American-Eurasian J. Agric. & Environ. Sci., 5 (2): 171-178, 2009
ISSN 1818-6769

Present and Long-Term Changes of Phytoplankton Communities in Hypertrophic Mediterranean Lagoon, Lake Manzala, Egypt

Mohamad Saad Abd El-Karim

National Institute of Oceanography and Fisheries, 101 El-Kaser El-Einy St. Cairo, Egypt

Abstract: This work was carried out to throw light on the present status of phytoplankton and the long-term changes resulted from heavy nutrients loading during the period 1979 - 2007. Based on cell density, present phytoplankton populations were dominated by chlorophytes followed by cyanoprokaryotes, whereas bacillariophytes ranked the third predominant positions. On cell biovolume base, Bacillariophytes were the most dominant class. Bacillariophytes were dominated by centric forms, *Cyclotella* spp and small pinnate forms, *Nitzschia* spp, whereas chlorophytes and cyanoprokaryotes were dominated by pico-coccoid taxa. Long-term changes of chlorophyll a showed a duplication from 34 µg/l in 1979 to 78.2 µg/l in 1987/88, followed by a climax of 988.3 µg/l, in 2007. Regressing the pooling data of chlorophyll a with TP and TIN indicated that chlorophyll a was significantly ($P<0.001$) correlated with TP, $R^2 = 0.45$, rather than TIN, $R^2=0.14$. Regarding phytoplankton community composition, Bacillariophyceae was the main component of phytoplankton during 1979, followed by a graded waning till 2007 when they harbored their least percentage abundance of 17.8%. Chlorophyceae and cyanoprokaryotes were of a significant importance in 1979. During the eutrophication phase, cyanoprokaryotes became the dominant algal group till year 2000, whereas chlorophytes still unchanged till 1987/88 followed by a slight increase during 2000, then they became the main component of the phytoplankton abundance during 2007. In the early years, the filamentous and large diatoms dominated. Later, however, small cells appeared in 1987/88 and recently they become more dominant. Cyanoprokaryotes during the commencement of the eutrophication were represented by large filamentous *Spirulina* sp and heterocystous *Anabaena* sp, *Chroococcus* and *Microcystis* appeared thereafter and became dominant during 2000. Among chlorophytes, *Tetraspora*, *Scenedesmus* and *Pediastrum* contributed significantly in late 1970s. After the peak of eutrophication, *Pediastrum* and *Tetraspora* declined whereas *Scenedesmus* and other pico-chlorococcales increased, specifically *Dictyosphaerium* spp till 2007.

Key word: Lake Manzala · Long-term changes · Phytoplankton · Chlorophyll a · Phosphorus

INTRODUCTION

Long-term studies in lakes have provided direct clues to the effect of increased major nutrients (nitrogen and phosphorus) on the productivity and variations in biota of the lakes, but the proposed mechanisms mediating this linkage differ drastically between lakes [1]. Lake Manzala is a highly dynamic system, today; it is very different from its original state, even during the last few decades. The main features of the lake (area, abiotic and biotic characters) had been changed. The introduction of perennial irrigation, the construction of canals and drains, the discharge of nutrients and land reclamation for agriculture are largely responsible for these changes [2]. The mean concentration of the major nutrients has increased markedly since the 1930s [3]; the eutrophication status of the lake has become more serious. The hydrobiont, mainly the planktons, benthos, macrophytes and the fishes, have also undergone significant changes in their quantity and specific composition.

The phytoplankton communities undergo changes from diatoms-dominated communities to non-diatoms-dominated communities. The early available studies of the phytoplankton, [2,4] indicated that the phytoplankton communities were numerically, diatoms-dominated, while cyanoprokaryotes and chlorophytes were subdominant. In mid 1990s, [5] reported a transient stage with dominance of diatoms through winter and spring, while chlorophytes and cyanoprokaryotes dominated through autumn and summer, respectively.

