two centuries to reach 410.0 km^2 in 1997 (Shaltout and Khalil, 2005). It has an irregular elongated shape, with a depth between 0.40 and 2.50 meters, the deepest part lies in the western basin, while the eastern basin is shallow (Okbah, 2005).

The lagoon receives water from two origins; seawater enters the lagoon through a long canal of about 250 meters long that connects the lagoon to the sea and the Nile water enters through eight drains and one fresh water canal. Listed from the west to the east, the drains and canals that enter Burullus Lagoon are Burullus west drain, Brimbal canal, Hooks drain, drain 9, drain 8, drain 7, Tira pump station (from Nasser drains), Kitchinar drain (El-Gharbia Outfall) and Burullus drain (Nassar and Gharib, 2014). Burullus Lgoon is classified into three basins: eastern (stations 1-3), middle (stations 4-8) and western (stations 9-12) (Fig. 1).

Methods:

During the period from summer 2013 to spring 2014, samples were collected seasonally for quantitative and qualitative phytoplankton analysis in 12 stations, with a bottle of 1-liter capacity, and fixed in 4% buffered formaldehyde to facilitate species identification. Phytoplankton water samples were immediately preserved in Lugol's iodine solution. Phytoplankton were counted and identified using 2-mL settling chambers with a Nikon TS 100 inverted microscope at 400x magnification using Utermöhl’s (1958) method. For the identification of phytoplankton species, the following references were consulted: El-Nayal (1935 and 1936), Huber-Pestalozzi, 1955, Prescott (1962 & 1978), Bold and Wynne (1978), and Vinyard (1981); the population density was expressed as cells mL^{-1}.

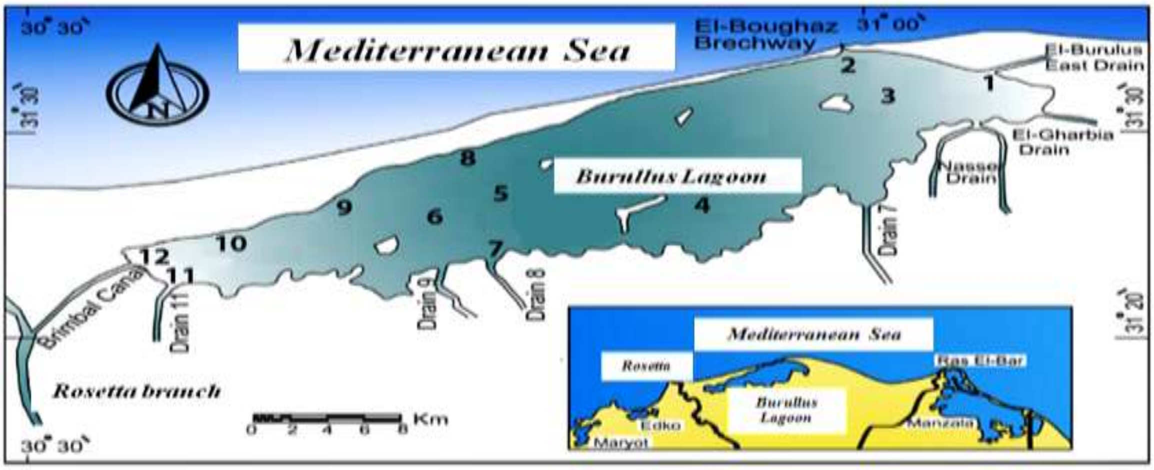

Fig. 1 A map showing the sampling stations at Burullus Lagoon.

Statistical analysis:

Three indices were used to estimate the community structure: diversity (H′), species richness (d) and evenness or equitability (J) indices were calculated using the diversity sub module of the PRIMER package (Xu *et al.*, 2008). Spearman rank correlation coefficients (r) were calculated using a Minitap program.

RESULTS:

Hydrographic conditions:

The estimation of Chlorophyll-*a* and the physicochemical characteristics of Burullus Lagoon were studied parallel to the present phytoplankton study, at the same time (from summer 2013 to spring 2014) and at the sampled stations that were reported in the site of Environmental monitoring program for the North lakes (E.M.P.N.L.) and are summarized in table 1.

Table 1. Evaluation of physicochemical parameters (averages or ranges) in Lagoon between 1987 and 2014.

year	Temp. (°C)	Transp. (cm)	pH	S‰	DO (mg/L)	Chl.a ((µM))	NO_2 (µM)	NO_3 (µM)	NH_4 (mg)	PO_4 (µM)	SiO_4 (mg)	Reference
1987	-	-	-	-	-	-	0.8	4	-	1.6	66.8	Abdel-Moati *et al*. (1988)
1997	-	-	-	-	-	-	2.1	5.7	-	2.9	47.3	Radwan *et al*. (1997)
2000	16.0-29.1	21.7-43.0	7.6-8.6	1.3-21.7	6.6-9.8	-	-	0.6-3.8	-	0.8-3.4	10.5-30.6	Radwan (2005)
2003	14.0-28.0	-	7.6-8.6	-	9.9-17.0	-	-	2.7-22.3	-	1.2-4.6	39.4-50.6	Fathi and Abdelzahar (2004)
2003	-	-	-	-	-	54.3±17.6	2.2±1.4	8.4±4.8	6.5±5.0	2.2±0.6	-	Okbah (2005)
2003	17.0-29.3	31.0±0.1	7.4-8.3	0.5-21.1	6.7-14.7	47.4	0.2-31.2	1.0-46.7	1.5-50.6	0.8-8.4	6.5-119.3	Okbah and Husein (2006)
2006	-	27.8±9.5	-	6.0-18.7	-	52.9±31.6	-	13.4±10.7	-	3.8±3.6	60.0±23.8	Ali and Khairy (2012)
2009-2010	22.3±5.2	31.0±11.1	8.0-8.6	1.9±1.8	8.6±2.3	-	1.1±0.8	2.8±2.3	-	1.2±1.1	41.7±25.1	Environmental monitoring program for the North Lakes
2010-2011	23.2	17.7	8.6	-	7.7	69.7	84.1	0.49	1.13	0.15	3.1	
2011-2012	23.1±5.3	23.8±3.7	8.4-0.1	5.0±2.0	9.6±3.0	62.7±24.0	0.1±0.03	0.2±0.1	0.9±1.1	0.21±0.11	6.0±4.7	http://www.eeaa.gov.eg/arabic/main/env_water.asp
2012-2013	22.4±5.0	23.4±3.6	8.4±0.2	3.6±1.0	8.4±1.1	73.0±22.0	0.1±0.1	0.20±0.12	0.7±0.7	0.15±0.13	3.3±1.5	
2013-2014	23.2±4.4	32.7±11.6	8.3±0.2	3.9±1.4	8.3±2.1	63.9±34.6	0.8±0.9	0.08±0.03	0.3±0.2	0.25±0.1	3.59±2.16	

