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ANALYSES OF PHYSICO-CHEMICAL CHARACTERISTICS AND PHYTOPLANKTON COMMUNITIES OF LAKE NASSER DURING THE LAST TWO DECADES

A. M. EL-OTIFY[1], H. M. SHAFIK[2,3] and E. SZŐKE[4]

[1]*Department of Botany, Faculty of Science, Aswan 81528, Egypt*
[2]*Department of Botany, Faculty of Science, Suez Canal University, Ismailia 41522, Egypt*
[3]*Balaton Limnological Research Institute, Hungarian Academy of Sciences*
H-8237 Tihany, Hungary, E-mail: hisam@tres.blki.hu
[4]*University of Veszprém, H-8200 Veszprém, Hungary*

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Lake Nasser is one of the largest man-made lakes in the world. The creation of Lake Nasser, due to the impoundment of the River Nile in Southern Egypt, was accompanied by alterations in the environmental conditions that consequently affect the biota. Such alterations lead to corresponding changes in the diversity, abundance and distribution of the phytoplankton community. Therefore, the phytoplankton populations were followed and investigated in Lake Nasser. The phytoplankton community structure revealed a floristical diversity and is composed of various planktonic algal taxa appertaining to the divisions: Chlorophyta, Bacillariophyta (diatoms), Cyanophyta (cyanobacteria), Dinophyta (Dinoflagellates) and Euglenophyta. Chlorophyta contribute more taxa to the phytoplankton than any other groups. However, diatoms and cyanobacteria are numerically the main components and alternate in dominance of the community. Dinoflagellates persist as frequent forms and the euglenoid algae are very scarcely represented. Remarkable spatial (horizontal and vertical) as well as temporal (seasonal) variations are recorded in the distribution of phytoplankton. Pronounced variations in the vertical distribution of the phytoplankton standing crop appear during the periods of thermal stratification (late spring, summer and early autumn). However, diatoms and cyanobacteria remain the most influential groups also in the vertical distribution of the phytoplankton. Water blooms are occasionally observed in limited areas of the southern region of Lake Nasser mainly due to the florishment of the cyanobacterium *Microcystis aeruginosa*.

Key words: distribution, diversity, Egypt, Lake Nasser, long-term study, physico-chemical characteristics, phytoplankton

INTRODUCTION

The positive utilisation of inland water systems is one of the highest development priorities of Egypt. For this purpose was the construction of Aswan High Dam (AHD) started in Upper Egypt to control the Nile River flow. The impoundment of the River Nile started in 1964 and consequently, a huge

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man-made reservoir (Aswan High Dam Lake, AHDL) was created as a storage resource for drinking water, to help in irrigation and to supply a sufficient headwater for electricity generation. This reservoir is one of the largest man-made lakes in the world. In terms of area it is the second among the African man-made reservoirs. The largest one is Lake Volta in Ghana.

In his book "The Nile, biology of an ancient river" Rzóska (1976) summarised the previous works on the Nile headwater lakes in Africa. Latif (1974) reported that the diatoms and Chlorophyta constituted about 38% and 2% of the total phytoplankton, respectively. Samman and Gaber (unpublished data) found that Cyanobacteria are the dominant group of phytoplankton in samples collected in summer 1976 and autumn 1979. Some physico-chemical characteristics and qualitative and quantitative counts of phytoplankton were recorded between 1982 and 1984 (Nour-El-Din 1985, Ahmed *et al*. 1989, Mohammed *et al*. 1989). El-Otify (1991) studied the physico-chemical and biological characteristics of the lake at AHD (10 km south of the Dam).

The research work which has been carried out since the early years of Lake Nasser formation reveal that it passes through different stages, namely: mesohumic–mesotrophic (1966–1971), mesotrophic–eutrophic (1972–1977) and after 1978 it can be considered as more or less an eutrophic lake.

Unfortunately, there are no regular studies on the distribution and diversity to monitor the phytoplankton standing crop in the lake.

The study aimed to 1: collect the phytoplankton data of one of the largest reservoirs in the world, 2: record the most important physico-chemical characteristics of the lake in the last three decades, 3: compare the diversity of phytoplankton in Lake Nasser to that of lakes mainly in Africa, and 4: analyse the available data to provide a brief and general overview on the changes and distribution of phytoplankton between 1979 and 1999.