Corresponding Author: Dr. Mohamad Saad Abd El-Karim, National Institute of Oceanography and Fisheries, 101 El-Kaser El-Einy St. Cairo, Egypt

More recently, [6] postulated that cyanoprokaryotes dominated the phytoplankton communities (relative abundance of 48.468%), Chlorophyceae (relative abundance of 29.204%), whereas Bacillariophyceae became subdominant (relative abundance of 20.7%). [7] conducted that diatoms, numerically, ranked the third predominant position, although they dominated when the phytoplankton abundance was expressed as biovolume. He expected that, afterward, diatoms will be decreased on both numeric and biovolume bases as silicate ratios decreased.

This study was conducted to infer the present status and long-term changes in Lake Phytoplankton and biomass with eutrophication process.

MATERIALS AND METHODS

Site Description: Description and feeding water of Lake Manzala was presented by Abd El-Karim [7]. In brief, the lake occupies the north eastern corner of the Nile Delta. Its area has been gradually decreased since the earliest decades of the twentieth century from 1,709 km^2 in 1900 to 904,785 km^2 as measured by Landsat imagery in 1981. The lake received 11.7 billion m^3/year; 4 m^3/year billion from Damietta Branch and about 7.7 billion m^3/year from the wastewater drains. Nine stations were selected which covered the whole area of the lake (Fig. 1).

Phytoplankton Sampling and Analysis: Phytoplankton samples were collected seasonally during 2007 and analyzed as described by Abd El-Karim [7]. Phytoplankton compound quotient (PCQ) was used to

Fig. 1: Map showing sampling stations in Lake Manzala

Table 1: Ecological status of the lake according to the phytoplankton compound quotient (PCQ), after [8]

Lake status	PCQ	Lake status	PCQ
Oligotrophic	< 2	Eutrophic	5-7
Mesotrophic	2-5	Hypertrophic	>7

Table 2: Years of sampling and publishing of the data used

Author	Year of sampling	Year of publishing
[1]	1979	1981
[9]	1987/88	1991
[6]	2000	2007
[10]	2007	2008
[11]	2007	2008
[7]	2007	2008

characterize the ecological status of the lake. PCQ gives quite good estimation to lake trophic condition, although algal groups in formula may contain species with different preferences to trophic conditions. Moreover, [8] added to the original formula 2 extra taxons: Cryptophyta to numerator and Chrysophyceae to denominator.

$$PCQ = \frac{\text{Cyanophyta*+Chlorococcales*+Centrales*+Euglenophyceae*+Cryptophyta*+1}}{\text{Desmidiales*+Chrysophyceae*+1}}$$

where * is the number of different species. The classification of values is represented in Table 1.

Data Source: The long term changes in Lake Manzala was studied through comparing the data of the available literature (Table, 2) based on sampling dates not on the dates of publishing. It is worth to know that the data of authors [7, 10, 11] were sampled concurrently during 2007.

Data Analysis: The pooled data of different authors were regressed using Statistica V. 8.

RESULTS

Lake Trophic Status: The main physical and chemical character of the lake is represented in Table 3. Lake Manzala is very shallow, soft water Lake, which is classified as eutrophic in 1979 and hypertrophic afterward (based on TP, *Chl a* and Secchi depth) according to the definition developed by OECD, [12].

Table 3: Main physical and chemical parameters of Lake Manzala (after [11])

	Minimum	Maximum	Mean
Depth (cm)	50	200	121
Temperature (°C)	19.8	30.5	24.5
Transparency (cm)	10.0	130.0	76.3
Salinity (‰)	1.4	4.4	2.8
E.C (µs/cm)	1910.0	6320.0	3455.0
TS (mg/l)	1156.0	4346.0	2410.6
pH	7.6	8.9	8.2
DO (mg/l)	1.2	12.0	5.6
BOD (mg/l)	4.6	18.7	9.4
HCO_3^- (mg/l)	135.5	292.1	214.8
NO_3^- (µg/l)	16.4	321.3	139.3
NO_2^- (µg/l)	5.3	284.1	105.8
NH_3 (µg/l)	196.0	7507.5	2761.6
Total-P (mg/l)	381.0	3870.0	1692.8
SiO_3^{2-} (mg/l)	1.2	9.4	4.1
Chlorophyll a (µg/l)	90.0	2400.0	988.0

