Algal Diversity of the Mediterranean Lakes in Egypt

Hanan M. Khairy, Kamal H. Shaltout, Mostafa M. El-Sheekh, and Dorea I. Eassa

Abstract— The five Mediterranean Lakes of Egypt (Mariut, Edku, Manzala, Burullus and Bardawil) are of global importance as they are internationally important sites for wintering of the migrating birds, providing valuable habitat for them and they are an important natural resource for fish production in Egypt. The present study aims to collect the available data on phytoplankton populations and environmental characters (physico-chemical characters) of these five lakes in order to analyze their species composition, diversity, behavior and abundance of the common species that characterizing each lake. The present phytoplankton list comprised 867 species related to 9 algal divisions, 102 families and 203 genera. Bacillarophyta was the most dominant group, while Cryptophyta, Rhodophyta and Phaeophyta were rarely recorded and represented by only one species. The species diversity of the five lakes can be arranged descendingly as follows: Manzala (383 spp.) > Mariut (376 spp.) > Bardawil (333 spp.) > Burullus (247 spp.) > Edku (183 spp.). The highest number of unique species was recorded in Bardawil (208 spp.) followed by Manzala (128 spp.), then Mariut (85 spp.), Burullus (76 spp.) and Edku (6 spp.). The highest number of unique species (208 spp.) in Lake Bardawil (62.4 % of the total species), may be attributed to its hyper saline nature compared with the other oligotrophic lakes. This may also due to the lower human impact around it associated with low level of water pollution.

Keywords— Algal Diversity, Mediterranean Lakes in Egypt.

I. Introduction

FIVE natural lakes occur: Mariut (western section), Edku, Burullus and Manzala (Deltaic section) and Bardawil (North Sinai) along the Mediterranean coast of Egypt. These Lakes are bodies of fresh, brackish and saline or hyper-saline water, with depth ranged from 50 to 180 cm. They are the most productive Lakes in Egypt. Also, they are internationally important sites for wintering of the migrating birds, providing valuable habitat for them and important natural resource for fish production in Egypt (Shaltout and Khalil 2005).

In recent years, especially after the construction of the Aswan High Dam, considerable changes have been observed in the morphology, water characters and biotic composition of these lakes. They were subjected to gradual shrinkage during the last decades due to land reclamation and transformation of significant parts into fish farms, particularly along their southern shorelines. In addition, large parts of the lakes are infested with aquatic vegetation which reduces the open water to nearly half of their total area. Pollution of the aquatic environment by inorganic chemicals has been considered a major threat to the aquatic organisms including fishes. The agricultural drainage water containing pesticides, fertilizers, effluents of industrial activities, in addition to sewage effluents supply the water bodies and sediments that include with huge quantities of inorganic anions and heavy metals. All these activities will not only cause the loss of the important habitats, but will also create new ecosystems (Shaltout and Khalil 2005). The levels of pollution in these lakes are Mariut > Manzalah > Edku > Burollus > Bardawil (Saad 2003). From the environmental view point; these lakes are highly structured and provide an obvious gradient in conditions. In general, chemical and hydro-physical characteristics of water affect diversity and structure of the algal communities of these lakes.

Phytoplankton comprises the base of the food chain in the aquatic environment, and constitutes the main group of primary producers (Abd El-Monem and Konswa 2001). They come in countless form and live in nearly all kinds of environments. It grows suspended in open water by taking up the nutrients from the water and energy from sunlight. Importance of phytoplankton in the aquatic environment can be originated from its biological nature as microscopic aquatic algae containing chlorophyll pigments and grow by photosynthesis. It absorbs nutrients from water or sediments, add oxygen to water and usually the major of organic nitrogen (Mohammed 2005). It is possibly the most important group of organisms on the planet as they generate most of the oxygen that we breathe. It has a critical role in primary production, nutrient cycling, food webs and make up a significant proportion of the primary production in aquatic systems of the lakes (Dawes 1998).

Phytoplankton forms a highly diverse group of micro-organisms, and has served as one of the paradigm systems for maintenance of species diversity (Huisman and Weissing 1999, Stomp et al. 2004). Many factors are known to affect phytoplankton species coexistence at a local scale, such as productivity (Leibold 1996), nutrient supply (Tilman 1982) and under water light intenisty (Huisman et al. 2004, Stomp et al. 2007). The influence of various factors on the seasonal appearance of phytoplankton differs significantly, with physical factors such as temperature and light intensity being the most important; and chemical factors such as dissolved oxygen, pH, salinity, total hardness, EC and nutrient level

Hanan M. Khairy, National Institute of Oceanography and Fisheries, Anfoushi, Qayet Bay, Alexandria, Egypt

Kamal H. Shaltout, Mostafa M. El-Sheekh, Dorea I. Eassa, are with Botany Department, Faculty of Science, Tanta University, Egypt.

http://dx.doi.org/10.15242/IICBE.C0715113

which being of relatively less importance (Reynolds 1984).

The dominance of Bacilariophyceae was attributed to the high concentration of silica, while the high amount of nitrate, phosphate and sulphate caused the abundance of Chlorophyceae, Cyanobacteria and Desmidiaceae (Talling and Lemoalle 1998). This is evident from the reduction seen in concentration of these nutrients with the phytoplankton growth and abundance. Nowrouzi and Valavi (2010) concluded that, increase of water temperature and nutrient in spring are both essential factors, which cause increasing of phytoplankton abundance and diversity. In summer, despite increasing water temperature, nutrient consumption by phytoplankton and also grazing by zooplankton causes decrease in phytoplankton abundance and diversity. On the other hand, considerable increase of nutrients in autumn as a result of plankton decomposition in late summer and entrance of sewages causes a sharp increase in phytoplankton abundance and diversity. Following this stage, phytoplankton diversity and density were decreased pursuant to nutrient reduction and low temperature in winter.

There are many published and un-published data about the phytoplankton in the Egyptian Mediterranean Lakes (Mariut, Edku, Manzala, Burullus and Bardawil), but they are scattered and not analyzed. Thus, the present study aims to: i) collect these data in order to analyze it in terms of species diversity, abundance and behavior of the common species, ii) determine the algal communities that characterizes these lakes, iii) assess the effect of the environmental conditions on the distribution of phytoplankton communities and iv) determine the gaps that need further studies.

II. Material and Methods

A. Study Area

The Mediterranean coastal region of Egypt extends for about 970 km, from Sallum in the west (31° 34´ N, 25° 09´ E) to Rafah in the east (34° 20´ N, 31° 25´ E). Five natural lakes extend along this coast: Mariut (Western Coast), Edku, Burullus, Manzala (Deltaic Coast) and Bardawil (Sinai Coast) (Fig. 1). These lakes cover about 6% of the non-desert surface area of Egypt. They are shallow, brackish water bodies with a depth ranged from 50 to 180 cm, and they are separated from the Mediterranean Sea by sand bars that are very narrow in several places and connected with the sea through narrow straits, these straits are either remnants of the mouths of old deltaic branches or merely gaps in weak sections of the bars known as tidal inlets (Abu Al-Izz 1971). The morphometry of the five northern delta lakes are represented in Table I after Shaltout and Galal (2006).