Water temperature in Burullus Lagoon did not deviate from the normal seasonal fluctuations on the south-eastern coast of the Mediterranean Sea (17.0 – 29.2°C) and generally followed that of the air due to its shallow depth. On the other hand, the lowest values were recorded during winter (17.0 – 20.0°C) and the highest were in the summer (25.0 - 27.0°C). Water transparency was relatively low with an average value of 32.7 cm, due to the suspended silt particles coming from the drainage water inflow. The highest and the lowest transparency were recorded in the eastern basin and the western basin, respectively. The pH of the lagoon water was on the alkaline side, fluctuating between 7.50 and 8.90 with a mean of 8.32. The highest value was recorded in the western and eastern basins, while the lowest one was measured in the middle basin. Minimum pH values (mean 8.11) were recorded in autumn, while the highest values (mean 8.53) were measured in spring.

Salinity exhibited seasonal fluctuations between 0.60 PSU and 35.60 PSU with an annual average of 3.89 PSU. The highest average was recorded in winter (5.59 PSU) and the lowest average in autumn (2.47 PSU). As for dissolved oxygen, the lowest average dissolved oxygen was 7.02 mg L^{-1} in summer and the highest average was 11.5 mg L^{-1} in spring. The lowest average and the highest average chlorophyll-*a* concentrations were recorded in summer (42.8 µgL^{-1}) and winter periods (115.6 µg L^{-1}), respectively.

The concentration of dissolved inorganic nitrogen varied widely between 523.0 (spring 2014) and 2750 µg L^{-1} (winter 2014). Ammonium was the dominant nitrogen form (54.7 - 76.7%). The maximum NO_3 level was observed in winter (average 0.55 mg L^{-1}), while the minimum was observed in summer (0.13 mgL^{-1}). The highest soluble reactive phosphorus was measured in autumn (mean 204 µgL^{-1}) and the lowest was in spring (mean 121.7 µgL^{-1}). The highest values of reactive silicate were observed during spring (mean 6.12 mgL^{-1}) and the lowest (mean 0.85 mgL^{-1}) were recorded in summer.

Phytoplankton community structure and composition:

A total of 163 phytoplankton species comprising of 69 genera under 5 divisions were quantified. Bacillariophyceae made up the highest number (61 species), followed by Chlorophyceae (46), Cyanobacteria (25), Euglenophyceae (19) and Dinophyceae (12) (Table 2). The most diverse genera were *Nitzschia* Hassall, 1845 (13 species), *Euglena* Ehrenberg, 1830 (12), *Navicula* Bory de Saint-Vincent, 1822 (10), *Desmodesmus* (R. Chodat) S. S. An, T. Friedl and E. Hegewald, 1999 (9) and *Pseudanabaena* Lauterborn, 1915 (8).

Table 2. Number of species and genera observed in each algal division in Burullus Lagoon from summer 2009 to spring 2014.

Period	Nassar and Gharib (2014)								present study	
	2009-2010		2010-2011		2011-2012		2012-2013		2013-2014	
Taxonomic Groups	species	genus	species	genus	species	genus	species	genus	species	genus
Chlorophyceae	31	N.R.	62	23	49	17	46	18	46	21
Bacillariophyceae	35	N.R.	72	30	53	22	50	20	61	27
Cyanobacteria	18	N.R.	35	13	27	11	27	13	25	11
Euglenophyceae	7	N.R.	21	2	20	3	20	3	19	3
Dinophyceae	3	N.R.	4	4	4	2	5	4	12	7
Chrysophyceae	1	N.R.	1	1	1	1	0	0	0	0
Xanthophyceae	0	N.R.	0	0	1	1	0	0	0	0
Total	95	55	195	73	155	57	148	58	163	69

N.R. Not recorded

High phytoplankton diversity (120 species) was recorded at the eastern basin, while a conspicuously smaller number (112 species) was found at the western basin. Middle basin sustained 115 species (Table 3). Qualitatively, Bacillariophyceae and Chlorophyceae constituted 65.6%, while quantitatively they formed 78.9% of the total taxonomic groups.

Table 3. Number of species of the different groups and their percentage to total phytoplankton species at the sampled basins.

Taxonomic Groups	Eastern Basin			Middle Basin			Western Basin		
	species	genus	%	species	genus	%	species	genus	%
Bacillariophyceae	47	22	39.17	34	16	29.57	34	15	30.36
Chlorophyceae	35	18	29.17	42	18	36.52	39	19	34.82
Cyanobacteria	19	11	15.83	21	10	18.26	23	9	20.54
Euglenophyceae	7	1	5.83	17	2	14.78	15	3	13.39
Dinophyceae	12	7	10.00	1	1	0.87	1	1	0.89
phytoplankton	120	59	100.00	115	47	100.00	112	47	100.00

The numbers of phytoplankton species recorded in summer, autumn 2013, winter and spring 2014 were 91, 104, 118 and 88, respectively (Table 4). A total of 54 species showed perennial distribution, meaning present in all four seasons. Out of these, 24 species belonged to Chlorophyceae, 10 belonged to Bacillariophyceae, 13 to Cyanobacteria, 6 to Euglenophyceae and one species to Dinophyceae. The maximum number of phytoplankton taxa in a single sample was 47 species which had occurred in winter at station 1, while the minimum (11 species) was in summer at station 3.