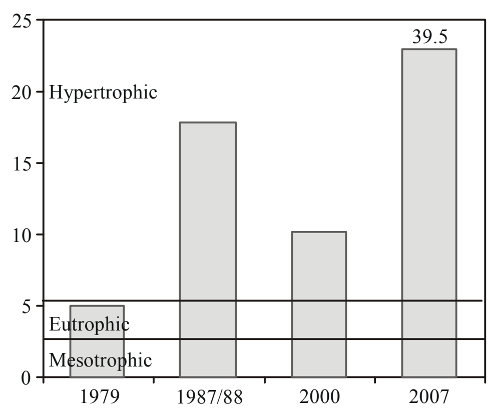

Fig. 2: Phytoplankton compound quotient in Lake Manzala since 1979 till 2007

According to phytoplankton compound quotient (PCQ). Fig. 2 shows a remarkable increase in the whole water column eutrophication since 1979 till 2007. In 1979 the quotient was at the upper limit of mesotrophic phase then exceeded the hypertrophic limit (7) in 1987/88 and remained on a very high level throughout the entire investigated period with a slight decrease during 2000.

Present Status of Phytoplankton Community Composition and Dominant Groups: A total of 234 algal taxa was observed, 124 taxa belonged to Chlorophyta, which accounted for 53% of the total number of species identified, whereas Bacillariophyta (42 taxa) and Cyanoprokaryotes (44 taxa) contributed approximately 18% and 19%, respectively. The species number of groups, Euglenophytes, Prasinophytes, Cryptophytes, Chrysophytes and Dinophytes were relatively low. The majority of Chlorophyta taxa consisted of Chlorococcales, with 92 taxa found and the number of taxa of some genera of Chlorococcales was also very high. For instance, 23, 9 and 7 taxa were identified as belonging to *Scenedesmus*, *Oocystis* and *Kirchneriella*, respectively. In cell density, however, the small coccoid Chlorococcales were dominant but in biovolume they become subdominant to diatoms. Of the 42 Bacillariophyta taxa observed, pinnate diatoms comprised more than 95% of the diversity. However, in terms of abundance, centric diatoms, especially *Cyclotella* spp and small pinnates, *Nitzschia* spp, were the dominants in most samples. Between the 44 cyanoprokaryotic taxa observed, the cell density of these species, especially *Lyngbya limnetica* Lemm.., *Microcystis aeruginosa* Kuetz. and many filamentous non-heterocystous, *Oscillatoria* spp and *Phormidium* spp, were the highest in summer and autumn. Euglenophyta could be a considerably present group throughout the year of sampling, whereas Cryptophyta could be present in autumn but completely disappeared in spring.

Long-Term Changes in Phytoplankton Biomass in Relation to Internal Total Phosphorus (TP) and Total Inorganic Nitrogen (TIN): The trends of TP concentration and phytoplankton biomass are displayed as the cumulative mean of the long-term average since 1979 to 2007 (Fig. 2). The internal lake total dissolved phosphorus (incorporate both organic and inorganic forms) and phytoplankton biomass, *Chl a*, were evidence for an analogous performance through the last 3 decades. The average internal phosphorus load of the lake since the end of 1970s (Fig., 3) was increased about twenty folds from 82.5 µg/l during 1979 to 1600 µg/l in 2007. Likewise, chlorophyll a concentrations increased thirty folds from 34.7 µg/l during 1979 to 988.3 µg/l during 2007. So, the annual increase in both internal lake total dissolved phosphorus and *Chl a* were 54.2 and 34.1 µg/l, respectively. Regressing raw data of both *Chl a* and TP since 1979 till 2007, a highly significant relation was developed (Fig. 4a):

$$\text{Chl a} = 16+19838\ \text{TP}\ R^2=0.45\ (P<0.001)$$

Total inorganic nitrogen (TIN) showed a gradual sharp increase, about 73 folds since 1979 till 2007, equivalent to the increase in internal load of TP and *Chl a*. When *Chl a* and TIN regressed, a non-significant relationship was obtained (Fig. 4b):