B. Data collection

The available data on physical, chemical and biological characters including phytoplankton composition in relation to environmental parameters of each lake were collected from available previous literatures (Table II). In addition, recent data on the environmental characters of the five Delta lakes were collected from the reports of Wetland Monitoring Program (2010/2011) for the Egyptian Northern Lakes (Ministry of Environmental Affairs). A raw table including all the species in the five lakes was prepared. The accepted names were chosen following the web site algaebase.com.

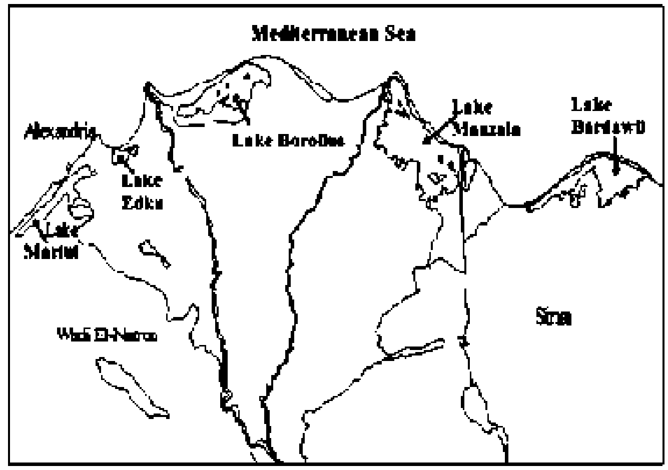

Fig.1 Location map of the five northern lakes of Egypt (after Shaltout and Galal 2006)

TABLE I
MORPHOMETRY OF THE FIVE MEDITERRANEAN LAKES UNDER STUDY (AFTER SHALTOUT AND GALAL 2006)

Lake	Latitude (N)	Longitude (E)	Area (km^2)	Depth (m)	Length (km)	Width (km)
Mariut	31° 12´ -31° 2´	29° 55 - 29° 55´	63	1.2	8.8	7.7
Edku	31° 13´ - 31° 16´	30° 07´ - 30° 14´	126	1.0	21.0	6.0
Burullus	31° 25´ - 31° 35´	30° 30´ - 31° 10´	410	1.02	64.0	16.0
Manzala	31° 00´ - 31° 30´	31° 16´ - 32° 20´	1200	1.1	64.5	49.0
Bardawil	31° 03´ - 31° 14´	32° 40´ - 33° 30´	650	1.0	75.0	22.0

C. Data analysis

Classification and ordination of the five lakes in relation to their species composition were applied following the two–way indicator species analysis (TWINSPAN) and Detrended Correspondence Analysis (DECORANA) (Hill 1979 a, b). Referring to the recent data collected from the Reports of Ministry of Environmental Affairs for Wetlands Monitoring program (2010/2011), the mean values of the physical and chemical characters of the five northern lakes of Egypt were recorded and tabulated. Canonical Correspondence Analysis (CCA), as a weighted averaging direct ordination whose axes are constrained by the environmental variables, was applied to the same sets of data algal divisions and water characters data.

III. Results

A. Water characters of the five lakes

The mean water temperature in the lakes fluctuated between a minimum mean value of 22.1 °C at Lakes Edku and Manzala to a maximum of 22.7 °C at Lake Burullus (Table III). Water transparency varied between 29.9 cm at

Lake Burullus and 147.5 cm at Lake Bardawil. pH values of the lakes water are generally on the alkaline side, ranging between 8.0 at Lake Manzala and 8.6 at Lake Mariut. The lowest mean value of water salinity was 3.8 ms cm^{-1} at Lake Burullus, while the highest was 14.8 ms cm^{-1} at Lake Bardawil. The minimum dissolved oxygen (DO) of 5.6 mg l^{-1} was recorded at Lake Mariut, while the maximum of 10.8 mg l^{-1} was recorded at Lake Bardawil (Table III).

TABLE II
REFERENCES USED IN COLLECTION OF THE PHYTOPLANKTON SPECIES THAT INHABITANT THE FIVE MEDITERRANEAN LAKES IN EGYPT

Mariut	Samman and Abdallah 1981, Abd-Elmoniem et al. 1987, Guerguess 1988, Koussa 2000, Abd-El-Satar 2005, Maher et al. 2009.
Edku	Samaan 1974, 1977, Darrag 1983, Shridah 1992, Gharib and Soliman 1983, 1998, Gharib 1999, Fathi et al. 2000, Zaghloul and Hussein 2000, Sayed 2003.
Burullus	Darrag 1974, El- Sherif and Aboul-Ezz 1988, Kobbia 1982, El-Sherif 1989, El-Sheekh and Zalat 1999, Radwan 2002, Shaltout and Khalil 2005, Okbah and Hussein 2005, El-Sayes et al. 2007, Ali and Khairy 2012, Farag and El-Gamal 2012, Nassar and Gharib 2014.
Manzala	Ibrahim 1997, El-Sherif and Gharib 2001, Shakweer 2005, Salah El Din 2005, Shaltout and Galal 2006, Abd El-Karim 2008.
Bardawil	Ehrlich 1975, Siliem 1989, Taha 1990, Shabana 1999, Toulibah et al. 2002, Abd-El-Satar 2005, Abd El-Karim and Hassan 2006, Khalil and Shaltout 2006, Konsowa 2007.

A minimum mean value of nitrate was recorded at Lake Manzala (5.6μg.l), while the maximum was recorded at Lake Edku (47.2 μg l^{-1}). The lowest mean value of nitrite was that of Lake Edku (4.5 μg l^{-1}), while the highest was that of Lake Mariut (28.4 μg l^{-1}). The minimum ammonia of 2.4 μg l^{-1} was recorded at Lake Bardawil, while the maximum of 28.2 μg l^{-1} was recorded at Lake Mariut. The minimum mean phosphate content of 3.6 μg l^{-1} was recorded at Lake Manzala, while the maximum of 52.1 μg l^{-1} was recorded at Lake Bardawil. The lowest silicate mean value of 1.5 μg l^{-1} was recorded at Lake Bardawil, while the highest of 93.9 μg l^{-1} was recorded at Lake Mariut.