Table 4. Number of taxa of taxonomical groups of algae in the studied basins and at the different seasons.

no. species	Summer			Total Phyto. SP.	Autumn			Total Phyto. SP.	Winter			Total phyto. SP.	Spring			Total Phyto. SP.
Group	E.B	M.B	W.B		E.B	M.B	W.B		E.B	M.B	W.B		E.B	M.B	W.B	
Bacillariophyceae	5	17	12	20	19	20	25	34	38	21	25	48	14	14	13	25
Chlorophyceae	29	32	27	36	19	29	26	34	17	27	24	34	21	28	30	35
Cyanobacteria	12	15	17	21	10	13	15	20	6	13	10	15	10	11	13	18
Dinophyceae	-	1	1	1	1	1	1	1	11	1	1	11	2	1	1	2
Euglenophyceae	5	13	11	13	2	12	11	15	5	6	8	10	3	7	7	8
Total phytoplankton	51	78	68	91	51	75	78	104	77	68	68	118	50	61	64	88

E. B.: Eastern Basin; M. B.: Middle Basin; W. B.: Western Basin

Mean phytoplankton abundances were highest at the western basin and lowest at the eastern basin. Although the diatoms were qualitatively more abundant, the bottom dwelling forms (Pennales) made up 40 species while the truly planktonic forms (centrales) made up 21 species. The most abundant pennate diatoms encountered were *Pseudo-nitzschia delicatissima* (Cleve) Heiden, 1928 (3.0%), *Navicula tripunctata* (O.F. Müller) Bory de Saint-Vincent, 1822 (1.49%) and *Nitzschia palea* (Kützing) W. Smith, 1856 (1.47%).

The true planktonic diatoms recorded were *Cyclotella meneghiniana* Kützing, 1844 (55.04%) and *Cyclotella glomerata* H. Bachmann, 1911 (30.82%) as their dominant representative during the study period. *Desmodesmus communis* (E. Hegewald) E. Hegewald, 2000 (13.4%), *Desmodesmus opoliensis* (P.G. Richter) E. Hegewald, 2000 (8.79%), *Acutodesmus obliquus* (Turpin) Hegewald and Hanagata, 2000 (8.0%) and *Willea rectangularis* (A. Braun) D.M. John, M.J. Wynne and P.M. Tsarenko, 2014 (7.54%), *Chlamydocapsa planctonica* (West and G.S.West) Fott, 1972 (6.1%) and *Coelastrum microporum* Nägeli, 1855 (5.0%) were the most abundant green algae recorded. *Geitlerinema amphibium* (C. Agardh ex Gomont) Anagnostidis, 1989 (52.29%) and to less numbers *Pseudanabaena limnetica* (Lemmermann) Komárek, 1974 (13.41%) were the largest number of representatives of blue green algae during the study period. Euglenoids were represented by the genera *Euglena* Ehrenberg, 1830 (84.24%), *Eutreptiella* A. da Cunha, 1914 (0.17%), *Lepocinclis* Perty, 1849 (0.48%) and *Phacus* Dujardin, 1841 (10.87%). *Ceratium* Schrank, 1793, *Dinophysis* Ehrenberg, 1839, *Prorocentrum* Ehrenberg, 1834, *Protoperidinium* Bergh, 1882 and *Scrippsiella* Balech ex A.R. Loeblich III, 1965 from Dinophyceae were recorded mainly in the eastern basin during winter, while *Gymnodinium* Stein, 1878 was the important genus of this group.

A few species were responsible for the main bulk of the community and represented > 5% of the total phytoplankton densities in each basin; they are recorded in table 5 and can serve as bio-indicators for each basin.

Table 5. Phytoplankton taxa as bio-indicator for different basins in Burullus Lagoon (> 5% of total annual average abundance).

Eastern Basin		Middle Basin		Western Basin	
species	%	species	%	species	%
Cyclotella meneghiniana	14.85	*Geitlerinema amphibium*	17.89	*Cyclotella meneghiniana*	16.55
Willea rectangularis	13.21	*Desmodesmus communis*	10.86	*Cyclotella glomerata*	13
Geitlerinema amphibium	9.15	*Cyclotella meneghiniana*	8.97	*Desmodesmus opoliensis*	7.48
Pseudo-nitzschia delicatissima	8.18	*Chlamydocapsa planctonica*	7.43	*Acutodesmus obliquus*	7.03

Many species (46 taxa) of this community were rare, with a frequency of 2.00% occurring in all samples, but they were very important because they controlled the levels of species diversity. The lowest and highest species diversities (H′) were 0.586 (station 2) in winter and 3.072 (station 4) in summer, with relatively higher values in the western basin. The correlations of phytoplankton abundance with species diversity indices were not significant (r = -0.157, p = 0.287), which means that low diversity does not mean stress or poor water quality, but may be a favorable condition. Species evenness (J) varied between 0.184 in winter (station 2) and 0.943 in summer (station 4), with higher values generally recorded in spring, indicating a decrease in the dominancy during this season.

The correlations between diversity-equitability, diversity-species number and diversity richness showed that diversity was influenced by the number of species (r = 0.436, $p < 0.05$) and had strong correlations with equitability (0.880, $p < 0.001$). As expected, diversity had a positive relationship with the richness index (r = 0.538, $p < 0.001$).

Seasonal variations of phytoplankton abundance:

During the study period, Chlorophyceae, Bacillariophyceae, and Cyanobacteria were the three dominant classes with respectively, 54.89%, 24.04%, and 16.06% of the total abundance. These classes had a progressively lower abundance from west to east. The average phytoplankton abundance was 1594 cells mL^{-1}; the highest values were registered in winter (1889 cells mL^{-1}) and the lowest ones were in autumn (1216 cells mL^{-1}). Generally, the highest values in cell densities of Chlorophyceae and of diatoms were recorded in spring and winter respectively (Figs 2 - 5), while the highest concentrations of cyanobacteria were recorded in summer.