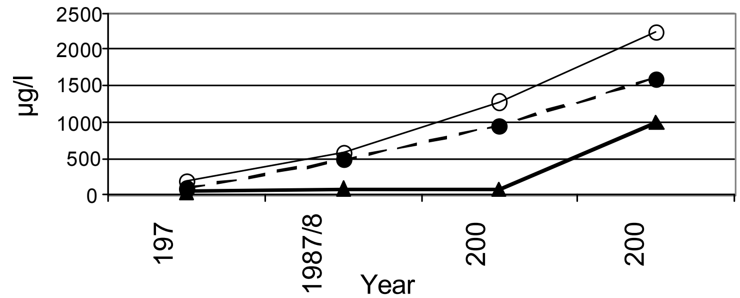

Fig. 3: Long-term distribution of TIN (open circles), TP (solid circle) and Chl a (Triangle) since 1979 till 2007

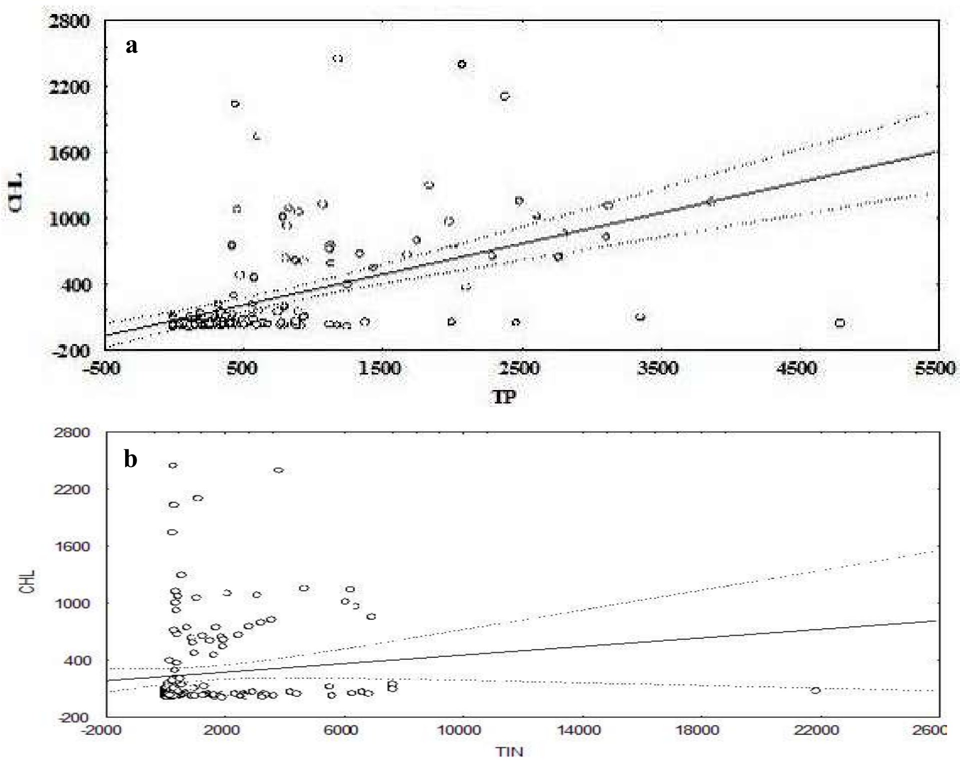

Fig. 4: Logarithmic regression line and 95% confidence limits for pooled data of chlorophyll a and TP (a) and TIN (b) in Lake Manzala since 1979 till 2007

Chl a = 171.7 + 0.05 TIN R^2 = 0.14 (P= 0.16)

For annual mean values, the *Chl a*: TP and *Chl a*: TIN ratios generally declined since 1979 till 2000 followed by a sharp increase, ten folds, during 2007.

Long-Term Changes in Phytoplankton Composition: With the onset of eutrophication in late 1970s, phytoplankton biomass began to augment, leading to more pronounced peaks, shifts in species composition and greater seasonality at the areas opposite to the discharging points of nutrients. The changes from the upper limit of the mesotrophic phase during 1979,through the period of increased nutrient loading are clearly reflected in the composition of phytoplankton communities. Based on cell density, Bacillariophyceae was the main component (Table 4) of phytoplankton at the end of the mesotrophic period (during 1979), followed by a graded waning till 2007 when they harbored their

Table 4: Long-term changes in percentage abundance of phytoplankton main groups

	Year			
Group	1979	1987/1988	2000	2007
Bacillariophyta	67	35.5	20.7	17.8
Cyanoprokaryotes	10	46.6	48.5	19.3
Chlorophyta	23	20	29.2	53.5