TABLE III
. PHYSICO-CHEMICAL PARAMETERS OF THE WATER OF THE FIVE MEDITERRANEAN LAKES OF EGYPT (WETLANDS MONITORING PROGRAM 2010/2011)

Water parameter	Mariut	Edku	Burullus	Manzala	Bardawil
			Physical parameter		
Temperature (°C)	22.2	22.1	22.7	22.1	23.3
Transperancy (cm)	55.6	49.3	29.9	65.9	147.5
			Chemical parameter		
pH	8.6	8.2	8.1	8.0	8.2
D O (mg $.l^{-1}$)	5.6	7.6	7.9	8.3	10.8
Salinity (mS cm^{-1})	4.2	4.7	3.8	7.3	14.8
Nitrate (μg l^{-1})	28.3	47.2	11.9	5.6	5.9
Nitrite (μg l^{-1})	28.4	4.5	10.8	4.6	17.5
Ammonia (μg l^{-1})	28.2	15.8	20.1	9.1	2.4
Phosphate (μg l^{-1})	51.1	44.9	7	3.6	52.1
Silicate (μg l^{-1})	93.9	7.0	53.8	34.6	1.5

B. Phytoplankton diversity in the five Mediterranean lakes

From the available collected data, the algal flora in the five northern lakes of Egypt includes 867 species belong to 9 algal divisions, 102 families and 203 genera. The recorded nine algal divisions arranged descendingly as follows: Bacillarophyta > Chlorophyta > Cyanophyt > Dinophyta > Euglenophyta > Cryptophyta > Chrysophyta > Phaeophyta > Rhodophyta (Table V). On the other hand, the ratio of species to genus (S/G) had a maximum value in Bacillarophyta (5.7) and a minimum in Chrysophyta (1.5). The ratio of genus to family (G/F) had a maximum value in Cyanophyta (2.8), followed by Bacillarophyta (2.1), while the minimum value was in Chrysophyta (1.3).

As represented in Table IV, the highly represented families of Bacillarophyta are Naviculaceae, Bacillariaceae, Fragillariaceae, Rhobalodiaceae and Stephanodiscaceae. The highly represented families of Chlorophyceae are: Scenedesmaceae, Oocystaceae, Selenastraceae and Chlorellaceae. The most diverse Cyanophytic families are: Oscillatoriaceae (34 species and 5 genera), Nostocaceae (19 species and 7 genera) and Chrococcaceae (14species and 6genera). The most diverse Dinophytic families are Peridiniaceae, Ceratiaceae and Gymnodiniaceae. Dinophyta were represented by families Peridiniaceae, Ceratiaceae and Gymnodiniaceae.

The species diversity of the five lakes can be arranged descendingly as follows: Manzala (383 spp.) > Mariut (376) > Bardawil (333) > Burullus (247) > Edku (183). Bacillarophytes have the following sequence: Bardawil (238 spp.) > Mariut (255) > Manzala (253) > Burullus (126) and Edku (87); while Chlorophytes sequence is Manzala (70 spp.) > Burullus (66.) > Mariut (65) > Edku (48) > Bardawil (14). Cyanophytes sequence is Manzala: (49 spp.) > Mariut (43) > Burullus (36) Edku (33) > Bardawil (22). Dinophytes sequence is: Bardawil (53 spp.) > Burullus (7) > Manzala (4) > Edku (2) > Mariut (1) specie; while Euglenophytes sequence is : Burullus (11 spp.) > Edku and Mariut (10 for each one) > Manzala (7) > Bardawil (1) (Table VII).

TABLE IV
TAXIC DIVERSITY OF THE MAJOR ALGAL DIVISIONS IN THE FIVE MEDITERRANEAN LAKES OF EGYPT

Divisions	Family (F)	Species (S)	Genus (G)	S/G	G/F
Bacillarophyta	45	537	94	5.7	2.1
Chlorophyta	28	141	47	3	1.7
Cyanophyta	12	104	34	3	2.8
Euglenophyta	1	19	4	4.7	4
Dinophyta	10	57	17	3.3	1.7
Chrysophyta	3	6	4	1.5	1.3
Cryptophyta	1	1	1	0.0	0.0
Rhodophyta	1	1	1	0.0	0.0
Phaeophyta	1	1	1	0.0	0.0

TABLE V
HIGHLY REPRESENTED FAMILIES IN RELATION TO THE 4 COMMON ALGAL DIVISION IN THE FIVE MEDITERRANEAN LAKES

Divisions	Family	Species	Genus
1-Bacillarophyta	Naviculaceae	68	3
	Bacillariaceae	67	5
	Fragillariaceae	24	8
	Rhobalodiaceae	21	2
	Stephanodiscaceae	17	3
2- Chlorophyta	Scenedesmaceae	33	5
	Oocystaceae	23	7
	Selenastraceae	11	3
	Chlorellaceae	7	5
3- Cyanophyta	Oscillatoriaceae	34	5
	Nostocaceae	19	7
	Chrococcaceae	14	6
4- Dinophyta	Peridiniaceae	16	1
	Ceratiaceae	9	1
	Gymnodiniaceae	8	2

TABLE VI
ALGAL SPECIES RICHNESS IN THE FIVE MEDITERRANEAN LAKES OF EGYPT. THE MAXIMUM VALUES OF THE ALGAL DIVISION IN RELATION TO THE FIVE LAKES ARE UNDERLINED.

Divisions	Mariut	Edku	Burullus	Manzala	Bardawil	Total species
Bacillarophyta	255	87	126	253	238	537
Chlorophyta	65	48	66	70	14	141
Cyanophyta	43	33	36	49	22	104
Dinophyta	1	2	7	4	53	57
Euglenophyta	10	10	11	7	1	19
Chrysophyta	1	1	0	0	5	6
Cryptophyta	0	0	1	0	0	1
Rhodophyta	0	1	0	0	0	1
Phaeophyta	1	1	0	0	0	1
Total species	376	183	247	383	333	867

The highest number of unique species was recorded in Bardawil (208 spp.) followed by Manzala (128), then Mariut (85), Burullus (76) and Edku (6) (Table VII). The Bacillarophytic sequence is as follows: Bardawil (141 spp.) >Manzala (74) > Mariut (61) > Burullus (27) > Edku (2). Sequence of Chlorophytes is: Burullus (33 spp.) > Manzala (26) > Mariut (12) > Bardawil (4) > Edku (1); while Cyanophytic sequence is: Manzala (27 spp.) > Bardawil (12) > Burullus (11) > Mariut (9) > Edku (3); Dinophytic sequence is Bardawil (46 spp.) > Burullus (1) and Euglenophytic sequence is: Burullus (3 spp.) Mariut (2) > Manzala (1)

TABLE VII
UNIQUE ALGAL SPECIES IN THE FIVE NORTHERN LAKES OF EGYPT

Algal Division	Mariut	Edku	Burullus	Manzala	Bardawil	Total
Bacillarophyta	61	2	27	74	141	305
Chlorophyta	12	1	33	26	4	76
Cyanophyta	9	3	11	27	12	62
Dinophyta	0	0	1	0	46	47
Euglenophta	2	0	3	1	0	6
Chrysophyta	0	0	0	0	5	5
Cryptophyta	0	0	1	0	0	1
Rhodophyta	1	0	0	0	0	1
Phaeophyta	0	0	0	0	0	0
Total	85	6	76	128	208	503
%	1.2	16.9	15.1	25.4	41.3	100

C. Multivariate analysis of the five lakes

Twinspan classification applied to the matrix of presence-absence of algal species in the five northern lakes indicated a separation of three clusters at level three; the DCA ordination verified the reality of this classification (Fig. 2). For Bacillarophyta and Cyanophyta, the three clusters are: Bardawil, Manzala - Burullus and Mariut - Edku. In case of Chlorophyta, they are Burullus, Bardawil - Manzala and Mariut - Edku; while in Dinophyta, they are: Manzala, Edku, Bardawil and Burullus - Mariut.

