Egyptian Journal of Aquatic Research (2014) 40, 133–142

HOSTED BY
ELSEVIER

National Institute of Oceanography and Fisheries

Egyptian Journal of Aquatic Research

http://ees.elsevier.com/ejar
www.sciencedirect.com

FULL LENGTH ARTICLE

Spatial and temporal patterns of phytoplankton composition in Burullus Lagoon, Southern Mediterranean Coast, Egypt

Mohamed Zein Alabedin Nassar [a,*], **Samiha Mahmoud Gharib** [b]

[a] *National Institute of Oceanography & Fisheries, Suez Branch, Egypt*
[b] *National Institute of Oceanography & Fisheries, Alexandria Branch, Egypt*

Received 28 April 2014; revised 18 June 2014; accepted 18 June 2014
Available online 28 July 2014

KEYWORDS

Phytoplankton;
Seasonal variations;
Burullus Lagoon

Abstract Burullus Lagoon is a shallow, turbid, and nutrient replete system, suffering from high level of aquatic plants, expansion in fish farming and agricultural drainage discharges. Phytoplankton was evaluated based on four years monitoring seasonally from summer 2009 to spring 2013 at 12 stations representing the eastern, central and western basins of the lagoon. Over the 4-year study period, a total of 283 taxa from 96 genera and eight classes were recorded. The lagoon showed a pronounced algal periodicity. Phytoplankton community was generally dominated by Chlorophyceae, Bacillariophyceae and Cyanobacteria. The western basin had the lowest mean salinity values and highest phytoplankton abundance, in which, blooms of Chlorophyceae, Bacillariophyceae and Cyanobacteria were common. The eastern basin had lowest phytoplankton density and chlorophytes were dominant followed by Bacillariophyceae and/or Cyanobacteria. Euglenophyceae strongly appeared in the eastern basin especially at the second station, which is located in front of El Burullus Drain. The central basin is subjecting to high loading of phosphorus and nitrogen from agricultural drains and had a prevalence of chlorophyte blooms which constituted more than 50% of the total abundance. This study has provided substantial evidence that the phytoplankton abundance and community are governed by the environmental conditions which vary each year, so does the phytoplankton seasonal succession. Generally, about 25-50% reduction was recorded in the phytoplankton densities between 2009 and 2013 and a dramatic decrease in the abundance of many nuisance and eutrophic species was evident. No sign of eutrophication was observed, and recession of Cyanobacteria blooming suggests a major improvement in the water quality of Burullus Lagoon.

* Corresponding author. Address: B.O. 182, Suez, Egypt. Tel.: +20 1009025726.
E-mail address: mnassar65@yahoo.com (M.Z.A. Nassar).

Peer review under responsibility of National Institute of Oceanography and Fisheries.

http://dx.doi.org/10.1016/j.ejar.2014.06.004
1687-4285 © 2014 Hosting by Elsevier B.V. on behalf of National Institute of Oceanography and Fisheries.

Introduction

Coastal lagoons rank among the most productive ecosystems on Earth. They are shallow brackish or marine bodies separated from the sea by a barrier island, spit, reef, or sand bank and connected at least intermittently to the open sea by one or more restricted tidal inlets (Gonenc and Wolflin, 2004). Lagoonal environments are vulnerable to environmental changes (Lloret et al., 2008), particularly to enhanced anthropogenic pressure, which can lead to eutrophication (Viaroli et al., 2004).

Coastal lagoons of the Nile River of Egypt are the largest lagoons in the north of Africa, representing approximately 25% of the total lagoons of the Mediterranean Sea and contribute no less than 50% of the total wild fish catch produced in Egypt (Saad, 2003). During the last few decades, as agriculture expanded and the excessive use of chemical fertilizers and pesticides and washing out of nutrients loaded to the drainage water which in turn feed the lagoons through several drains. Such fertilization may hold the danger of shifting the lagoon ecosystem from a macrophyte-dominated state to one with perennial Cyanobacteria blooms.

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 has been exposed to nutrient over-enrichment. The central basin receives the drainage water from six agricultural drains, phosphorus concentration is observed to be higher in the central part of the lagoon (Okbah, 2005) and the western basin receives fresh Nile water from Brimbal Canal. On the other hand, the eastern basin receives water directly from the sea and therefore, water in this basin is much salty. Water salinity showed wide variations between 0.45 and 21.13‰, this variation is attributed to the source water coming into the lagoon (Okbah and Hussein, 2006). However, the environment of Burullus Lagoon has witnessed a significant change during the last three decades and so; it was designated as a Protected Area in 1998.

The first monitoring of phytoplankton populations of Burullus Lagoon was performed by El-Sherif (1983), followed by a second study during a low-flow Nile year (El-Sherif, 1993) evidencing that the phytoplankton community was composed by seven classes with 110 species in which diatoms were the dominant group. More recent evaluations of the phytoplankton included by Radwan (2002), Fathi and Abdelzahar (2004), Okbah and Hussein (2006) and recently, Ali and Khairy (2012). 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 microfloral species richness, followed by Chlorophyceae and then Cyanobacteria came only in third position, but had increased from 1.7% to 9.5% in 20 years. This order is not fully confirmed by the CASSARINA Project (Flower, 2001).

Comparison between evaluation of nutrient levels in the last decades (Abdel-Moati et al., 1988; Radwan, 1997, 2004, 2005; Okbah, 2005; Okbah and Hussein, 2006; Ali and Khairy, 2012) showed irregular fluctuations in nutrient concentrations but with more or less decrease especially in phosphorus concentrations.

This paper aims to study the spatio-temporal distribution of the phytoplankton in Burullus Lagoon during four years, and to evaluate the possible risks of Cyanobacteria algal blooms and to answer the question why Cyanobacteria blooms has not occurred yet?

Materials and methods

Study area

Burullus Lagoon is an alkaline, shallow, slightly brackish and moderately polluted lagoon (Eid, 2012). The lagoon lies between longitude 30° 30′ and 31° 10′ E, and latitude 31° 21′ and 31° 35’ N (Fig. 1). It has an irregular elongated shape, with a depth between 0.40 and 2.50 m (Okbah, 2005). The deepest part lies in the western basin, while the eastern basin is shallow and contains an outlet of about 250 m long canal that connecting the lagoon to the sea (Doumont and El-Shabrawy, 2007). The bottom sediments of the lagoon are predominantly structure less silty clay, with high organic content in parts, and large areas of shelly to silty muddy sand (Coutlier and Stanley, 1987). The lagoon has a length of about 47 km and the width varied 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). Approximately 75 islands are scattered throughout Burullus Lagoon, with various surface areas, offering a variety of habitat types. It is characterized by having an extensive growth of hydrophytes (*Phragmites* and *Typha*) particularly along its southern shores beside extensive patches of submerged *Potamogeton pectinatus*; these are important refuges for fish fry (Ramdani et al., 2001).