Table 5: Functional groups of phytoplankton populations since 1979 till 2007, after [13] (+, means present)

	Functional groups										
	Bacillariophytes			Chlorophytes			Cyanoprokaryotes				
	P	D	B	J	X1	F	K	S2	H1	M	X1
1979	+			+				+	+		
1987/88	+	+		+			+	+			
2000		+		+						+	
2007		+	+	+	+	+				+	+

Table 6: Habitats and representatives of different functional group since 1979 till 2007 after [13]

Codon	Year	Representative	Habitat	Tolerance
J	1979	*Pediastrum* and *Scenedesmus*	shallow, enriched lakes	
	1987/88	*Scenedesmus*		
	2000	*Scenedesmus, Dictyosphaerium pulchellum*		
	2007	*Scenedesmus*, *Coelastrum Dictyosphaerium pulchellum*		
D	1987/88	*Nitzschia closterium*	Shallow, enriched turbid lakes	Flushing
	2000	*Nitzschia closterium, Cyclotella* spp		
	2007	*Nitzschia closterium, Cyclotella* spp		
P	1979	*Melosira*	eutrophic lakes	Mild light and C deficiency
	1987/88	*Fargilaria crotonensis*		
S2	1979	*Spirulina*	shallow, turbid mixed layers	Light deficient
	1987/88	*Oscillatoria*		
M	2000	*Microcystis aeruginosa*	mixed layers of eutrophic, lakes	High insulation
	2007			
X1	2007	*Monoraphidium, Chroococcus, Chlorella* spp	shallow mixed, enriched conditions	low light
B	2007	*Cyclotella meneghiniana*	Shallow turbid, enriched lakes	Light deficiency
K	1987/88	*Aphanocapsa*	short, nutrient-rich columns	
H1	1979	*Anabaena*	large mesotrophic lakes	low nitrogen

least percentage abundance of 17.8%. Chlorophyceae and cyanoprokaryotes were of a significant importance, while other groups contributed very little. During the peak of the eutrophication phase, cyanoprokaryotes became the dominant algal group till year 2000 when they comprising more than 48 % of the total annual mean of phytoplankton density, followed by a sharp decline in 2007 with annual percentage of 19.3%. Chlorophytes still unchanged from 1979 till 1987/88 then they showed a slight increase during 2000, later they became the main component of the phytoplankton abundance during 2007 with annual percentage abundance of 53.5%.

The phytoplankton populations were represented by 25 genera in late 1970s, reached their highest number, 100 genera, in late 1987/88, afterward they slightly declined to 95 in/after 2000. In the early years, 1979, the filamentous and large centric diatoms, *Melosira* and *Coscinodiscus*, were more important and shared dominance with pinnate forms *Synedra* and *Nitzschia*. Later results of *Melosira* and *Coscinodiscus* indicated their presence on decidedly lower levels, whereas the small centric *Cyclotella meneghiniana* Kuetz and both small pinnate *Fragilaria crotonensis* Lyngb and *Nitzschia closterium* Smith appeared and become more dominant later. During 2000 and afterward, *C. meneghiniana*, *N. closterium* in addition to *C. ocellata* Pant. were the dominants.

Cyanoprokaryotes, during the commencement of the eutrophication peak, were represented by filamentous *Spirulina* and heterocystous *Anabaena*. *Chroococcus* and *Microcystis* appeared later and became dominate during the peak of the eutrophication. The chlorophytes, *Tetraspora*, *Scenedesmus* and *Pediastrum* contributed significantly in late 1970s.

During the peak of eutrophication, *Pediastrum* and *Tetraspora* declined whereas *Scenedesmus* and other pico-chlorococcales increased till 2007. In late 1980s, small green flagellates *Chlamydomonas globosa* Snow and *Pyramimonas tetrahyncous* Schm appeared, the former declined gradually whereas the later increased in importance and reach a climax during 2007.