During summer, phytoplankton abundance averaged 1457 ± 1333 cells mL^{-1} with 91 species, in which coccal chlorophytes (40.2%, 36 species) was the dominant group, followed by Cyanobacteria (36.3 %, 21 species) and Bacillariophyceae (19.0%, 20 species) as illustrated in figure 2. The total abundance varied between 20 cells mL^{-1} (station 3) and 3744 cells mL^{-1} (station 8). At the eastern basin, the seasonal mean total of phytoplankton cell abundance was 559 ± 580 cells mL^{-1}, with 51 species. The middle basin had an average abundance of 1917 ± 1686 cells mL^{-1}, with 78 species. Spatial fluctuation showed a wide variation in abundance and dominant species. Highest phytoplankton densities were observed in stations 6, 8 and 5 in which Cyanobacteria was predominant (47-61%). The development of euglenoids cell abundance also reached the maximum in stations 4 and 7 (24.7 - 41.4%). The seasonal mean value of total phytoplankton cell abundance in the western basin was 1555 ± 1152 cells mL^{-1} with 68 species. The total abundance varied between 582 cells mL^{-1} (station 9) and 3,187 cells mL^{-1} (station 10). The dominant group was Chlorophyceae at all stations except for station 9 in which diatoms were predominant. There was an increase in the cell abundance of Cyanobacteria at station 10.

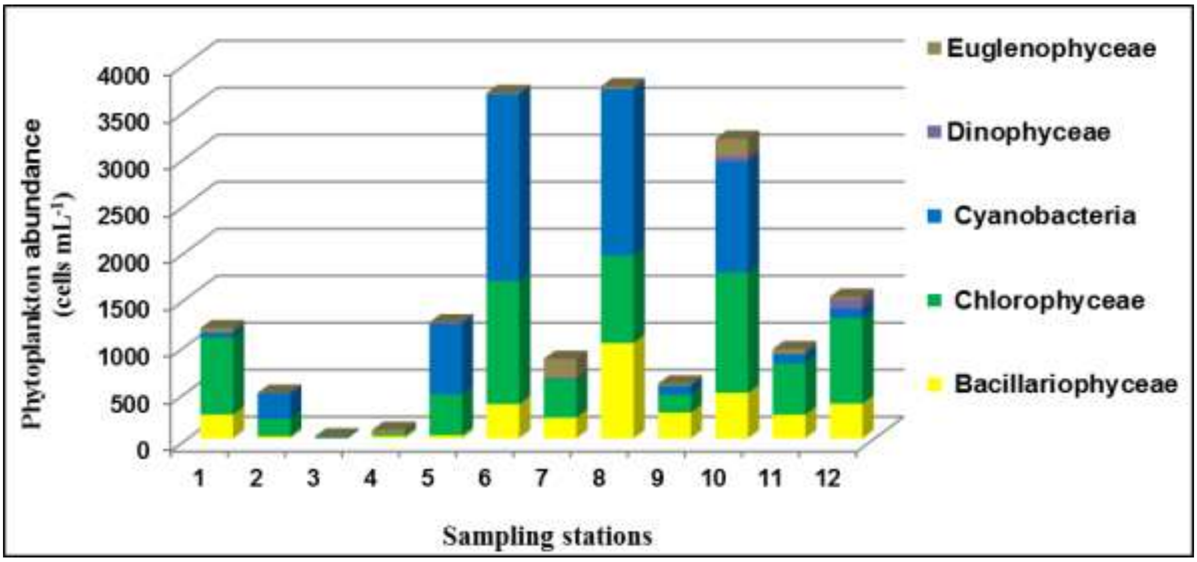

Fig. 2 Phytoplankton abundance subdivided by algal groups of the lagoon stations during summer 2013.

The lowest phytoplankton abundance (Fig. 3) was observed in autumn (1216 ± 646 cells mL^{-1}) with 104 species, in which Chlorophyceae (56.19%, 34 species) was the dominant group, followed by Bacillariophyceae (17.67%, 34 species) and Cyanobacteria (15.54%, 20 species). The total abundance varied between 165 cells mL^{-1} (station 2) and 2483 cells mL^{-1} (station 5). In the eastern basin, the seasonal mean total phytoplankton cell abundance was 443 ± 381 cells mL^{-1}, with 51 species. Bacillariophyceae and Chlorophyceae were predominant, about in equal proportions to each other (47.3-49.0%) at station 1, and the last division with Cyanobacteria (33.0 - 58.0%) was at stations 2 and 3. The middle basin had an average abundance of 148 ± 589 cells mL^{-1}, with 75 species. The dominant group was Chlorophyceae at all stations except for station 5, where Cyanobacteria and Chlorophyceae were nearly equal in abundance. Bacillariophycea abundance was important at rates from 10.3 to 20.1% of the total phytoplankton abundance. The development of euglenoids was also obvious at stations 4 and 7 reaching from 24% to 28% of the total phytoplankton densities. The seasonal mean value of total phytoplankton cell abundance in the western basin was 1463 ± 415 cells mL^{-1} with 78 species. The dominant group was Chlorophyceae at all stations (58.3 - 83.4%), except for station 11 in which Bacillariophyceae was predominant with 36.1% followed by Chlorophyceae (25.0%). Dinoflagellates and euglenophyceans were well represented at station 11 by 20.2 and 16.2% of the total abundance, respectively.