MATERIAL AND METHODS

Source of data

The analysis of phytoplankton is based on work and data of different studies on the lake during the last decades. All data and work filed, except that of 1979 and 1995, were investigated by El-Otify *et al*.

Study area

Aswan High Dam Lake (AHDL) extends from Aswan High Dam in Egypt to the Dal Cataract in Sudan between 23° 58′ and 20° 27′ north latitude and between 30° 35′ and 33° 15′ east longitude. The length of the reservoir is about 480 km, of which 300 km in the Egyptian territory (Lake Nasser) and 180 km in north Sudan (Lake Nubia).

Lake Nasser (Fig. 1) is the northern part of the AHDL constituting about 84% of its area. It lies in a subtropical arid region and is bordered by a desert

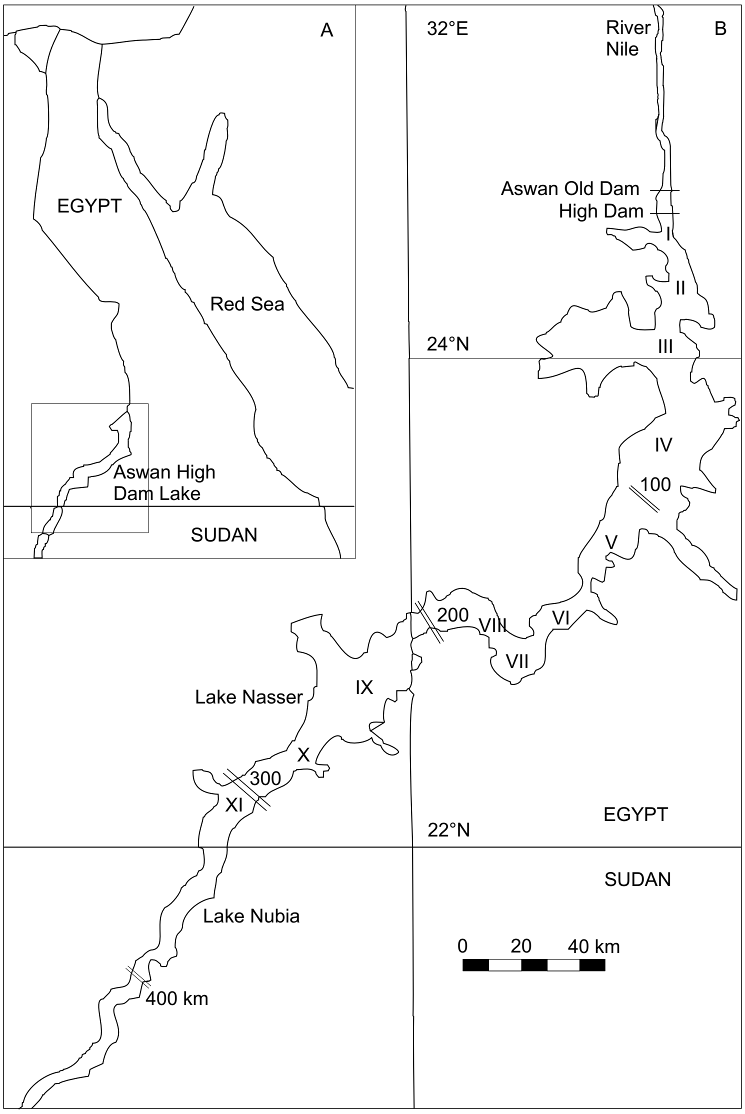

Fig. 1. Map of Egypt and north Sudan shows the situation of Aswan High Dam Lake (A) and Lake Nasser in Egypt, Lake Nubia in Sudan and the sites of sampling between 1979 and 1999

Table 1
The main morphometric features of Lake Nasser at two different water levels

Water level (m)	160	180
Surface area (km²)	2585	5248
Volume (km³)	55.6	132.5
Shore line length (km)	5380	7844
Mean width (km)	8.9	18
Maximum width (km)	21.5	25.2
Mean depth (m)	21.6	25.2
Maximum depth (m)	110	130

with mountains and vast plains of varying elevations. The morphometric features of Lake Nasser vary concomitantly with the water level fluctuations (Table 1, Entz 1974). The lake has many side areas (creeks), locally known as Khors. The total number of important Khors is 85 (48 on the eastern and 37 on the western shore).