Long-Term Changes in Functional Groups: Since late 1970s till 2007, the phytoplankton populations were represented by ten groups. The recorded groups were P, D, B, J, X1, F, K, S2, H1 and M. The habitats of the different groups and their representative species were indicators of nutrient enriched (Table 5 and 6), shallow, turbid systems. The gradual increase of internal nutrients loading was reflected in the succession of the functional groups. Group J was the most represented, whereas group H1 reported only in late 1970s. Among diatoms, *Nitzschia* spp and *Cyclotella* spp were the most important representatives specifically during 1987/88 and afterward. Prior to the peak of eutrophication, chlorophytes were represented mainly by chlorococcales specially genus *Scenedesmus*. Although the small flagellates, *Chlamydomonas* and *Pyramimonas*, were dominant during 1987/88 but they were not represented in the functional groups.

DISCUSSION

Compared with data obtained in late 1970s [2], a trend for increased proportion of small-sized species was very obvious afterward especially in 2000-2007. Also, there was a considerable increase in the number of individuals (or cells) of the dominant species since the 1970s. Similar results have been obtained in different studies and the authors of those studies interpreted such increases as a sign of eutrophication [14,15]. It is generally agreed that, under the same ecological conditions, the higher the total standing crop and the number of individuals of the dominant species, the higher the trophic status [14,16]. A paleolimnological study in a Canadian lake found that land use parameters (rural and urban) were stronger determinants of increased algal biomass and nuisance cyanoprokaryotes species, than climatic factors [17]. In addition, paleolimnological studies in Florida lakes have also shown that cyanoprokaryotes and pico-chlorophytes proliferation increased recently and abruptly in response to eutrophication [18]. Chlorophyll concentrations tracked cyanoprokaryotes and chlorophytes abundance in Lake Manzala. Both biomass of chlorophytes and cyanoprokaryotes flourishing accompanied the increase in loadings of TIN and TP [19] and were attributed to progressively increase in discharging of sewage and agricultural effluent.

Two developmental phases of the lake can be identified from the time sequence of total phosphorus and phytoplankton biomass (chlorophyll a). Moderate total phosphorus levels in late 1970 which were associated with mean annual chlorophyll a concentrations of 34.5 µg/l. According to the classification proposed by Anonymous, [12] and Vollenweider and Kerekes [20], this period was a clear eutrophication phase. During the following decades, total phosphorus levels increased dramatically reaching 1600 µg/l in 2007 [11]. This sharp increase was a response to the enhanced nutrient loading from agriculture and sewage drains. This eutrophication phase can be identified as a transition period leading to the starting of hypertrophic conditions by 1987/88. While nutrients increased by an order of magnitude or less, the phytoplankton community responded with a doubling of annual average chlorophyll a (34.3 µg/l in 1979 to 78.7 µg/l in 1987/88). This is less than would be predicted from Vollenweider and Kerekes [20] and can be attributed to the strong light limitation of the system which revealed by the low transparency of 82.2 and 59.3 cm which reported by Gaballah, [9] and Abdel-Satar [11].

Responses in the taxonomic composition of phytoplankton are to be expected along trophic gradients in time. However, differences in Lake Manzala can not be explained by trophic state alone without considering other abiotic and biotic interactions. For example grazing by herbivores and competition for resources are likely to be important. There were significant qualitative and quantitative changes of zooplankton populations since 1979 till 2007 [21] where effects on phytoplankton species composition are probable. Moreover, zooplankton was heavily grazed by planktivorous fish (mainly tilapias) which may influence phytoplankton composition through 'top-down' control. Increased emergent and decline of submerged macrophytes, may also affect the phytoplankton populations.

Since silicate limitation of diatom growth cannot be inferred from dissolved Si-concentrations, abiotic factors in combination with biotic interactions seem to be responsible for the observed changes in diatom composition from filamentous, *Melosira granulata* (Ehr) Ralfs and large cells, *Coscinodiscus* sp, to small size cells. The introduction of small centric diatoms which are indicative of enriched conditions [22] may reflect the decreasing ratio of silica to available phosphorus as small centric species have been shown to have a lower optimum Si:P ratio than the larger forms [23,24]. According to Sommer [25], decreasing Si:P ratios should favor small centric diatoms. However, these species increased considerably accompanied with increasing of small species of *Nitzschia* spp as *N. closterium* and *N. frustulum* var *perpusilla* (Rabh) Grun , when Si:P ratios must have decreased. Permanent mixing seems to influence diatom composition by selecting for small centric diatoms [26].