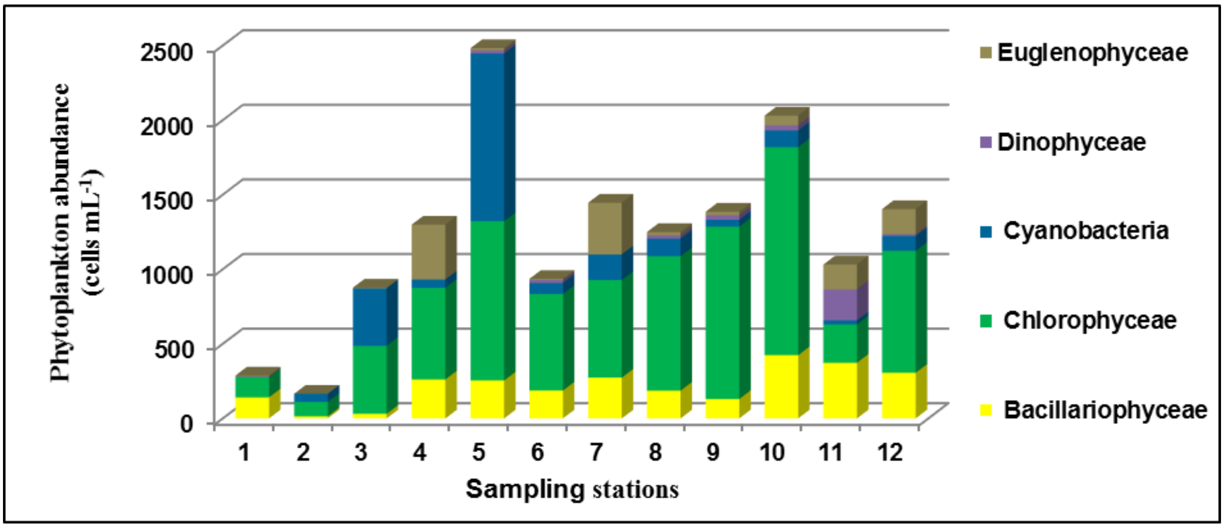

Fig. 3 Phytoplankton abundance subdivided by algal groups of the lagoon stations during autumn 2013.

During winter, phytoplankton abundance was distinctly greater than the other seasons (Fig. 4), with average 1889 ± 418 cells mL^{-1} and the highest diversity (118 taxa). The phytoplankton communities consisted mainly of Bacillariophyceae and Chlorophyceae, even if their contribution to the composition of the community in terms of abundances was different at the different stations. The phytoplankton at the eastern basin averaged

381 ± 243 cells mL^{-1}, with 77 species and showed a pronounced increase of marine diatoms. Bacillariophyceae reached their highest average abundance percentages, in which they constituted 95.0 and 71.4% of the phytoplankton community at stations 2 and 1, respectively, whereas Chlorophyceae represented 23.3% at station 3. *Pseudo-nitzschia delicatissima* prominent taxa, which is primarily of marine form, formed > 95% of the total diatoms at station 2. The taxa could be indicators of marine or brackish water. *Desmodesmus* and *Ankistrodesmus* were the most dominant green algae genera well represented at stations 1 and 3. In addition to the other recorded genera that were dominant species at station 1 and 3, respectively. The community greatly differed in the middle basin and averaged between 773 and ± 882 cells mL^{-1}, with 68 species; it was replaced by the green algal taxa which had constituted 59.5 - 81.5% at stations 5, 6, 7, and 8. Some of them were key species for eutrophic phytoplankton such as *Ankistrodesmus* spp., *Chlorella vulgaris, Coelastrum microporum*, *Crucigenia* spp., *Oocystis solitaria* Wittrock, 1879, *Pediastrum* spp., *Desmodesmus communis* and *Sphaerocystis schroeteri*. The green algal bloom had collapsed the western basin and dominance of the algal assemblage shifted to diatoms except at station 12 in which the chlorophyceans *Desmodesmus*, *Crucigenia* and *Planktosphaeria*, were the dominant genera. The density had an average of 4416 ± 7088 cells mL^{-1} with 68 species. Diatoms constituted 45.1 to 52.2% of the total community at stations 9, 10 and 11 with special reference to *Cyclotella* spp. and *Nitzschia* spp. Significantly higher phytoplankton abundances were recorded at station 10. There was an increase in the cell abundance of Euglenophyceae at station 11 (11.4%).

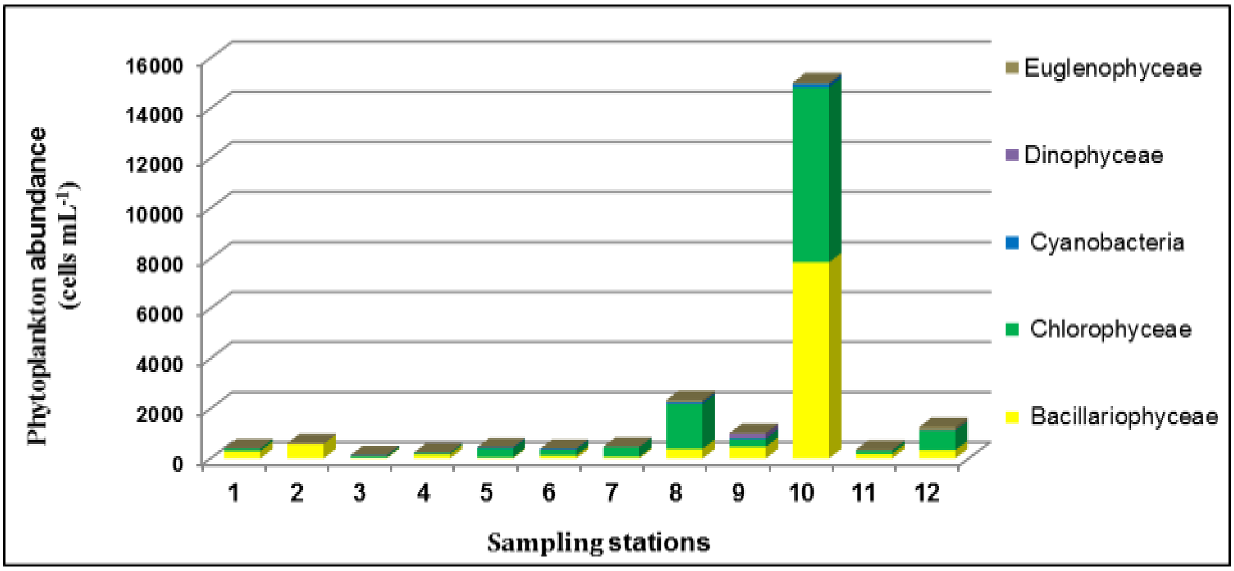

Fig. 4 Phytoplankton abundance subdivided by algal groups of the lagoon stations during winter 2014.