Burullus Lagoon is classified into three basins: eastern, central and western, each one has some sort of homogeneity in the geomorphological, hydrological and biological characteristics. The eastern basin comprised three stations; the first station is located in front of EL-Burullus Drain, the second station is located in front of the canal connecting the lagoon to the sea. The central basin (Stations 4–8) received discharged waters through several drains, while the western basin (Stations 9–12) receives estuarine Nile water from Brimbal Canal.

Methods

During the period from summer 2009 to spring 2013, samples were collected seasonally for quantitative and qualitative phytoplankton analysis (16 cruises with 12 stations) using Ruttiner bottle. Water samples were preserved by Lugol’s solution and phytoplankton analyzed according to Utermöhl’s method (Utermöhl, 1958). The identification and counting of the algal taxa were done according to APHA (2005), and the population density was expressed as cells/ml.

Statistical analysis

Two indices were used to estimate the community structure: diversity (H′) (Shannon and Wiener, 1963), and evenness or equitability (J) (Pielou, 1975) using the SPSS 8.0 Statistical Package Program.

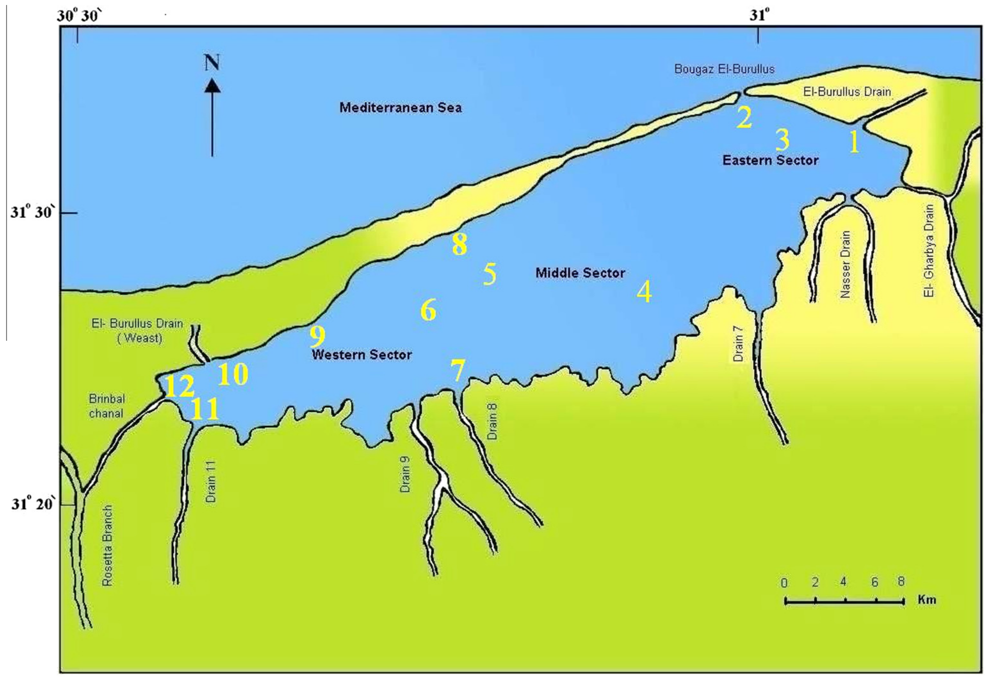

Figure 1 Positions of the sampling stations of Burullus Lagoon.

Results

Hydrographic conditions

The estimation of Chlorophyll-*a* and the physico-chemical characteristics of Burullus Lagoon were studied parallel to the present phytoplankton study at the same time and at the sampled stations as reported in the site of Environmental monitoring program for the North lakes (E.M.P.N.L.) together with previous data in sequence years are summarized in Table 1.

Water temperature in Burullus Lagoon did not deviate from the normal seasonal fluctuations on the south-eastern coast of the Mediterranean Sea (~22.4 ± 5.0 °C), and generally followed that of the air, due to the shallow depth. Water transparency showed a gradually decrease to reach < 25 cm. In spite of the pH of the lagoon water lies in the alkaline side (~8.4 ± 0.2), it showed a slight increase over the years of study. Salinities exhibited a wide variation; they varied between > 17 PSU at the eastern basin to < 5 PSU in the central and western basins. As for dissolved oxygen, the lagoon water was well oxygenated (~8.5 mgl^{-1}). The results of nutrient showed a gradual decrease in the concentrations, while Chlorophyll-*a* concentrations recorded a gradually increase.

Phytoplankton community structure and composition

The phytoplankton of Burullus Lagoon exhibited extensive variability, both in respect to the number of taxa and phytoplankton abundance. Over the 4-year study period, a total of 283 taxa from 96 genera and 8 classes namely; Bacillariophyceae (111 taxa), Chlorophyceae (81 taxa), Cyanobacteria (50 taxa), Euglenophyceae (29 taxa), Dinophyceae (10 taxa) and taxon for each of Cryptophyceae, Xanthophyceae and silicoflagellates were recorded for the study. The numbers of taxa found in Burullus Lagoon in the four subsequent years of studies within individual phytoplankton classes were dissimilar (Table 2). *Cyclotella* and *Nitzschia* genera from Bacillariophyceae were particularly vastly represented. *Chlorella vulgaris* Beyerinck [Beijerinck], 1890, *Scenedesmus* quadricauda (Turpin) Brébisson, *Scenedesmus* bernardii G.M. Smith, *Ankistrodesmus falcatus* (Corda) Ralfs, 1848 and *Schroederia setigera* (Schröder) Lemmermann from Chlorophyceae were found to be dominant and subdominant organisms in certain months alternately. Cyanobacteria were dominated by *Oscillatoria* spp.

Trends in relative abundance of algal divisions from 2009 to 2013 suggest an increase in Bacillariophyceae and Dinophyceae and decrease in Chlorophyceae and Cyanobacteria. The most common genera were *Navicula* (21 species), *Nitzschia* (17 species), *Scenedesmus* (12 species), *Oscillatoria* (11 species) and *Euglena* (18 species). Many species of the community were rare, having a negligible frequency of occurrence, but they were very important because they controlled the levels of species diversity.