Cyanoprokaryotes developed in 1979 with tow large filamentous, *Anabaena* and *Spirulina*. These genera decreased in time but occasionally appeared with clear dominance of coccoid, small size non-heterocystous forms which flourished during the peak of eutrophication. Also, [27] report a reduction in heterocystous cyanoprokaryotes during eutrophication of lakes in Denmark, in contrast to non-heterocystous forms which initially increased their densities during eutrophication. This may reflect the greater affinity of non-heterocystous cyanoprokaryotes to phosphorus, as suggested by Jensen *et al.* [28]. These observations support the suggestion that during eutrophication, non-heterocystous species may become an increasing proportion of the cyanoprokaryotes of lakes as reported by Jeppese *et al.* [29]. This shift in cyanoprokaryotes composition may be ascribed to: firstly, increasing turbidity and delaying light penetration which sustain heterocystous forms with energy needed to fix atmospheric nitrogen and, secondly, enhancement of both organic and inorganic nitrogen which exhausted easily by small coccoid forms [26]. Chlorophyceae, especially *Monoraphidium*, *Scenedesmus* and *Dictyospaerium*, apparently responded best to increased phosphorus levels. Their growth in turbulent, nutrient rich waters is in accordance with reported growth K_s-values [30]. Increasing chlorophytes over the cynaoprokaryotes in 2007 might be attributed to lower growth rates of cynaoprokaryotes compared to chlorophytes [18].

In conclusion, long-term changes in Lake Manzala demonstrate a significant response of phytoplankton to the intensification of nutrients specifically in phosphorus over a time scale of about 30 years. It is proposed that the relatively rapid biomass response resulted from direct coupling to the phosphorus supply. A clear shifts in species composition was also recognized by transportation from phase dominated by large, siliceous forms to another dominated by pico-non-siliceous forms.

REFERENCES

1. Dokulil, M.T. and K. Reubner, 2005. Do phytoplankton communities correctly track trophicchanges? An assessment using directly measured and palaeolimnological data. Freshwater Biology, 50: 1594-1604.
2. Maclaren Engineers, Planners and Scientists 1981. Lake Manzalah study. EGY/76/001-07. Draft Report to Arab Republic of Egypt. Ministry of Development and New communities and UNDP Scientists, Inc. Toronto, Canada, 12 Vols.
3. Montasir, A.H., 1937. Ecology of Lake Manzalah. Bulletin of Faculty.of Sci. Cairo Univ. pp: 12-50.
4. Khalil, M.T., 1990. Plankton and primary productivity of Lake Manzala. Egypt. Hydrobiologia, 196: 201-207.
5. El-Sherif, Z.M. and S.M., Gharib, 2001. Spatial and temporal patterns of phytoplankton communities in Manzalah Lagoon. Bulletin of National Institute of Oceanography and Fisheries. 27: 217-239.
6. Sobhy, H.E., 2007. Distributions of phytoplankton and epipelic microalgal communities of Lake Manzala. Girls College, Ain-Shams University, pp: 267.
7. Abd El-Karim, S.M., 2008. Monthly Variations of Phytoplankton Communities in Lake Manzala. Global Veterinaria, 2: 343-350.
8. Ott, I. and R. Laugaste, 1996. Futoplanktoni koondindeks (FKI), u¨ ldistus Eesti ja¨ rvede kohta. Eesti Keskkonnaministeeriumi infoleht 3: 7-8. The Phytoplankton Compound Quotient (PCQ), generalisation about Estonian small lakes. Estonian.
9. Gaballah, M.M., 1990. Ecological studies on phytoplankton in Lake Manzala. Ph.D. Thesis, Faculty of Science, Suez Canal University.
10. Abd El-Hady, H.H., 2008. Effect of environmental factors and different pollutants on biochemical contents of phytoplankton in Lake Manzala, Egypt. Egyptian J. Aquatic Res., 34:121-134.
11. Abdel-Satar, M.A., 2008. Chemistry of major ions, nutrient salts and heavy metals in Lake Manzala, Egypt. Egyptian J. Aquatic Res., 34: 135-147.
12. OECD, Organization for Economic Co-Operation and Development 1982. Eutrophication of Waters, Monitoring, Assessment and Control. OECD, Paris.
13. Reynolds, C.S., V. Huszar and C. Kruk, 2002. Towards a functional classification of the freshwater phytoplankton. J. Plankton Res., 24: 417-428.
14. Reynolds, C.S., 1984. The ecology of freshwater phytoplankton. Cambridge Univ. Press, Cambridge, New York, New Rochelle, Melbourne, Sydney, pp: 384.