During spring, phytoplankton abundance averaged between 1816 and ± 1217 cells mL^{-1} with 88 species, while the abundance of Bacillariophyceae (9.4 %, 25 species) appeared to decrease towards the end of the study. There was an increase in the abundance of Chlorophyceae (71.6%, 35 species) and Cyanobacteria (15.1%, 18 species) (Fig. 5). The total abundance varied widely between 12 cells mL^{-1} (station 2) and 3599 cells mL^{-1} (station 6), except at stations 2, 4 and 10 where chlorococcalean algae played a key role in the eastern, middle and western basins (69.63, 83.8, and 55.3%, respectively). At the eastern basin, the seasonal mean total phytoplankton cell abundance was 867 ± 1392 cells mL^{-1} with 50 species. Chlorophyceae was the dominant division at station 1 (70.2%) and station 3 (62.62%), while Bacillariophyceae was predominant at station 2 (75.76%)The middle basin had an average abundance of 2228 ± 1365 cells mL^{-1} with 61 species. Except for station 4, Chlorophyceae dominated the community (80.7 - 91.5%), and the highest densities were observed in stations 6 (3599 cells mL^{-1}). The seasonal mean value of total phytoplankton cell abundance in the western basin was 2012 ± 648 cells mL^{-1} with 64 species. The dominant group was Chlorophyceae at all stations except for station 10 in which Cyanobacteria was predominant. Most dominant phytoplankton species were *Cycloteltа* from diatoms, *Ankistrodesmus*, *Crucigenia* and *Desmodesmus* from green algae and the freshwater cyanobacterium *Pseudanabaena limnetica* (station 10) from blue green algae and *Gymnodinium* sp. from Dinophyceae at station 12.

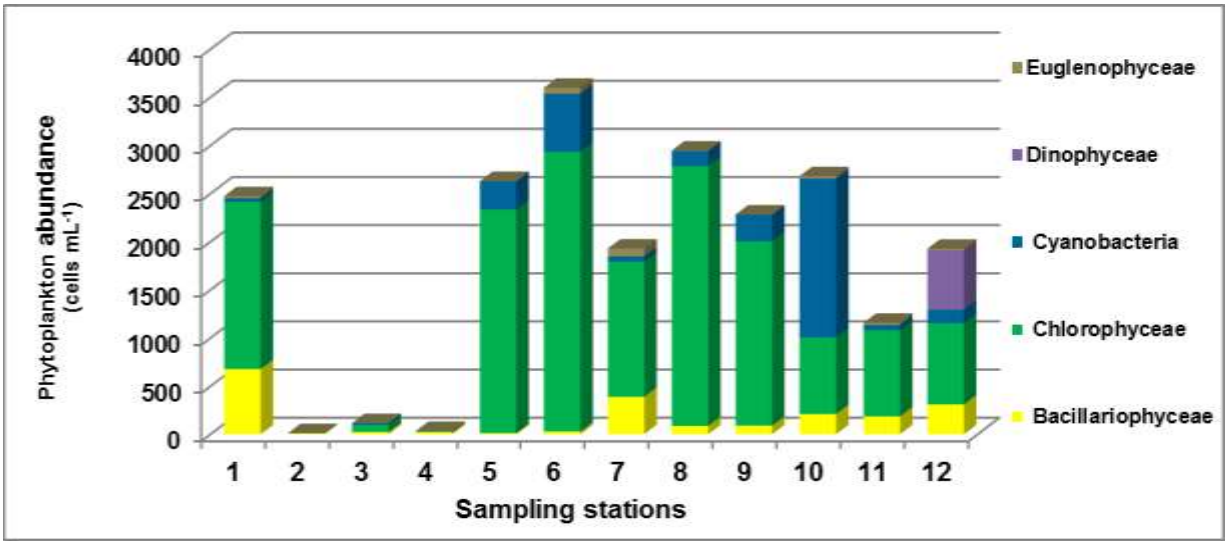

Fig. 5 Phytoplankton abundance subdivided by algal groups of the lagoon stations during spring 2014.

In general, the overall average cell abundance was 1594 cells mL^{-1}, and the highest cell abundance of phytoplankton was observed in winter due to the high Chlorophyceae and Bacillariophyceae abundance, while the lowest was recorded in autumn.

DISCUSSION:

Burullus Lagoon receives huge amounts of water mixed with industrial wastes, untreated sewage and agriculture drainages. Also, the lagoon receives Mediterranean seawater from a canal at the northeastern side, but the drainage water has exceeded the seawater that had been discharged into the lagoon.

It was expected that physicochemical conditions would be significantly different between the eastern, middle and western basins due to extreme differences in background conditions and levels of anthropogenic stress in each of them. The middle basin has the lowest transparency due to the high load of drainage water that is rich with suspended materials (Radwan, 1997), while the western basin has the highest transparency due to the high density of *Potamogeton pectinatus*, its tuber production may be limited under turbid conditions (Van Dijk and Van Vierssen, 1991). pH values usually lie on the alkaline side; a slight increase was observed over the last two decades due to a rise in photosynthetic activity of planktonic algae (Al-Sheikh and Fathi, 2010). The present study shows a slight decrease in pH levels due to the obvious decline in phytoplankton abundance.

Salinity values of the lagoon water decreased from east to west. The variation of the salinity values depends on the amount of drainage water that enters the lagoon from the south drains, the fresh Nile water from Brimbal Canal at the west and on the sea water from the canal at the east. The western basin exhibited the lowest salinity; in contrast, the relatively high salinities observed were at the eastern basin especially at station 2 which is close to the opening of the Mediterranean Sea. Marine phytoplankton species are restricted only in station 2 and in some cases they dominate the community in the eastern basin like in the winter when water salinity reached 35.6 PSU (Station 2), with the observed drop in phytoplankton abundance.

According to previous references, the salinity of the lagoon increased from year to year and that created high brackish water conditions in the eastern basin (>17 PSU, Zalat and Vildary, 2005). The high salinity and presence of marine forms in the eastern basin, especially in winter, could be due to the closure policy of the pumping drain stations which diminishes the water level to below sea level and permits sea water to enter the lagoon (El-Shinnawy, 2003). On the long term, salinity of the lagoon increased gradually from a mean of 1.9 ± 1.8 PSU during 2009 - 2010 (Nassar and Gharib, 2014) to a mean of 3.9 ± 1.4 PSU during the present study. This indicates the impact of invasion of sea water, and so variations in salinity values can be considered a stress factor for phytoplankton abundance and community structure.