Over the four-year period of the study, mean phytoplankton density was higher in the western basin (3642 ± 2538 cells/ml) than the middle and eastern basins (3074 ± 1299 and 1671 ± 500 cells/ml, respectively). The spatial differences between basins were most pronounced during the study period. The eastern basin was frequently dominated by Chlorophyceae and/or Cyanobacteria. Diatoms came second in importance, while euglenoids appeared in obvious numbers at the first station in front of El Burullus Drain. In the middle basin, Chlorophyceae was more often the dominant. While in the western basin, diatoms were generally higher except for station 11 where cyanophytes were the first.

The lowest and highest species diversities (H′) were 0.27 and 3.23 (station 11) in summer 2009 and autumn 2011, respectively. The correlations of phytoplankton abundance with species diversity indices were insignificant ($r = 0.157$, $p = 0.287$).

Table 1 Evaluation of physicochemical parameters (averages or ranges) in Burullus Lagoon between 1987 and 2013.

Year	Temp. (°C)	Transp. (cm)	pH	Salinity ‰	DO (mgl^{-1})	Chl. a (mgl^{-1})	NO_2 (μmol/L)	NO_3	NH_4	PO_4	SiO_4	Reference
1987	–	–	–	–	–	–	0.8	4	–	1.6	66.8	Abdel-Moati et al. (1988)
1997	–	–	–	–	–	–	2.1	5.7	–	2.9	47.3	Radwan (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 Hussein (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
2010–2011	23.2	17.7	8.6	–	7.7	69.7	84.1	0.49	1.13	0.15	3.1	for the North Lakes
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/
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	env_water.asp

Species evenness (J) varied between 0.11 (station 12) in summer, 2009 and 0.87 (station 10) in autumn, 2012.

Seasonal variations of phytoplankton

In terms of the more general phytoplankton community, certain overall spatial and temporal patterns in composition and abundance were apparent from the results. Over the 4-year study period, Chlorophyceae, Bacillariophyceae and Cyanobacteria were the three dominant classes with respectively, 41.6%, 27.2% and 25.3% of the total abundances. However, all the three dominant classes (Fig. 2 and Table 3) had a progressively lower abundance from west to east. Generally, phytoplankton dominance in the different basins varied from year to year, and also from season to season.

During 2009–2010, phytoplankton abundance averaged 3150 cells/ml, in which Bacillariophyceae (34.4%) was the dominant group, followed by Chlorophyceae (32.0%) and Cyanobacteria (27.8%). At the beginning of the investigations (summer, 2009), an algal bloom dominated the eastern basin by Cyanobacteria (*Chroococcus* turgidus (Kützing) Nägeli, 23% and *Oscillatoria tenuis* C. Agardh, 1813, 20.5% of the total count). The *Chroococcus* bloom had collapsed by the central basin and dominance of the algal assemblage shifted to *Anabaena spiroides* f. *crassa* (Lemmermann) Elenkin (13.4%). The western basin was dominated by *Cyclotella meneghiniana* Kützing, 1844 (55%) followed by *Dolichospermum spiroides* (Kleb.) Wacklin, L. Hoffm. & Komárek, 2009 (15%). During autumn, various phytoplankton species grew successively in the eastern basin but briefly: the main types were ascribable to eutrophic nanoplankton, *Euglena*-dominated plankton (41%), *Chlorella vulgaris* Beyerinck [Beijerinck], 1890 (18%) dominated Chlorophyceae and centric diatom *Cyclotella meneghiniana* and *Melosira* sp. The central basin showed the same distribution of the eastern basin, with a slight shift to *Oscillatoria tenuis* (11%). The community greatly differed in the western basin, and the species replaced by the centric diatoms (46%) *Cyclotella meneghiniana*, *Melosira* sp., *Merismopedia punctata* Meyen, 1839 (17%) and *Chlorella vulgaris* (12%). In the winter, the phytoplankton was dominated in the eastern basin by the small nanoplanktonic non-motile chlorophytes, *Chlorella vulgaris*, and *Oocystis borgei* J. Snow, 1903 which formed > 90% of the total density. Chlorophyte assemblage declined in the central basin, diatom (*Cyclotella meneghiniana*, 27%) and blue green (*Chroococcus turgidus* (Kützing) Nägeli, 1849, 14%) appeared. The community in western basin was dominated by the same autumn species. During spring, *Chlorella vulgaris* and *Chroococcus turgidus* dominated the community in the eastern and central basins (76–86%), while the western basin dominated by *Aulacoseira granulata* (Ehrenberg) Simonsen, 1979 (59%).

During 2010–2011, phytoplankton abundance was distinctly greater than the other periods, with average 4537 cells/ml, in which Chlorophyceae (49%) was the dominant, followed by Cyanobacteria (24.6%) and Bacillariophyceae (20.2%). Highest cells concentrations measured during autumn in the western basin (Stations 9 and 10), while lowest counts recorded in summer at the eastern basin. The phytoplankton at the eastern basin showed a pronounced increase of marine diatoms appeared in summer, as *Asterionellopsis glacialis* (Castracane) Round, 1990 (12.5%) and *Leptocylindrus minimus* Gran, 1915

Table 2 Number of species and genera observed in each algal division in Burullus Lagoon from summer 2009 to spring 2013.

Class	2009–2010		2010–2011		2011–2012		2012–2013	
	Species	Genus	Species	Genus	Species	Genus	Species	Genus
Chlorophyceae	31	17	62	23	49	17	46	18
Bacillariophyceae	35	21	72	30	53	22	50	20
Cyanobacteria	18	9	35	13	27	11	27	13
Euglenophyceae	7	3	21	2	20	3	20	3
Dinophyceae	3	3	4	4	4	2	5	4
Xanthophyceae	0	0	0	0	1	1	0	0
Cryptophyceae	1	1	0	0	0	0	0	0
Silicoflagellates	0	0	1	1	1	1	0	0
Total	95	54	195	73	155	57	148	58

(27%). *Cyclotella meneghiniana* was frequently observed in the eastern basin, forming about 9–21% of the total abundance. Euglenoids were the most prevalent forms in spring (70% of the total abundance) while *Chlorella vulgaris* constituted 39% in autumn. As for the central basin, phytoplankton communities were changed, and the major changes were *Scenedesmus quadricauda* (16.7%, summer), *Oscillatoria limnetica* Lemmermann, 1900 (56%, autumn), *Cyclotella* (2 spp., 49.4%, winter). The community shared by *Cylindrotheca closterium* (Ehrenberg) Reimann & J.C. Lewin, 1964 (27.5%), *Ankistrodesmus falcatus* (Corda) Ralfs, 1848 (14.0%), and *Cyclotella. meneghiniana* (12.0%). The most obvious events occurred in the western basin were the predominant of *Pseudanabaena limnetica* (Lemmermann) Komárek, 1974 which formed about 90% of the total abundance during autumn, *Acutodesmus bernardii* (G.M. Smith) E. Hegewald, C. Bock & Krienitz (>60%) in spring and *Cyclotella meneghiniana* (44.5%).