For the Bacillarophyta, Burullus occupies the upper left quarter of the CCA biplot which coincides with nitrate; Manzala and Mariut occupy the lower left quarter which coincides with ammonia, silicate, pH and DO; while Bardawill occupies the lower right quarter which coincides with water transparency, nitrite, phosphate and temperature (Fig. 3).

For the Chlorophyta, Manzala and Bardawill occupy the upper left quarter of the biplot which coincides with water transparency and DO; while Edku and Mariut occupy the lower left quarter which coincides with pH, nitrate, nitrite, silicate and phosphate. For the Cyanophyta, Manzala occupies the upper left quarter which coincides with DO, temperature and ammonia; while Burullus occupies the lower left quarter which coincides with silicate; Bardawill occupies the upper right quarter which coincides with water salinity and transparency; while Edku and Mariut occupy the lower right quarter which coincides with nitrate, nitrite, phosphate and pH. The CCA of Dinophyta indicated that Lake Bardawill occupies the lower left quarter of the biplot which coincides with water transparency, salinity, phosphate and nitrate; while Edku and Mariut occupy the upper right quarter which coincides with nitrate, silicate, ammonia and pH. Lake Manzala occupies the lower right quarter which coincides with DO and temperature.

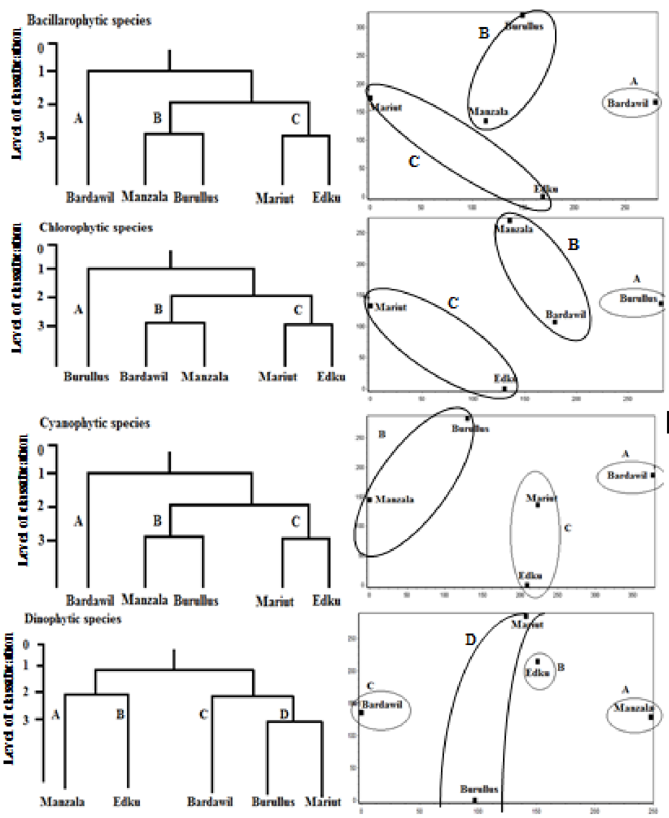

Fig. 2 TWINSPAN classification and DECORANA ordination of the five Mediterranean lakes of Egypt

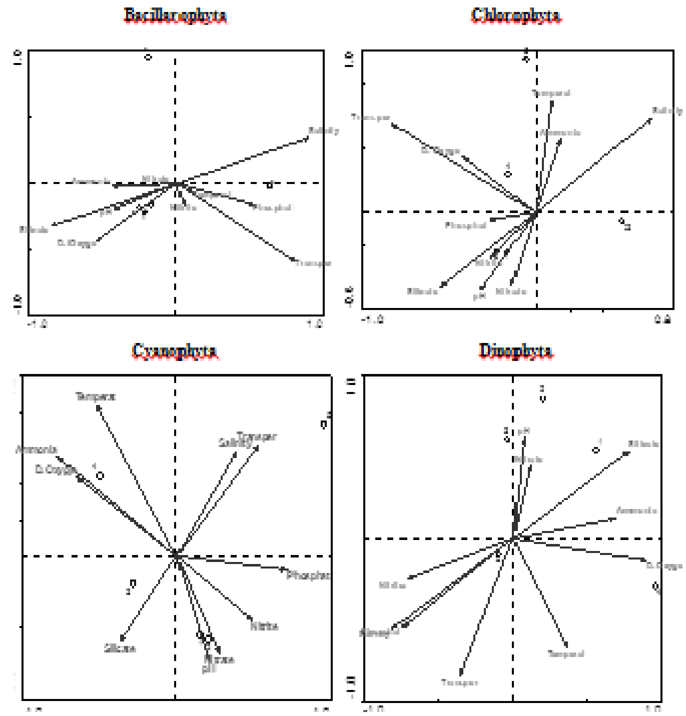

Fig. 3 Canoco ordination of the five northern lakes of Egypt based on the mean values of the water characters. 1: Edku, 2: Mariut, 3: Burullus, 4: Manzala and 5: Bardawill

IV. Discussion

From the survey of the literature on phytoplankton assemblages of the five northern lakes of Egypt, there is a large variation among the researchers in the species composition and density depending on the surveyed stations, water depth, sampling season, water quality, environmental conditions and water pollution of the lakes, (Shaltout and Khalil 2005). During the period between 1985 and 2009, the present study revealed that 867 species were recorded in the five Mediterranean lakes of Egypt; these species are related to 203 genera, 102 families and 9 divisions. In comparison, the biodiversity of the phytoplankton populations in the Egyptian parts of Mediterranean and Red Sea approximated 678 species (EEAA 1995). On the other hand, a preliminary estimation of the phytoplankton in the fresh water habitats in Egypt approximated 871 species and 39 varieties (EEAA 1995). This finding is closely related to the species recorded from the five lakes only. This means that an extensive survey of the available data in the published and unpublished writing should be carried out in order to give a reasonable figure on the diversity of phytoplankton in the Egyptian water.