Dissolved oxygen concentrations are usually more than the WHO standards (5 mgL^{-1}) that are necessary for aquatic organisms (Nkwo *et al.*, 2010). Concentrations of dissolved oxygen fluctuated between 2.0 and 19.3 mgL^{-1} with a mean of > 7.0 mgL^{-1} during summer, autumn and winter. However, during spring the dissolved oxygen reached an average level of 11.5 mg L^{-1}. Phytoplankton that bloomed in eutrophic water raised the dissolved oxygen dramatically; this may explain the extremes in the dissolved oxygen values in Burullus Lagoon.

The variation of phosphate concentrations (13.1 - 609.2 μM) indicates the changeability in the load of organic matter found in the discharged wastes, with the lowest average being in spring and the highest one in autumn. The high phosphorus levels in the lagoon (middle and western basins) make a good habitat for macrophyte communities (Shaltout and Al-Sodany, 2008) and their rapid growth may cause a limitation of nitrogen but not of phosphorus (Ozimek *et al.*, 1990). This may facilitate the obvious decrease in dissolved inorganic nitrogen during the sequence years. Phosphate contents increased during the present study (annual average: 0.25 ± 0.1 µM) when compared to the values recorded during 2010 - 2013 (Nassar and Gharib, 2014), but they were lower than the values recorded by Ali and Khairy (2012) and Okbah (2005). The increase in phosphate in Burullus Lagoon over the years is attributed to the huge agricultural runoff.

In the present study, nitrate dropped to reach a minimum value (0.08 ± 0.03 µM) due to its intensive uptake by the phytoplankton blooms. Ali and Khairy (2012) and Okbah (2005) recorded higher values of nitrate reached 13.4 ± 10.7 µM during 2006. Such decrease means that the eutrophication level in Burullus Lagoon had decreased considerably during the past two decades. Also, the ammonium concentration value was found to be lower than that in earlier reports (Nassar and Gharib, 2014), this variation also relates to its consumption by phytoplankton as their preferable nitrogenous compound.

The mean values of chlorophyll-*a* concentrations were high in comparison to the published data recorded between the years 2003-2006 (Okbah, 2005; Okbah and Hussein, 2006; Ali and Khairy, 2012), but lower than the values recorded during the periods from 2010 to 2013 (Nassar and Gharib, 2014), this may be due to phytoplankton's low density during the present study in comparison to the its density in previous records (Nassar and Gharib, 2014).

The ecosystem of Burullus Lagoon is extremely complex, partly due to the strong influence of many different sources of pollution. In this frame, chemical parameters, considered independently, may not be sufficient to furnish a complete picture of the environment (Bianchi *et al.*, 2003). Therefore, phytoplankton is an important factor in recognizing the state of the aquatic system. The changes in the community structure may indicate the beginning of an environmental alteration (Tilman *et al.*, 1982). Therefore, the present study of phytoplankton was carried out and the data was compared with the previous years. Spatial and temporal distributions of phytoplankton in the lagoon were not limited to phytoplankton densities, but extended to community structure as well; this variation might further reflect the surrounding environmental factors over time (Shen *et al.*, 2010).

The results showed that the most eutrophic stations are those located in the western basin since they have been heavily influenced by agricultural discharge (high concentrations of dissolved nutrients). While the stations present in the middle basin were discovered to be less eutrophic than those of the western basin as they were influenced by polluted drainage water. The eastern basin, which comes in contact with marine water through the Boughaz, encompassed the lowest phytoplankton abundance. The ratio of phytoplankton abundance between the eastern, middle and western basins was 1: 2.8: 4.2.

A total number of 163 phytoplankton taxa were recorded in the lagoon and were characterized by different ecological affinities. Few species were responsible for the main bulk and could serve as bio-indicators for each basin. A clear decreasing trend was observed for phytoplankton abundances over the years (Okbah and Hussein 2006; Nassar and Gharib, 2014), reaching an average of 1,594 cells mL^{-1} in the present study. This may be due to the competition for nutrients which were greatly consumed by the extensive growth of the macrophytes that cover a large area of the lagoon.

The species diversity index can serve as an indicator that the ecosystem is under the influence of pollution stress or eutrophication (Telesh, 2004). Rich phytoplankton diversity was recorded in Burullus Lagoon (163 taxa). The maximum number of phytoplankton taxa was observed at the eastern basin (120) due to the presence of marine forms. The minimum number (112) was found at the western basin. Diversity index values (average of 2.391) were higher than those that had been recorded during the period 2009 - 2014 (1.51-2.28) by Nassar and Gharib (2014), meaning that the water quality has recovered. Seasonal variation of diversity and equitability indices follow each other closely with the lowest values in summer. Data analysis showed a significant positive correlation between diversity and evenness indices (r = 0.880, $p < 0.001$) and between diversity and species numbers (r = 0.436, $p < 0.05$). These relationships are close to the observation of Reed (1978).

In summer, the phytoplankton community in the middle basin was dominated by the cyanobacteria, *Geitlerinema amphibium* (47.2%). The species showed toxicity effects (Dogo *et al.*, 2011). This is a very common pattern in shallow and turbid lakes (Dokulil and Teubner, 2000). Although it is still under discussion what factors might favor cyanobacteria (Scheffer *et al.*, 1997), it is acknowledged that nitrogen-fixing species are thought to develop in water with surplus phosphorus, and low N: P ratio that promotes the bloom of cyanobacteria because they are better competitors for nitrogen than any other algae and they become rare when N: P mass ratio goes above 29 (Smith, 1983). Cyanobacterial blooms are usually considered a major problem in any ecosystem because they are non-edible for zooplankton, potentially harmful to the other organisms and dangerous to human health (Wielgat-Rychert *et al.*, 2015).

The centric diatom *Cyclotella meneghiniana* was the most frequently encountered species (13.23% of the total counts). It is a cosmopolitan species, abundantly present in rivers and lakes, under different conditions. Houk *et al.* (2010) defined the species as common in eutrophic stagnant water or slowly running rivers.