During 2011–2012, phytoplankton abundance average 2343 cells/ml, with the dominant of Chlorophyceae (42.5%), followed by Cyanobacteria (27.6%) and Bacillariophyceae (25.4%). The highest cell concentrations were measured during summer in the central basin, while lowest counts recorded in winter. The most significant contributors to the species composition in the eastern basin were *Acutodesmus acuminatus* (Lagerheim) Tsarenko (28.6%), *Geitlerinema amphibium* (27.3%) and *Cyclotella meneghiniana* (21.4%) during summer. Euglenophyceae appeared again, but during autumn with 18 species and the most dominant were *Euglenaria caudata* (Hüber) A. Karnowska-Ishikawa, E. Linton & J. Kwiatowski (22.3%) and *Euglena deses* Ehrenberg, 1833 (11.2%). *Cyclotella* (2 spp., 44.3%) and *Bacillaria paxillifer* (O.F. Müller) T. Marsson, 1901 (15.0%).

During 2012–2013, while the abundance of Cyanobacteria (16.9%) and Chlorophyceae (36.5%) appeared to be decreasing towards the end of the study period, there was an increasing abundance of Bacillariophyceae (39.1%). This was associated with an increasing diversity of Bacillariophyceae. Phytoplankton abundance averaged 1144 cells/ml. The highest cell concentrations were measured during summer, while the lowest counts were recorded in spring. *Pseudanabaena limnetica* which was prevalent in the eastern basin during summer with 46.4% of the total abundance, decreased to 33.7% in the central basin and reached lowest percentage of 8% in the western basin. *Cyclotella* (2 spp.) formed 31.5% in summer decreased to 23.5% in the central basin, and increased to 39.5% in the western basin, but was prevalent in the community during winter in the three basins (eastern: 28.9%, central: 36.0%, western: 78.6%). Green algae dominated the community in the three basins during autumn, with special reference to *Ankistrodesmus falcatus* (18.5%), *Chlorella vulgaris* (15.7%) in the eastern basin, and the latter two species in addition to *Scenedesmus* (2 spp., 16.4%) were dominated during autumn in the central basin. *Cyclotella* (2 spp.) formed 68.6% in the western basin during winter.

Discussion

Brackish ecosystems, such as Burullus Lagoon, are subjected to great modifications in time and space because they are closely associated with drainage basin conditions, and with the action of seawater driven through lagoon-sea connection (Lara-Lara et al., 1980). The central basin of Burullus Lagoon has the lowest transparency due to the high load of drainage water rich with suspended materials (Radwan, 1997), while the north and western basin have the highest transparency, this may explain the high density of *Potamogeton pectinatus* in this basin, which its tuber production may be limited under turbid conditions (Van Dijk and Van Vierssen, 1991). PH values usually lie in the alkaline side, and a slight increase was observed over the last two decades, due to the increased photosynthetic activity of planktonic algae (Al-Sheikh and Fathi, 2010). Salinity distribution in the lagoon water reflects a decreased gradient from the east to west. This gradient depends on the amount of drainage water that comes from the south drains, fresh Nile water from Brimbal Canal at the west, and sea water from the sea outlet at the east, and therefore marine phytoplankton species are restricted only in the eastern basin and in some cases dominate the community. According to previous references, the salinity of the lagoon increased from year to year which creates high brackish water conditions especially 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 diminish the water level to be below sea level and permits sea water to inter the lagoon (El-Shinnawy, 2003). In this point, it is important to mention that the lagoon renewed its water six times a year (Darrag, 1985), i.e. the flushing rate is 61 days.

The water of Burullus Lagoon had dissolved oxygen concentration values usually above the minimum WHO standard of 5 mg/l required for water quality assessment (Nkwo et al., 2010), and so the lagoon water consider as well oxygenated ecosystem.

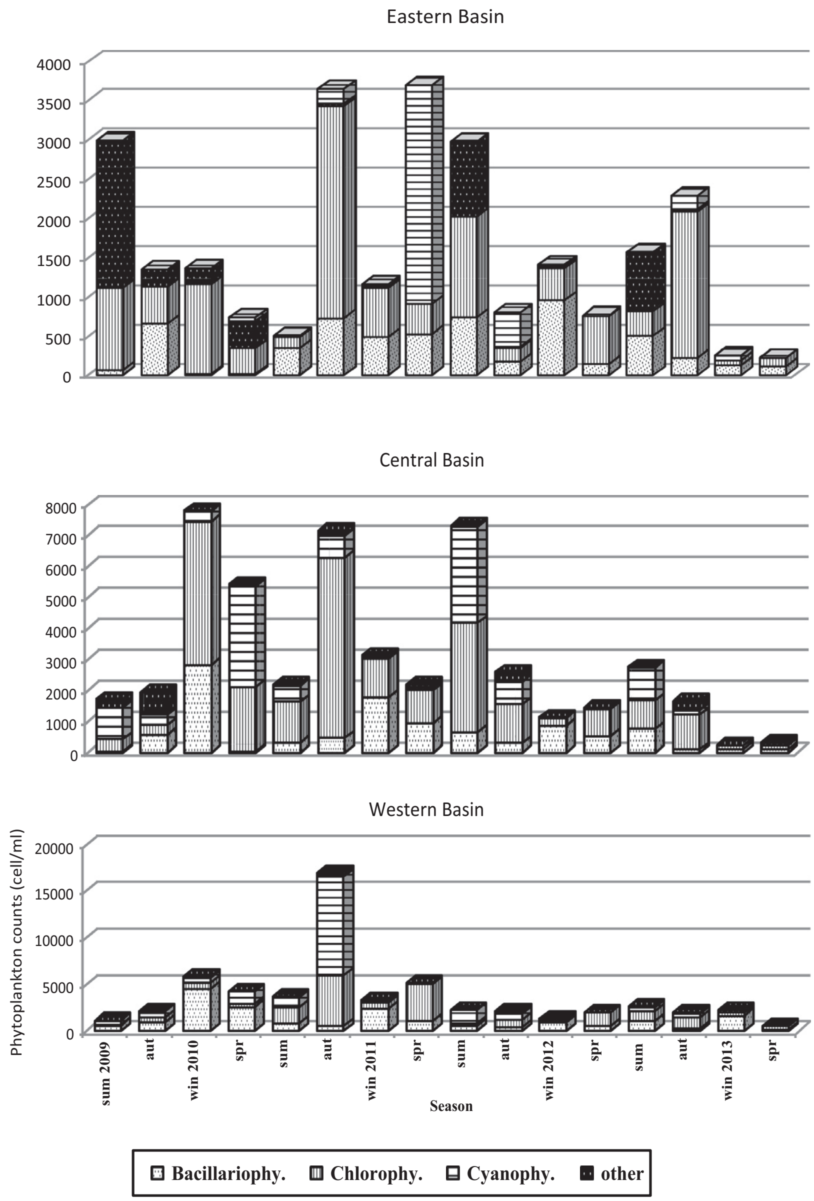

Figure 2 Seasonal variations of phytoplankton abundance subdivided by algal groups at the different basins of Burullus Lagoon from summer 2009 to spring 2013.