Lake Mariut

Lake Mariut is heavily polluted lake in Egypt as it suffered from severe ecological damage as a result of industrialization, modern agricultural systems and unexpected side effects from many industrial projects. Although the present study indicated that the lake is the second most diverse after Manzala but it include some toxic

http://dx.doi.org/10.15242/IICBE.C0715113

Cyanobacterial species such as *Microcystis aeruginosa*, *Spirulena* and Anabaena species (Allem and Samaan 1969). As a result of the extensive input of nutrients from Alexandria city, the enclosed nature of the lake and the shallowness of the water, heavy algal blooms and domination of plankton existed.

Although the present study indicated that the Bacillarophyta is the most diversified in the lake but Koussa (2000) reported that Cyanophytes are the most abundant (80 % of the total density of all algal taxa), followed by Bacillarophytes (17 %). Koussa (2000) indicated two main peaks of abundance; the first at the early spring (March), and the second in summer. He noticed also that the blooming of phytoplankton in summer is mainly due to the increasing dominance of 4 Cyanophytes: *Spirulina platensis, Oscillatoria okeni, O. geminata* and *O. tenuis*. Two relationships were depicted between phosphate and nitrate levels and phytoplankton densities (Koussa 2000).

Lake Edku

The present study indicated the lake Edku is the less diverse comparing with the other four lakes (183 spp. = 21.17 % of the total species in the lakes). According to Abbas et al. (2001), Lake Edku is characterized by high nutrient concentrations of NO_2-N (5.4 µg l^{-1}), NH_4-N (4.5 µg l^{-1}), PO_4-P (7.8 µg l^{-1}) and SiO_2-Si (97.7 µg l^{-1}), as well as high level of dissolved oxygen (8.3 mg l^{-1}). This is mostly attributed to the excessive amounts of drainage and waste water discharged into the lake. Although this lake is the less diverse, but it sustained a heavy growth of phytoplankton. The highest abundant species were *Carteria*, *Nitzschia, Scenedesmus* and *Phacus* species. This was associated with a moderate value of nutrient salts (Zaghloul and Hussein 2000).

Bacillarophyta which is the most diverse division as depicted in the present study attained its highest counts during winter, mainly due to the high count of *Cyclotella meneghiniana* and attributed to higher values of pH and lower values of nutrients as this outstanding peak consume nutrient salts (El-Shinawy 2002). Also, high counts of diatoms were recorded during summer that was dominated by *Nitzschia* and *Melosira* species and this increase was accompanied with the highest values of DO and low values of TDS, silicate, phosphate, ammonia and nitrate.

Chlorophytes had a maximum persistence in spring, where the most dominant species was *Carteria* sp.; and this was probably due to the high values of PO_4, SiO_2, NH_4 and DO, as well as lower values of TDS. Members of Euglenophyta occupied the third level along the dominance gradient and represented mainly by *Euglena, Lipoclinlis, Phacus* and *Trachaelomonas* species. The highest population of Euglenophytes was recorded during autumn. Genus *Euglena* tops a list of sixty most tolerant genera to pollution (Palmer 1969) and is generally considered as biological indicator of organic pollution (Munawar 1972). Cyanophytes which are more characteristic to eutrophic than oligotrophic water showed irregular production, represented mainly by *Oscillatoria*, *Merismopedia*, *Rhaphidopsis* and *Spirulina* species. The highest standing crop of Cyanophytes was recorded during warm seasons (spring and summer) as they usually prefers the warm water and reached its maximum in July coupled with high concentrations of ammonia (Tilman et al. 1986).

Lake Burullus

The present study indicated that phytoplankton community of Lake Burullus is considered moderately rich but most of species are fresh or brackish as it is found along the species richness scale and few are saline water forms. The count of phytoplankton in the middle sector was higher than that in the other sectors, probably due to the lower density of submerged hydrophytes which created an open area (Shaltout and Khalil 2005). Diatoms were the most productive algal group, of which genus *Cyclotella* was the most dominant among the other genera; it was represented by *C. menenghiana* and *C. kutzengiana*, the development of both species may be attributed to high load of organic matters discharged with the drainage water (Abdallah et al. 1991).

Radwan (1997) found that the flourishment of this genus in Damietta branch was subjected to the same conditions of organic pollution. *Nitzschia* took up the second important position among the other genera of diatoms in Lake Burullus and it was mainly represented by *N. palea*. The highest number of this species was recorded in the eastern sector, where the high load of organic matters and high values of chlorosity (Radwan 2002). Nassar and Gharib (2014) recorded up to 50 % in the phytoplankton densities between 2009 and 2013. No sign of eutrophication was observed, and recession of Cyanophytes blooming suggests a major improvement in the water quality of Lake Burullus.

Chlorophyta was the second diverse and dominant group. Genus *Scenedesmus* was the first dominant among the other genera of this group. The species belonging to this genus were *S. quadricauda* and *S. acuminatus*, which developed near by the drains, where the high levels of organic nutrients and phosphate (Radwan 2002). The flourishment of *Pediastrum* species in the western sector was mainly influenced by low levels of chlorosity and high levels of pH and dissolved oxygen.

Cyanophytes were rarely recorded in this lake, where *Microcystis aeruginosa*, *Lyngbya limnetica*, *Anabaena* sp. and *Oscillatoria limnetica* are the most common species were more abundant in the eastern sector due to the flourishment of *Oscillatoria* and *Gleocapsa*, this may be attributed to high load of domestic sewage and nutrient salts discharged water (Radwan 2002). Euglenoides were more common at the southern margins due to continuous discharged of organic matters with domestic sewage (Radwan 2002). Dinoflagellates were rare and restricted only in the eastern sector near to the sea outlet where the water is more saline.

Lake Manzala

The present study indicated that the phytoplankton is the most rich in this lake, compared with the four lakes. It is varied widely in areas neighboring the outfalls of discharged water and within narrow range far from the effect of drainage water (El-Sherif and Gharib 2001). In spite of the considerable amounts of wastes discharged in to Lake Manzala, the eutrophication remained local and occurred in the central and northern stations. The dense and luxuriant phytoplankton during eutrophication is effective for natural purification of waste water (Ibrahim 1997).

El-Sherif and Gharib (2001) reported maximum phytoplankton production was found in spring with a secondary peak in summer. Such pattern revealed that spring is still the season of the highest phytoplankton production in Lake Manzala as well as the other Egyptian Delta Lakes; while the minimum standing crop was recorded in autumn, mostly in September. As the other Egyptian lakes, the present study indicated that Lake Manzala is mostly rich by diatoms. They were the most abundant during winter and spring (as high chlorides coupled with low concentration of nutrients); while Chlorophytes were mainly observed during autumn. Euglenophytes were occasionally abundant in January depending on inorganic sources of nitrogen and phosphorus (El-Sherif and Gharib 2001). Cyanophytes reached its maximum in July coupled with high concentrations of ammonia, they usually prefer the warm water, (Tilman et al. 1986) they are characteristic to eutrophic more than oligotrophic water.