It is interesting to note that during winter, Mediterranean Sea water flushed the lagoon and salinity reached > 35 PSU at station 2; marine water species dominated the community, particularly the diatoms *Pseudo-nitzschia delicatissima* and the dinophlagellates *Protoperidinium* spp. This state did not occur before in previous works. *Pseudo-nitzschia* spp also emerged as indicators of high inorganic N concentration, although this genus was recorded only during winter and found in more than 90% of the total count in station 2. Many authors discovered the ability of several *Pseudo-nitzschia* species to produce the neurotoxin domoic acid (Bates *et al.*, 1998).

Generally, the stations with high pollution levels such as stations 4, 7 and 11, which are located in front of drain 7, drain 8 and El-Hooks drain, received untreated discharged water with high concentration of pesticides and heavy metals (Shriadah, 1991). This led to the development of saprobiontic Euglenophyceae which assimilated lots of organic matter (Barrera *et al.*, 2008) and became dominant during summer and autumn (16.16 - 41.44% of the total count). Palmer (1969) noted that the genus *Euglena* tops the list of the sixty most tolerant genera to pollution. Munawar (1972) also considered the genus as a biological indicator for organic pollution. The western basin is subjected to huge amounts of fresh Nile water rich in nutrient salts that come from Brinbal Canal and are characterized by the dominancy of Bacillariophyceae and Chlorophyceae, as *Cyclotella* spp., *Desmodesmus opoliensis* and *Acutodesmus obliquus.* Earlier study of (El-Sherif, 1993) classified Burullus Lagoon as a mesotrophic lake. On the other hand, Okbah and Hussein (2006) and other reports stated that Burullus Lagoon is considered as an eutrophic area. El-Sayed (2010) assessed that the lagoon lies between oligotrophic to mesotrophic states. Later, Ali and Khairy (2012) classified the lagoon as hyper eutrophic with bad to very bad environmental conditions, but the study carried out by Nassar and Gharib (2014) showed no sign of eutrophication in the lagoon.

CONCLUSIONS:

Burullus Lagoon is continuously contaminated with discharge water that is enriched with chemicals fertilizers in addition to domestic and industrial effluents. These contaminants lead to prominent changes in physicochemical conditions and in the phytoplankton community. The present data suggests that the phytoplankton in the lagoon could be considered as a bioindicator of water quality in different basins. The high concentrations of dissolved oxygen mean no sign of eutrophication occurred in the lagoon. So, this study encourages the mechanical removal of the extensive hydrophytes, which enhances mixing of lagoon water and the use of a long-term monitoring framework to build an understanding of how water quality and phytoplankton communities respond to different flow events. The study also aims at capturing the onset of unforeseen events such as harmful cyanobacterial blooms. Also, we recommend optimizing the amount of fertilizer applied to crops by testing the soil and modeling the bare minimum amount of fertilizer needed. Accordingly, it is recommended that waste water should be treated according to sanitary regulations before being discarded into the lagoon.

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دراسات على التوزيعات المكانية والزمانية للعوالق النباتية في بحيرة البرلس، ساحل جنوب البحر الأبيض المتوسط، مصر

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تشكل الهائمات النباتية جزءاً أساسياً من المواد العضوية ببحيرة البرلس، كما أنها تمثل المستوي الأول للهرم الغذائي وكذلك تكون الغذاء الأساسي للكائنات الحيوانية بالبحيرة. ويهدف البحث إلى دراسة التغيرات في بنية مجتمعات العوالق النباتية وتنوعها في بحيرة البرلس وتقييم إنتاجية البحيرة. كذلك التعرف على أنواع ومجتمعات العوالق النباتية التي يمكن اعتبارها مؤشرات مميزة للأحواض المختلفة على طول البحيرة، لإعطاء صورة صحيحة للوضع الصحي للبحيرة والمساعدة على تطوير المخزون السمكي وجودة البروتين. فتمت الدراسة لمدة 4 فصول تبدأ من صيف 2013 حتى ربيع 2014 من 12 محطة غطت الأجزاء المختلفة للبحيرة. حيث قُسمت البحيرة الى ثلاث أحواض: الحوض الشرقي (محطات1-3) ; الحوض الأوسط (محطات 4-8); الحوض الغربي (محطات 9-12). سجل تركيزٌ الكلوروفيل *a* متوسط 42.8 ميكٌروجرام/لتر في فصل الصيف و 115.6 ميكٌروجرام/لتر في فصل الشتاء على التوالي. أما بالنسبة تركيزٌات الأملاح المغذيةٌ فقد كانت الأمونياٌ هي المصدر الأساسي لأملاح النيٌتروجينٌ الذائب حيثٌ تراوحت تركيزات بين (54.7-76.7%). وقد أظهرت الدراسة اختلاف واضح في الغزارة الكليةٌ وكذا في تركيبٌة العوالق النباتيةٌ بينٌ المحطات المختلفة على مدار السنة. وبالنظر إلى الكثافة العددية لمجموعات الهائمات النباتية احتلت مجموعة الطحالب الخضراء المرتبة الأولي 54.9% من العدد الكلي للهائمات النباتية بينما سجلت المشطورات المرتبة الثانية بنسبة 24.0% من العدد الكلي، بينما في العام السابق لهذه الدراسة (2013 – 2012) كانت مجموعة المشطورات في المرتبة الأولي بنسبة 39.1% من العدد الكلي للهائمات النباتية. بينما كانت نسبة الطحالب الخضراء 42.5% في العام 2012 - 2011 مما يشير إلي زيادة نسبية في معدلات الأملاح المغذية عن العام المنصرم. وبصفة عامة تعتبر بحيرة البرلس من البحيرات الغنية بالهائمات النباتية لأنها ذات إنتاجية عالية. بالتعرف على أنواع ومجتمعات العوالق النباتية التي يمكن اعتبارها مؤشرات مميزة للأحواض المختلفة على طول البحيرة وكانت *Cyclotella meneghiniana* واحداً من أهم مكونات العوالق النباتية في الأحواض الثلاثة للبحيرة بينما شَكلت *Geitlerinema amphibium* نسبةً متوسطةً في كلٍ من الحوض الشرقي و الأوسط. وبالمثل سجلت *Desmodesmus communis* نسباً متوسطةً في الحوضين الأوسط والغربي.