Due to the barriers of macrophyte communities, shallowness of water, weakened wave action and the slightly increase in temperature, all these factors make water column of the lagoon to be vertically mixed, and so nutrients of sediment are easily diffuse into the overlying water and thus increasing the nutrient concentrations in the water columns (Yin et al., 2001). The high phosphorus levels in the central and western basins make a good habitat for macrophyte communities. *Phragmites australis*, *Potamogeton pectinatus* and *Arthrocnemum macrostachyum* are the predominant species in Burullus Lagoon (Shaltout and Al-Sodany, 2008). Rapid growth of these macrophytes may cause a limitation of nitrogen but not of phosphorus (Ozimek et al., 1990).

The results obtained by Radwan (2005), Fathi and Abdelzahar (2004), Okbah and Hussein (2006) and Ali and Khairy (2012), and the evaluation performed for the four years later, showed gradually decrease in nutrient concentrations, except for abrupt increase in nitrite concentrations (average of 84.1 μM) recorded during 2010–2011. As a result, important changes in phytoplankton population took place with increasingly frequency of Chlorophyceae which was predominant at all lagoon basins.

Further evidence of the high nutrient availability in the lagoon is the high concentration of chlorophyll-*a*, which showed a steady increase over the years parallel to the decrease in numerical abundance. This means that, the bulk of the biomass comprised mainly of small cells (nanoplankton, 3–20 μm; picoplankton, < 3 μm) that were not counted during the present study and constituted a considerable amount of the photosynthetic biomass, as reported by Lindell and Post (1995).

Phytoplankton is an important indicator of the status of aquatic ecosystem, and structural changes in its community may indicate the beginning of environmental alteration (Tilman et al., 1982), therefore, a study of phytoplankton

Table 3 Annual mean phytoplankton densities (cells/ml ± standard deviation) in Burullus Lagoon by taxonomic division in different basins.

Basin	Year	Chlorophyceae		Bacillariophyceae		Cyanobacteria		Euglenophyceae		Dinophyceae		Cryptophyceae		Xanthophyceae		Silicoflagellates	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Eastern	2009–2010	749	688	188	509	665	821	248	820	0.1	0.2	0.1	0.2	0	0	0	0
	2010–2011	962	2120	525	581	18	19	748	2410	5.1	11.3	0	0	0	0	0.2	0.1
	2011–2012	623	1128	503	735	243	603	121	376	1.5	3.5	0	0	0	0	0	0
	2012–2013	583	1055	241	412	200	627	52	114	9.4	21.7	0	0	0	0	0	0
	Mean	729	170	364	174	282	274	292	314	4	4	0	0	0	0	0	0
Middle	2009–2010	1870	2256	861	1735	1231	1533	268	550	0.2	0.3	5	22	0	0	0	0
	2010–2011	2378	2928	876	1035	333	489	83	143	12	43	0	0	0	0	0	0
	2011–2012	1470	1810	595	735	972	1766	95	268	1.6	4.6	0	0	0	0	0	0
	2012–2013	576	672	263	448	302	783	103	244	3.3	11	0	0	0	0	0	0
	Mean	1574	762	649	288	710	465	137	88	4	4	13	25	0	0	0	0
Western	2009–2010	408	434	2205	3463	735	777	17	35	0.1	0.2	0.4	1.2	0	0	0	0
	2010–2011	2975	4795	1260	1261	2924	7097	111	161	45	65	0	0	0	0	0	0
	2011–2012	682	835	662	518	543	743	59	63	52	118	0	0	1.1	3.6	0	0
	2012–2013	751	843	832	901	200	279	77	89	39	64	0	0	0	0	0	0
	Mean	1204	1190	1240	691	1101	236	65	40	33	23	0.1	0.2	0.3	0.6	0	0

was carried out in Burullus Lagoon throughout continuous four years. The data of this study showed that there are marked spatial and seasonal differences in the quantitative and qualitative composition of the phytoplankton communities; this spatial variation might further reflect the surrounding environmental factors over time (Shen et al., 2010). Nutrient level and availability should be one of the direct factors that could not only control phytoplankton abundance but also influence the community composition (Blanco et al., 2008). Besides the dissolved nutrients, many other factors might also influence the species composition, like currents, temperature, feeding pressure by zooplankton and benthos (Song et al., 2002). In Burullus Lagoon there were consistent differences in the phytoplankton community in the different basins, but species are mainly fresh or brackish water forms. A clear decreasing trend was observed for phytoplankton abundances over the years to reach lowest counts in 2009–2010. This may be due to the competition for nutrients which greatly consumed by the extensive growth of the macrophytes that cover large area of the lagoon. In the same way, the development of Bacillariophyceae was favoured in compared to other classes which respond rapidly to nutrient inputs specially silica as reported by Cloern and Dufford (2005).

Diversity is dependent on key ecological processes such as competition, predation, and succession, and therefore changes in these processes can alter the species diversity index through changes in evenness (Stirling and Wilsey, 2001). Rich phytoplankton diversity was recorded in Burullus Lagoon (283 taxa). In such shallow lagoons high diversity occurred because these lagoons are always thoroughly mixed at the bottom and therefore occurrence of various species is not limited by mixing rather may be limited by other environmental factors such as nutrients (Sekadende et al., 2004). The species diversity index of plankton communities can serve as an indicator that the ecosystem is under the influence of pollution stress or eutrophication (Telesh, 2004). Lower species Shannon-Wiener diversity index values (average of 1.51) were recorded in the first period (2009–2010) indicated that the lagoon is under the influence of pollution. During the other three periods, an increasing in diversity values (average of 2.21–2.28) means the water quality is recovered. However, a low species diversity index also showed that there is domination by a few species in the area (Margalef, 1978), which is evident in our study where several species were present but were dominated by a small number species. Our analysis showed a significant correlation between diversity index and evenness ($r = 0.823$, $p < 0.001$) but the relationship between species numbers and the diversity index was insignificant. This relationship is similar to that in the study by Reed (1978), who found that diversity indices were closely related to evenness, whereas species numbers (richness) were unimportant in determining species diversity for plankton and microbenthos.