Lake Bardawil

The present study indicated that the species diversity of phytoplankton in Bardawil lagoon is characterized by high species diversity. It comes after Manzala and Mariut lakes. It was noticed that the species diversity of phytoplankton is high near the inlets compared with the center of the lagoon; this decrease is obviously related to the increase in salinity (Taha 1990, Khalil and Shaltout 2006). In a previous study, Ehrlich (1975) documented a decrease in number of phytoplankton species southward in the lagoon, due to increase in salinity. In Lake Bardawil as a hyper saline lagoon, the present study indicated that Dinophytes come in the second order after Bacillarophytes. Bacillarophytes usually dominated the community except in August when Dinophytes were the prominent group. On the other hand, species belonging to Chlorophytes, Cyanophytes, Euglenophytes and Chrysophytes were always relatively rare. The most abundant genera of diatoms were *Chaetoceros*, *Bacteriastrum*, *Leptocylindrus*, *Skeletomema*, *Thalassiosira* and *Thalassionema* species. Diatoms were of relatively high abundance near the opening of the two artificial inlets especially during mid-summer and autumn (Konsowa 2007).

Dinophytes increased during summer and decreased during spring. The most important recorded genera were *Prorocentrum, Exuviella, Diplopsalis, Ceratium, Peridinium* and *Oxytoxum.* Chlorophytes were mainly represented by *Pediastrum duplex, Scenedismus bijuga, Tetraedron minimum* and *Cosmarium connatum.* Cyanophytes were mainly represented by *Oscillatoria thiebauti.* While, Euglenophytes were only represented by *Euglena* spp. (Konsowa 2007). The abundance of Dinophyta and other diatoms declined markedly when *Chaetoceros* species bloomed. Therefore it is important to restrict summer diatoms blooms to maintain species diversity and increase water quality in the lagoon (Konsowa 2007).

The present study indicated the Lake Bardawil is the lagoon which had the highest number of unique species (208 = 62.8 % of the total species). This may be attributed to its hyper-saline nature compared with the other oligotrophic lakes. It is characterized by high species diversity due to the lower human impact around it, associated with low level of water pollution. The unique species in this lake prefer the unpolluted water, in addition to hyper salinity of water.

REFERENCES

[1] Abbas, M.M.; Shakweer, L.M. and Youssef, D.H. 2001. Ecological and fisheries management of Edku Lake. 1- Hydro-chemical characters of Edku Lake. Bull. Nat. Inst. Oceanog. Fish. ARE, 27: 65-93.

[2] Abdalla, R.R.; Samaan, A.A. and Ghobrial, M. G. 1991. Eutrophication in Lakr Mariut. Bull. Natio. Inst. Oceanog. & Fish. ARE., 17(1): 157-166.

[3] Abd El-Karim, M.S. 2008. Monthly variations of phytoplankton communities in Lake Manzala. 2(6): 343-350.

[4] Abd El-Karim, M.S. and Hassan, H. 2006. Epiphytic species composition and biochemical distribution in Bardawil lagoon. Bull. Nat. Inst. Oceanog. Fish. ARE, 45: 53-83.

[5] Abdel-Moniem, A. M. and Konswa, A. H. 2001. Some biotic and abiotic variables controlling primary productivity in hyper trophic lake (Lake Qarun, Egypt. Egypt Jour. Aquati. Boil. & Fish., 5(3): 1-16.

[6] Abdel-Moniem, M. A.; El-Sharkawy, F. M. and Samaan, A. A. 1987. Some chemical features of Lake Mariut. Bull. Nat. Inst. Oceanog. Fish. ARE, 13(1):201-217.

[7] Abd-El-Satar, A. M. 2005. On the water quality of Lake Bardawil, Egypt. Jour. Egypt Acad. Soc. Environ. Devolop., 6(1):49-73.

[8] Abu Al-Izz, S.M. 1971. Land forms of Egypt. Translated by Dr Y. A. Fayid. American Univ. Cairo Press, Cairo, 281 pp.

[9] Aleem, A. A. and Samaan, A. A. 1969. Productivity of Lake Mariut, Egypt. Part I: Physical and chemical aspects. Int. Revue ges. Hydrobial. 54(3):313-355.

[10] Ali, M. E. and H. M. Khairy, 2012. Variation in phytoplankton carbon biomass, community assemblages and species succession along Lake Burullus, Northern Egypt. J. Enviro. Biology 33: 945-953.

[11] Darrag, A. A. 1974. Study of the hydroghraphic conditions and nutrient salts of Lake Burullus waters. M. Sc. Thesis Alex. Univ. pp276.

[12] Darrag, A. A. 1983. The occurrence and distribution of some trace metals (Fe, Mn & Cu) in Lake Edku and their relation to organic matter. Ph. D. Thesis Fac. Of Sci. Alex. Univ. pp388.

[13] Dawes, C. J. 1998. Marine Botany. 2nd edition.

[14] EEAA 1995. Egyptian Environmental Affairs Agency report on Egypt Country. Study on Biological Diversity.

[15] Ehrlich, A. 1975. The diatoms from the surface sediment of the Bardawil lagoon (Northern Sinai). Paleoecological significance. Rapp. P. V. Reun. Ciesm., 23(3):235-275.

[16] El-Sayes, A.; A. Radwan, and L. Shakweer, 2007. Impact of drainage water inflow on the environmental conditions and fishery resources of Lake Burullus. Egyptian journal of Aquatic research, 33(1):312-351.

[17] El-Sheekh, M. and Zalat, A. 1999. Diatom assemblages from two brackish Egyptian lakes. Egypt Jour. Bot., 39:53-76.

[18] El-Shinawy, I. (2002): El-Burullus wetland's hydrological study. Med Wet Coast, Global Environmental Facility (GEF) & Egyptian Environmental Affaris Agency (EEAA), Cairo.

[19] El-Sherif, Z. M. 1989. Biomass of the standing crop of phytoplankton in Lake Burullus, Egypt. Bull. Nat. Inst. Oceanog. Fish. ARE, 15:179-189.

[20] El-Sherif, Z. and Aboul-Ezz, S. 1988. Preliminary study on phytoplankton zooplankton relationship in Lake Burullus, Egypt. Bull. Nat. Inst. Oceanog. Fish. ARE, 14:23-30.

[21] El-Sherif, Z. M. and Gharib, M. Samiha, 2001. Spatial and temporal patterns of phytoplankton communities in Manzalah lagoon. Bull. Nat. Inst. Oceanog. Fish. ARE, 227:-239.