15. Korneva, L.G. and N.M. Mineeva, 1996. Phytoplankton composition and pigment concentrations as indicators of water quality in the Rybinsk reservoir. Hydrobiologia, 322: 255-259.
16. Round, F.E., 1981. The Ecology of Algae. Cambridge University Press, Cambridge.
17. Kagaloua, I.E., I. Papastergiadoub and S. Leonardosa, 2008. Long term changes in the eutrophication process in a shallow Mediterranean lake ecosystem of W. Greece: Response after the reduction of external load. J. Environ. Manage., 87: 497-506.
18. Riedinger-Whitmore, M.A., T.J. Whitmore, J.M. Smoak, M. Brenner, A. Moore, J. Curtis and C.L. Schelske, 2005. Cyanobacterial proliferation is a recent response to eutrophication in many Florida lakes: a paleolimnological assessment. Lake Reservoir Management, 21: 423-435.
19. Johansson, J.O. and R.R. Lewis, 1992. Recent improvements in water quality and biological indicators in Hillsborough Bay, a highly impacted subdivision of Tampa Bay, Florida, USA. Sci. Total Environ 1199-1215 Suppl.
20. Vollenweider, R. and J. Kerekes, 1982. Eutrophication of waters. Monitoring, assessment and control. OECD, Paris, pp: 154.
21. Anonymous, 2008. Ecology and Fisheries of Lake Manzala. Nat. Inst. of Ocean. Fish. Final Rep., pp:108.
22. Kohler, J., H. Behrendt and S. Hoeg, 2000. Long-term response of phytoplankton to reduced nutrient load in the flushed Lake Muggelsee (Spree system, Germany). Archiv fur Hydrobiologie, 148: 209-229.
23. Phillips, G.L., A. Bramwell, J. Pitt, J. Stansfield and M. Perrow, 1999. Practical application of 25 years' research in the management of shallow lakes. Hydrobiologia, 395/396: 61-76.
24. Phillips, G., M. Kelly, J. Pitt, R. Sanderson and E. Taylor, 2005. The recovery of a very shallow eutrophic lake, 20 years after the control of effluent derived phosphorus. Freshwater Biology, 50: 1628-1638.
25. Sommer, U., 1989. The role of competition for resources in phytoplankton succession. In U. Sommer (ed.), Plankton ecology. Succession in plankton communities. Springer Verlag, Berlin, Heidelberg, New York, London, Paris, Tokyo: 57-106.
26. Dokulil, M.T. and J. Padisak, 1994. Long-term compositional response of phytoplankton in a shallow, turbid environment, Neusiedlersee (Austria/Hungary). Hydrobiologia, 275/276: 125-137.
27. Jeppesen, E., J.P. Jensen, M. Søndergaard and T.L. Lauridsen, 2005. Response of fish and plankton to nutrient loading reduction in eight shallow Danish lakes with special emphasis on seasonal dynamics. Freshwater Biology, 50: 1365-1413.
28. Jensen, J.P., E. Jeppesen, K. Olrik and P. Kristensen, 1994. Impact of nutrients and physical factors on the shift from cyanobacterial to chlorophyte dominance in shallow Danish lakes. Canadian J. Fisheries and Aquatic Sci., 51: 1692-1699.
29. Jeppesen, E., J.P. Jensen and M. Søndergaard, 2002. Response of phytoplankton, zooplankton and fish to re-oligotrophication: an 11 year study of 23 Danish Lakes. Aquatic Ecosystem Health and Management, 5: 31- 43.
30. Sommer, U., 1991. A comparison of Droop and Monod models of nutrient limited growth applied to natural populations of phytoplankton. Functional Ecology, 5: 535-544.