A comparison with previous works revealed a more or less similar phytoplanktonic composition with the three dominant classes (Chlorophyceae, Bacillariophyceae and Cyanobacteria) but in different relative abundances and a remarkable increase in species richness associated with a sharp decrease in the community density (Radwan, 2005; Fathi and Abdelzahar, 2004; Okbah and Hussein, 2006; Ali and Khairy, 2012). It is of interest to indicate that, Cryptophyceae appeared in the phytoplankton samples as frequent or dominant form (El-Sherif, 1993; Fathi and Abdelzahar, 2004) and during 2009–2010 (the first period of the present study) while in the subsequent years it has not been found in phytoplankton samples. This may be due to that the Cryptophyceae is restricted to freshwater habitats (Hoef-Emden and Melkonian, 2003), and the slightly increased in salinity of the lagoon water may inhibit its growth, or due to the dense growth of ciliate (unpublished data) which primarily feed on Cryptophyceae (Pedròs-Aliò et al., 1995; Tirok and Gaedke, 2007), or may be due to the blooming of *Oscillatoria*, which inhibited its reproduction (Infante and Abella, 1985).

The occurrence and dominance of fresh water species in the eastern basin during summer of the four periods, in particular the Cyanobacteria which caused or participated in induction of water blooming, included *Chroococcus turgidus*, *Merismopedia punctata, Geitlerinema amphibium, Pseudanabaena limnetica*, was unusual in such a marine dominated ecosystem. It was suggested that these species might be accidentally carried by the fresh water on the western or central basins and acclimatized to marine waters. Additionally, its occurrence and dominance also was possibly associated with the enhanced nutrient supply in the lagoon water, in particular enrichment of dissolved nitrogen as described earlier. For these Cyanobacteria that do not contain heterocysts, both high nitrogen and phosphorus are needed to grow and develop (Pearl et al., 2001). *Geitlerinema* and *Pseudanabaena* are recognized as the most important genera with toxigenic species (Carmichael, 2001).

Generally the stations with high pollution level such as the first one, which is located in front of El Burullus Drain and received untreated discharged waters, led to the development of saprobiontic Euglenophyceae which assimilate lots of organic matter (Barrera et al., 2008) and become dominant (41.7% of the total count) during 2010–2011. Also, the Stations 9 and 10 which are located near Brinbal Canal and subjected to huge amounts of fresh Nile water rich in nutrient salts characterized by presence of Cyanobacteria, in which *Pseudanabaena limnetica* constituted about 90 and 42% of the total counts during autumn 2010 and summer 2011, respectively. The marine influence (Station 2) permitted the presence of marine forms as *Asterionellopsis glacialis* and *Leptocylindrus minimus*.

From the survey of the literature on phytoplankton assemblages of Burullus Lagoon, there is a large variation among the researchers in the species composition and density depending on the surveyed station, water depth, sampling season, water quality, environmental condition and water pollution of the lagoon. For example, Kobbia (1982) recorded 49 species belonging to six algal divisions: 14 of Chlorophyceae, 19 of Cyanobacteria, 12 of Bacillariophyceae, two of Cryptophyceae, and one species for each of Chrysophyceae and Dinophyceae. On the other hand, El-Sherif (1993) recorded 113 species distributed among algal divisions as follows: 52 species of Bacillariophyceae, 41 of Chlorophyceae, 15 of Cyanobacteria, two of Euglenophyceae, two of Dinophyceae and one Cryptophyceae. The study of El-Sherif et al. (1989) on the ecology of Bacillariophyceae indicated the presence of 59 species, where *Nitzschia* spp. and *Cyclotella meneghiniana* were the dominant diatom species, but Chlorophyceae represented as the dominant group formed 58.9% of the total counts, while Bacillariophyceae represented 31.1% and Cyanobacteria 8.8% of the total counts. Recently, Zalat and El-Sheekh (1999) recorded 75 diatom species, and found that *Cyclotella meneghiniana* was the most dominant species (73–89% of the total diatom assemblages). While Okbah and Hussein (2006) recorded 170 taxa, comprising 68 Bacillariophyceae, 54 Chlorophyceae, 26 Cyanobacteria, and 15 Euglenophyceae as well as six species of Dinophyceae and one species of silicoflagellates. Bacillariophyceae was the most dominant group (44.8%) and the most dominant diatoms genera were *Stephanodiscus*, *Nitzschia, Navicula, Aulacoseira* and *Cyclotella*. Ali and Khairy (2012) recorded 156 taxa during 2006, about 64 species of Bacillariophyceae, 52 of Chlorophyceae, 24 of Cyanobacteria, 12 of Euglenophyceae and four Dinophyceae, and the diatoms were the most dominant, in which *Nitzschia*, *Navicula*, *Aulacoseira* and *Cyclotella* were the dominant genera.

From the above historical review, it is evident that the phytoplankton community changed from 1982 till 2013 and these changes in number and dominant species should be taken into consideration for further studies in the lagoon in order to explore the reasons of these changes.

Earlier study (El-Sherif, 1993) classified Burullus Lagoon as mesotrophic lakes due to the decreased amount of the drainage water flowing into the lake, and the increased density of the submerged hydrophytes, particularly *Potamogeton pectinatus*. On the other hand, Eeaa and Gef (2002) and Okbah and Hussein (2006) and other reports stated that Burullus Lagoon is considered as an eutrophic area. El-Sayed (2010) assessed the eutrophication status of the lagoon by applying empirical models for Chl-*a* and nutrients, it was found that the lagoon lies between oligotrophic to mesotrophic states. Latter, Ali and Khairy (2012) classified the lagoon as hypereutrophic with bad to very bad environmental conditions.

Summary and conclusion

Burullus Lagoon has been subjected during the last century to a drastic rate of drainage discharges leading to prominent changes in physico-chemical conditions and phytoplankton community. The study of phytoplankton abundance indicated that the maximum density of phytoplankton occurred in the western basin. This basin received the discharged water inflow from Brinbal Canal. On the other hand, the eastern basin had the highest density of Euglenophyceae in particular at Station 1, which is located nearby the inflow of El-Burullus Drain that discharges a huge amount of organic matters was discharged from this drain. The shifting dominancy to Bacillariophyceae in the last study period means a healthy trophic status. The high concentrations of dissolved oxygen means no sign of eutrophication occurred in the lagoon. The increasing concentration of Chlorophyll-*a* means the dominance of nanoflagellates which does not seem to represent in the community structure.