[22] Farag, H. and El-Gamal, A. 2012. Assessment of the Eutrophic Status of Lake Burullus (Egypt) using Remote Sensing. International Journal Of Environmental Science and Engineering (IJESE), 2: 61-74

[23] Fathi, A. A.; Hani, M. A. Abdel-Zaher, and Mohammed, A. El-Nagy, 2000. Limnological studies on Edku Lake, Egypt. Elminia Science Bulletin, 13(1):44-60.

[24] Galal, M. T. 2005. Flora and vegetation of the Northern Lakes of Egypt. Ph.D. Thesis, Faculty of science, Helwan Univ.

[25] Gharib, Samiha, M. 1999. Phytoplankton studies in Lake Edku and adjacent waters (Egypt). Egypt. Journ. Aquatic Biolo. & Fish., 3(1):1-23.

[26] Gharib, Samiha, M. and Soliman, M. Asgad 1983. Some water characteristics and phyto-zooplankton relationship in Lake Edku (Egypt) and adjacent sea. Bull. Fac. Of Sci. Alex. Univ., 1,2:10-40.

[27] Gharib, Samiha, M. and Soliman, M. Asgad 1998. Some water characteristics and phyto-zooplankton relationship in Lake Edku (Egypt) and adjacent sea. Bull. Fac. Of Sci. Alex. Univ., 5.2:25-44.

[28] Guerguess, S. K. 1988. Plankton of Lake Mariut outlet, west from Alex. Bull. Nat. Inst. Oceanog. Fish. ARE, 14(2):153-172.

[29] Hill, M. O. 1979a. TWINSPAN: A FORTRAN program for Detrended Correspondonence Analysis and Reciprocal Averaging: Corn II University, Ithaca, New York, 42pp.

[30] Hill, M. O. 1979b. DECORANA: A FORTRAN program for Detrended Correspondonence Analysis and Reciprocal Averaging: Corn II University, Ithaca, New York, 52pp.

[31] Huisman, J. and Weissing, F.J. 1999. Biodiversity of plankton by species oscillations and chaos. Nature 402: 407-410. http://dx.doi.org/10.1038/46540

[32] Huisman, J. J.; Sharples, J. M.; Stroom, P. M.; Visser, W. E. A.; Kardinaal, J. M. H.; Verspagen, N. and B. Sommeijer, 2004. Changes in turbulent mixing shift competition for light between phytoplankton species. Ecology 85:2960–2970. http://dx.doi.org/10.1890/03-0763

[33] Ibrahim, A. E. 1997. Studies on phytoplankton in some polluted areas of Lake Manzalah. Bull. Nat. Inst. Oceanog. Fish. ARE, 15:1-19.

[34] Khalil, M.T.; Shaltout K.H. 2006. Lake Bardawil and Zaranik Protected area. State ministry of Environment – Biodiversity Unit – Medwetcoast Project, Publication of Biodiversity Unit. No.15.

[35] Kobbia, I. A. 1982. The standing crop and primary production of phytoplankton in Lake Burullus. Egypt. Jour. Bot,. 25:109-128.

[36] Konsowa, H. Adel. 2007. Spatial and temporal variation of phytoplankton abundance and composition in hyper saline Bardawil lagoon, North Sinai, Egypt. Journal of applied sciences researches, 3(10):1240-1250.

[37] Koussa, A. A. 2000. Effect of industrial and organic pollution on potential productivity and fish stock of Lake Mariut, Northern Egypt with a predictive study of that effect on the Lake. Ph. D. Thesis Fac. Of Sci. Ain Shams Univer.

[38] Leibold, M. A. 1996. A graphical model of keystone predators in food webs: trophic regulation of abundance, incidence and diversity patterns in communities. American Naturalist 147:784–812. http://dx.doi.org/10.1086/285879

[39] Maher, M.; Jafri, S.; Leghari, S. and Khuhawar, M. 2009. Seasonal periodicity of phytoplankton and chlorophyll content in lake Manchar. Pak. J. Bot, 41(2): 871-884.

[40] Mohamed, A. M. H. 2005. Ecological studies on phytoplankton composition of newly formed aquatic depressions at Abou-Zabal Quarries region. M. Sc. Thesis faculty of science El- Azhar Univ., Egypt.

[41] Munawar M. 1972. Ecological studies of Eugleninae in certain polluted and unpolluted environments. Hydrobiologia 39: 307-320. http://dx.doi.org/10.1007/BF00046647

[42] Nassar, M.Z., Gharib, S.M. 2014. Spatial and temporal patterns of phytoplankton composition in Burullus Lagoon, Southern Mediterranean Coast, Egypt . Egyptian Journal of Aquatic Research, 40, 133–142. http://dx.doi.org/10.1016/j.ejar.2014.06.004

[43] Nowrouzi, S. and Valavi, H. 2010. Effects of Environmental Factors on Phytoplankton Abundance and Diversity in Kaftar Lake. Biol., 46: 63-74.

[44] Okbah, M. A. and Hussein, N. R. 2005. The effect of environmental conditions on the distribution of phytoplankton communities, Lake Burullus. International conference of aquatic resources of the Arab Region, 7-9th May 2005, Alex. Egypt.

[45] Palmer, C. P. 1969. A composition rating of algae tolerating organic pollution. Jour. Phycol. 5:78-82. http://dx.doi.org/10.1111/j.1529-8817.1969.tb02581.x

[46] Radwan, A. M. 1997. Effect of salinity changes and drainage water discharged on the concentration of some heavy metals in Lake Burullus. Bull. Nat. Inst. Oceanog. Fish. ARE, Baltim Research station, Baltim.

[47] Radwan, A.M. 2002. Comparative study on the phytoplankton standing crop in the different sectors of Burullus Lake during 1997-1998. Bull. Nat. Inst. Oceanog. Fish. ARE, 28:189-305.

[48] Reynolds, C.S. 1984. Phytoplankton periodicity: The interactions of form, function and environmental variablility. Freshwater Biol., 14: 111-142. http://dx.doi.org/10.1111/j.1365-2427.1984.tb00027.x

[49] Saad, L. 2003. Environmental concern down this earth day. Gallup News Service. Poll Analyses, 17 April. Available at http://www.gallup.com/poll/releases.

[50] Salah El Din, R.A. 2005. Changes in physic-chemical characters and its impact on phytoplankton structure of Lake Manzala. Egyptian Journal of Phycology, 6:111-126.

[51] Samaan, A. A. 1974. Primary production of Lake Edku. Bull. Nat. Inst. Oceanog. Fish. ARE, 4:261-317.

[52] Samaan, A. A. 1977. Distribution of zooplankton in Lake Edku. Bull. Nat. Inst. Oceanog. Fish. ARE, 6:159-196.