So, this study encourages the mechanical removal of the extensive hydrophytes, which enhances the mixing well of lagoon water, also, use a long-term monitoring framework to build an understanding of how water quality and phytoplankton communities respond to different flow events and determine habitat preferences of particularly phytoplankton species or groups, that is able to capture the onset of unforeseen events such as harmful Cyanobacteria blooming. Also, we recommend optimizing the amount of fertilizer applied to crops, by testing the soil and modeling the bare minimum amount of fertilizer needed.

References

Abdel-Moati, A.R., Beltagy, A.I., El-Mamoney, M.H., 1988. Chemistry of Lake Burullus 1. Changes in nutrients chemistry between1970 and 1987. Rapp. Comm. Int. MerMedet. 31 (2), 68–83.

Ali, E.M., Khairy, H.M., 2012. Variation in phytoplankton biomass, community assemblage and species succession along Lake Burullus, northern Egypt. J. Inviron Biol. 33, 945–953.

Al-Sheikh, H., Fathi, A.A., 2010. Ecological studies on Al-Asfar Lake, Al-Hassa, Saudi Arabia, with Special References to the Sediment. Res. J. Environ. Sci. 4 (1), 13–22.

American Public Health Association (APHA), 2005. Standard Methods for the Examination of Water & Wastewater, twenty first ed. APHA, Washington.

Barrera, B.C., Vásquez, I., Barceló, Q.A., Bussy, A.L., 2008. Microalgal dynamics in batch reactors for municipal wastewater treatment containing dairy sewage water. Water Air Soil Pollut. 190, 259–270.

Blanco, A.C., Nadaoka, K., Yamamoto, T., 2008. Planktonic and benthic microalgal community composition as indicators of terrestrial influence on a fringing reef in Ishigaki Island, Southwest Japan. Mar. Environ. Res. 66, 520–535.

Carmichael, W.W., 2001. Health effects of toxin-producing cyanobacteria: 'The CyanoHABs'. Hum. Ecol. Risk Assess. 7 (5), 1393–1407.

Cloern, J.E., Dufford, R., 2005. Phytoplankton community ecology: principles applied in San Fran Sisco Bay. Mar. Ecol. Prog. Ser. 285, 11–28.

Coutlier, V., Stanley, D.J., 1987. Late quaternary stratigraphy and paleogeography of the eastern Nile delta, Egypt. Int. J. Mar. Geol. 27, 257–339.

Darrag, A., 1985. "The occurrence and distribution of some trace metals and their relation to organic matter", Ph.D. dissertation, Faculty of Science, Alexandria University, Alexandria, Egypt.

Doumont, H., El-Shabrawy, G., 2007. Lake Borullus of the Nile Delta: a short history and uncertain future. R. Swed. Acad. Sci. Ambio 36 (8), 677–682.

Eeaa and Gef, 2002. Management plan for Burullus protected area, Conservation of Wetland and Coastal Ecosystems in the Mediterranean Region, Project number EGY/97/G33/A/1G/99, Egyptian Environment Affairs Agency (EEAA) and Global Environment Facility (GEF), Egyptian lakes, Egypt. J. Bot. 39, 53–76.

Eid, E.M., 2012. *Phragmites australis* (Cav.) Trin. ex Steud.: its Population Biology and Nutrient Cycle in Lake Burullus, a Ramsar Site in Egypt LAP. LAMBERT Academic Publishing, Saarbrücken.

El-Sayed, A., 2010. Eutrophication assessment of El-Burullus Lake, Egypt. In: First International Conference on Coastal zone management of River Deltas and Low Land Coastlines, CZMRDLLC, 2010.

El-Sherif, Z.M., 1983. Limnological Investigations on the Aquatic Plants in Lake Burollus in Relation to the Environmental Conditions. PhD Thesis, Cairo University, Cairo, Egypt. pp. 385.

El-Sherif, Z.M., 1993. Phytoplankton standing crop, diversity and statistical multispecies analysis in Lake Burollus, Egypt. Bull. Natl. Inst. Oceanogr. Fisheries A.R.E. 19, 213–233.

El-Sherif, Z., Samaan, A., Abdelallah, R., 1989. Ecology of Bacillariophyceae in Lake Burullus, Egypt. Bull Natl. Inst. Oceanogr. Fish 15, 101–118.

El-Shinnawy, I.A.E., 2003. "Water Budget Estimate for Environmental Management at Al-Burullus Lake, Egypt". In" Proc. of 4th International Conference and Exhibition for Environmental Technologies Environment, 2003.

Environmental monitoring program for the North Lakes (E.M.P.N.L.): http://www.eeaa.gov.eg/arabic/main/env_water.asp.

Fathi A.A., Abdelzahar, H.M.A., 2004. Monitoring and the environmental status of Lake Burullus, Egypt with special references to sediment and water quality. In: The Second Saudi Science Conference, Faculty of Science, king Abdulaziz University, Kingdom of Saudi Arabia.

Flower, R.J., 2001. Change, stress, sustainability and aquatic ecosystem resilience in North African wetland lakes during the 20th century: an introduction to integrated biodiversity studies within the CASSARINA Project. Aquat. Ecol. 35, 261–280.

Gonenc, I.E., Wolflin, J.P. (Eds.), 2004. Coastal Lagoons: Ecosystem Processes and Modeling for Sustainable Use and Development. CRC Press, Boca Raton, Florida.

Hoef-Emden, K., Melkonian, M., 2003. Revision of the genus *Cryptomonas* (Cryptophyceae): a combination of molecular phylogeny and morphology provides insights into a long-hidden dimorphism. Protist 154, 371–409.

Infante, A., Abella, S.E.B., 1985. Inhibition of daphnia by oscillatoria in Lake Washington. Limnol. Oceanogr. 30, 1046–1052.

Kobbia, I.A., 1982. The standing crop and primary production of phytoplankton in Lake Brollus, Egypt. J. Bot. 25, 109–128.

Lara-Lara, J.R., Alvarez Borrego, S., Small, L.F., 1980. Variability and tidal exchange of ecological properties in a coastal lagoon. Estuarine Coastal Shelf Sci. 11, 613–637.

Lindell, D., Post, A.F., 1995. Ultraphytoplankton succession is triggered by deep winter mixing in the Gulf of Aqaba (Eilat), Red Sea. Limnol. Oceanogr. 40, 1130–1141.