[53] Samaan, A. A. and Abdallah, R. R. 1981. Effect of pollution on the development of periphyton in Lake Mariut, Egypt. Bull. Nat. Inst. Oceanog. Fish. ARE, 7(3):527-537.

[54] Sayed, Essam, A. M. 2003. Study of some chemical and physical changes of waters and sediments of Lake Edku. M. Sc. Thesis Fac. Of Sci. Alex. Univ. Pp108.

[55] Shabana, E. 1999. Limnological studies on Lake Bardawil. M. Sc. Thesis Suez Canal Univ., Egypt. 138pp.

[56] Shakweer, L. 2005. Ecological and fisheries development of Lake Manzalah (Egypt). 1- Hydrography and chemistry of Lake Manzalah. Bull. Nat. Inst. Oceanog. Fish. ARE, 31(2):253-269.

[57] Shaltout, K. H. and T. M. Galal, 2006. Report on Ecosystem of Lake Manzala.

[58] Shaltout, K. H.; Khalil, M. T. 2005. Lake Burullus (Burullus protected area). Publication of national biodiversity unit. No. 13.

[59] Shriadah, M.A. and Tayel, F.T. 1992. Impact of Industrial, Sewage and Agriculture Effluents of Lake Edku and Abu Qir Bay, Egypt. Bull. Fac. Sci. Alexandria Univ., Alexandria, 32: 130-155.

[60] Siliem, T. A. E. 1989. Chemical conditions in Bardawil lagoon. 3- Some lomnological studies. Bull. Nat. Inst. Oceanog. Fish. ARE, 15(1):21-33.

[61] Stomp, M.; J. Huisman, F. de Jongh, A. J.; Veraart, D.; Gerla, M.; Rijkeboer, B. W.; Ibelings, U. I. A.; Wollenzien, and L. J. Stal. 2004. Adaptive divergence in pigment composition promotes phytoplankton biodiversity. Nature 432: 104–107. http://dx.doi.org/10.1038/nature03044

[62] Stomp, M.; Huisman, J.; Vörös, L.; Pick, F.R.; Laamanen, M.; Haverkamp, T.; Stal, L.J. 2007: Colourful coexistence of red and green picocyanobacteria in lakes and seas. Ecology Letters 10: 290–298. http://dx.doi.org/10.1111/j.1461-0248.2007.01026.x

[63] Taha, E. O. 1990. Some ecological studies on phytoplankton in Lake Bardawil. Ph. D. Thesis Fac. Of Sci. Zagazig Univ. 228pp.

[64] Talling, J.F. and Lemoalle, J. 1998. Ecological dynamics of tropical inland waters, 82-117.

[65] Tilman, D. 1982. Resource competition and community structure. Princeton University Press, Princeton, New Jersey, USA.

[66] Tilman, D.; Kieling, R.; Sterner, R.; Kilham, S. S. and Johnson, F. A. 1986. Green-blue algae and diatoms; Taxonomic differences in competitive ability for phosphorus, silicon and nitrogen. Arch. Hydrobiologia, 106:473-485.

[67] Toulibah, H.; Safik, H.; Gab-Allah, M. and Taylour, W. 2002. Phytoplankton and some abiotic features of El-Bardawil Lake. Sinai, Egypt. African J. Aquatic Science, 27:97-10. http://dx.doi.org/10.2989/16085914.2002.9626581

[68] Wetland Monitoring program (2010/2011) for Egyptian Northern Lakes, Ministry of Environmental Affairs:

1- http://www.eeaa.gov.eg/english/reports/water/reportAug10/%D9%85%D8%B1%D9%8A%D9%88%D8%B7.pdf (Lake Mariut, August 2010).
2- http://www.eeaa.gov.eg/english/reports/water/reportNov10/%D9%85%D8%B1%D9%8A%D9%88%D8%B7.pdf (Lake Mariut, November 2010).
3- http://www.eeaa.gov.eg/english/reports/water/reportMay11/%D9%85%D8%B1%D9%8A%D9%88%D8%B7%20%D9%85%D8%A7%D9%8A%D9%88%202011.pdf (Lake Mariut, May 2011).
4- http://www.eeaa.gov.eg/english/reports/water/reportAug10/%D8%A5%D8%AF%D9%83%D9%88.pdf (Lake Edku, August 2010).
5- http://www.eeaa.gov.eg/english/reports/water/reportNov10/%D8%A5%D8%AF%D9%83%D9%88.pdf (Lake Edku, November 2010).
6- http://www.eeaa.gov.eg/english/reports/water/reportMay11/%D8%A5%D8%AF%D9%83%D9%88%20%D9%85%D8%A7%D9%8A%D9%88%202011.pdf (Lake Edku, May 2011).

7- http://www.eeaa.gov.eg/english/reports/water/reportAug10/%D9%85%D8%B1%D9%8A%D9%88%D8%B7.pdf (Lake Burullus, August 2010).
8- http://www.eeaa.gov.eg/english/reports/water/reportNov10/%D9%85%D8%B1%D9%8A%D9%88%D8%B7.pdf (Lake Burullus, November 2010).
9- http://www.eeaa.gov.eg/english/reports/water/reportMay11/%D9%85%D8%B1%D9%8A%D9%88%D8%B7%20%D9%85%D8%A7%D9%8A%D9%88%202011.pdf (Lake Burullus, May 2011).
10- http://www.eeaa.gov.eg/english/reports/water/reportAug10/%D8%A5%D8%AF%D9%83%D9%88.pdf (Lake Manzala, August 2010).
11- http://www.eeaa.gov.eg/english/reports/water/reportNov10/%D8%A5%D8%AF%D9%83%D9%88.pdf (Lake Manzala, November 2010).
12- http://www.eeaa.gov.eg/english/reports/water/reportMay11/%D8%A5%D8%AF%D9%83%D9%88%20%D9%85%D8%A7%D9%8A%D9%88%202011.pdf (Lake Manzala, May 2011).
13- http://www.eeaa.gov.eg/english/reports/water/reportAug10/%D8%A5%D8%AF%D9%83%D9%88.pdf (Lake Bardawill, August 2010).
14- http://www.eeaa.gov.eg/english/reports/water/reportNov10/%D8%A5%D8%AF%D9%83%D9%88.pdf (Lake Bardawill, November 2010).
15- http://www.eeaa.gov.eg/english/reports/water/reportMay11/%D8%A5%D8%AF%D9%83%D9%88%20%D9%85%D8%A7%D9%8A%D9%88%202011.pdf (Lake Bardawill, May 2011)

[69] Zaghloul, F. A. and Hussein, N. R. 2000. Impact of pollution on phytoplankton community structure in Lake Edku, Egypt. Bull. Nat. Inst. Oceanog. Fish. ARE, 26:297-318