Lloret, J., Marín, A., Marín-Guirao, L., 2008. Is coastal lagoon eutrophication likely to be aggravated by global climate change? Estuarine Coastal Shelf Sci. 78, 403–412.

Margalef, R., 1978. Life-forms of phytoplankton as survival alternatives in an unstable environment. Oceanol. Acta 1, 493–509.

Nkwo, J.A., Onyemai, C., Igbo, J.K., 2010. Wet season spatial occurrence of phytoplankton and zooplankton in Lagos Lagoon, Nigeria. Sci. World J. 5 (2), 7–14.

Okbah, M.A., 2005. Nitrogen and phosphorus species of Lake Burullus water (Egypt). Egypt. J. Aquat. Res., 1110-0354 31 (1).

Okbah, M.A., Hussein, N.R., 2006. Impact of environmental conditions on the phytoplankton structure in Mediterranean Sea lagoon, Lake Burullus, Egypt. Water Air Soil Pollut. 172, 129–150.

Ozimek, T., Van Donk, E., Gulati, R.D., 1990. Can macrophytes be useful in biomanipulation of lakes? The Lake Zwemlust example. Hydrobiologia 200 (201), 399–409.

Pearl, H.W., Fulton, I.I.I.R.S., Moisander, P.H., Dyble, J., 2001. Harmful freshwater algal blooms, with an emphasis on cyanobacteria. Sci. World 1, 76–113.

Pedrós-Alió, C., Massana, R., Latasa, M., García-Cantizano, J., Gasol, J.M., 1995. Predation by ciliates on a metalimnetic Cryptomonas population – Feeding rates, impact and effects of vertical migration. J. Plankton Res. 17, 2131–2154.

Pielou, E.C., 1975. Ecological Diversity. Wiley-Intersci, New York, pp. 165.

Radwan, A.M., 1997. Effect of salinity changes and drainage water discharged on the concentration of some heavy metals in Lake Burullus. Nat. Inst. Oceanogr. and Fish., Baltim Research Station, Baltim.

Radwan, A.M.R., 2002. Comparative study of the phytoplankton standing crop in the different sectors of Burullus Lake during 1997–1998. Bull. Natl. Inst. Oceanogr. Fish. A.R.E. 28, 289–305.

Radwan, A.M., 2004. Evaluation of water quality in Lake Borullus, Egypt. Egypt. J. Aquat. Biol. Fisheries 8, 15–33.

Radwan, A.M., 2005. The levels of heavy metals in Lake Burullus water compared with the international permissible limits. J. Egypt. Acad. Soc. Environ. Dev. 6, 11–26.

Ramdani, M., Flower, R.J., Elkhiati, N., Kraïem, M.M., Fathi, A.A., Birks, Hilary H., Patrick, S.T., 2001. North African wetland lakes: characterization of nine sites included in the CASSARINA Project. Aquat. Ecol. 35, 281–302.

Reed, C., 1978. Species diversity in aquatic micro-ecosystems. Ecology 59, 481–488.

Saad, A.M., 2003. Impact of diffuse pollution on the socio-economic development opportunities in the coastal Nile Delta lakes. In: Diffuse Pollution Conference, Dublin.

Sekadende, B.C., Mbonde, A.S.E., Shayo, S., Lyimo, T.J., 2004. Phytoplankton species diversity and abundance in satellite lakes of Lake Victoria basin (Tanzanian side). Tanz. J. Sci. 31, 1.

Shaltout, K.H., Khalil, M.T., 2005. Lake Burullus: Burullus Protected Area. Publication of National Biodiversity Unit No. 13 Egyptian Environmental Affairs Agency (EEAA), Cairo (2005).

Shaltout, K.H., Al-Sodany, Y.M., 2008. Vegetation analysis of Burullus Wetland: a RAMSAR site in Egypt. Wetlands Ecol. Manage October 2008, Volume 16, Issue 5, pp 421–439.

Shannon, C.E., Wiener, 1963. The Mathematical Theory of Communications. Univ, Illinois, Urbana, 117 pp.

Shen, P.P., Tan, Y.H., Huang, L.M., Zhang, J.L., Yin, J.Q., 2010. Occurrence of brackish water phytoplankton species at a closed coral reef in Nansha Islands, South China Sea. Mar. Pollut. Bull. 60, 1718–1725.

Song, X.Y., Huang, L.M., Qian, S.B., Yin, J.Q., 2002. Phytoplankton diversity in waters around Nansha Islands in spring and summer. Biodivers. Sci. 10, 258–268 (in Chinese).

Stirling, G., Wilsey, B., 2001. Empirical relationships between species richness, evenness, and proportional diversity. Am. Nat. 158, 286–299.

Telesh, I.V., 2004. Plankton of the Baltic estuarine ecosystems with emphasis on Neva Estuary: a review of present knowledge and research perspectives. Mar. Pollut. Bull. 49, 206–219.

Tilman, D., Kilham, S.S., Kilham, P., 1982. Phytoplankton community ecology: The role of limiting nutrients. Annu. Rev. Ecol. Syst. 13, 349–372.

Tirok, K., Gaedke, U., 2007. Regulation of planktonic ciliate dynamics and functional composition during spring in Lake Constance. Aquat. Microb. Ecol. 49, 87–100.

Utermöhl, H., 1958. Zur Vervollkömmung der quantitative Phytoplankton-Methodik. Mitteilungen internationale Vereinigung für theoretische und angewandte Limnologie 9, 1–38.

Van Dijk, G.M., van Vierssen, W., 1991. Survival of a *Potamogeton pectinatus* L. population under various light conditions in a shallow eutrophic lake (Lake Veluwe) in the Netherlands. Aquat. Bot. 39, 121–129.

Viaroli, P., Bartoli, M., Giordani, G., Austoni, M., Zal dívar, J.M., 2004. Biogeochemical Processes in Coastal Lagoons: from Chemical Relations to Ecosystem Functions and Properties. IOC Workshop Report No.195: 27–28.

Yin, K., Qian, P.Y., Wu, M.C.S., Chen, J.C., Huang, L.M., Song, X., Jian, W.J., 2001. Shift from P to N limitation of phytoplankton biomass across the Pearl River estuarine plume during summer. Mar. Ecol. Prog. Ser. 221, 17–28.

Zalat, A., EL-Sheekh, M., 1999. Diatom assemblages from two brackish Egyptian lakes, Egypt. J. Bot. 39, 53–76.

Zalat, A., Vildary, S.S., 2005. Distribution of diatom assemblages and their relationship to environmental variables in the surface sediments of three northern Egyptian lakes. J. Paleolimnol. 34 (2), 159–174. http://dx.doi.org/10.1007/s10933-005-1187-0.