The deepest part of the lake is the main stream of the ancient river with the adjacent strips of cultivated lands forming together the original river valley, called the central area or the main water body of the lake. The bottom of this part elevates from 85 to about 150 m a.s.l. (above mean sea level). The side areas lie between 150 and 180 m a.s.l. The ecosystem of Lake Nasser is almost lacustrine except in its southern part (about 50 km in length) which is a fluviatile and has riverine characteristics particularly during the flood seasons. This part of the lake can be considered as an extremely slow river (Entz 1997). In general, the range of the current speed in the lake is 0–3 cm sec^{-1}. Entz (1997, pp. 82–87) summarised some morphometric and hydrological data of the lake.

Sample collection and preservation

Sampling was carried out at different successive sites situated along the main water body of Lake Nasser at variable distances between 3 and 320 km south of AHD (Fig. 1, Table 3). The sample collection trip extended between three and five weeks in each season. In years 1986 and 1987 samples were collected from different depths at one site (AHD, site I). Water samples from the surface and from various depths were collected in 1986, 1987, 1993 and 1999. Water sampler (Nansen bottle, Goodwin and Goddard 1974) on a research ship was used. Aliquots for phytoplankton determinations were immediately fixed by Lugol's solution and stored in an ice-box (4 °C) until examination. Phytoplankton species were analysed qualitatively and quantitatively using counting cells after settling (Stein 1973). These methods are used for all samples collection and preservation.

Physical and chemical measurements

In conjunction with the sampling of phytoplankton some physical and chemical parameters were always monitored. Water temperature, pH (pH meter, Orion Research model 201), water transparency (30 cm Secchi-disk), turbidity (digital turbidity meter, Orbeco-Hellinge calibrated by the Orbeco-Hellinge standard solution) and the electric conductivity (Amber Science Inc. Sandiego conductivity meter model 1062) were measured *in situ*. The nutrients were determined according to the methods described in APHA (1985).

Data Analysis

Diversity. Shannon-Weaver function (Shannon 1948) is the most widely applied to estimate biotic diversity:

$$H' = -\sum_{i=1}^{s} \frac{n_i}{N} \log_2 \frac{n_i}{N'} \qquad (1)$$

where n_i is the density measure (in this case the cell, colony or filament counts) of i-th algal group; s is the number of algal species in the sample; and

$$N = \sum_{i=1}^{s} n_i \qquad (2)$$

Throughout this study, equation (1) was used to calculate diversity.

Cluster analysis. For cluster analysis of similarity the software program Syn-tAx 2000 (Podani 2001) was used.

RESULTS

Physical and chemical features

The water level in Lake Nasser is fluctuating from year to year (Fig. 2) in response to variations in the quantity of water supply from the headwater areas.

Based on the available data we summarised some physico-chemical characteristics of the lake water in the last three decades. Water temperature fluctuated between a minimum of 15 °C and a maximum of 30.4 °C. Measurements of the pH indicate that the water of Lake Nasser is alkaline and favourable for biological processes in general and fish production in particular. The pH value is affected by the phytoplankton photosynthetic activity. Consequently, the pH values of the surface water are mostly above 8.5. However, pH values up to 9.6 were recorded due to the intensive assimilation processes. The lowest pH value (7.73) was observed in autumn 1982 and 1985 at site III. Electric conductivity (specific conductance) was slightly fluctuated throughout the lake with a value of 241±21 μSiemens cm^{-1}.

A gradual decrease of transparency was observed going southward with a minimum of 25 cm in summer 1985 at site IX and 450 cm in spring 1987 at site I. Turbidity gradually increased southward between 5.08 (site I) and 45.8 N.U.T. (site IX).

The minimum value of dissolved oxygen was 4.27 mg l^{-1} (49.8%) in autumn 1982 at site I and it was over saturation in many sites in summer seasons.

Nitrogen concentrations are often low in early spring and late summer, the lowest value was 2.35 μg l^{-1} and the main value is around 25 μg l^{-1} in summer. Higher values between 300 and 400 μg l^{-1} were recorded in deep layers (15–20 m).

The dissolved phosphate and sulphate as well as soluble reactive silica contents remained more or less constant during the last two decades. Phosphate concentrations decrease concomitantly with the increase of the phytoplankton population density. The concentration of phosphate is ranged between undetected level at some sites in summer and about 1 mg l^{-1} at site XI in winter. The concentration of silica was around 1.5 mg l^{-1} and it decreases as a result of the depletion by planktonic diatoms. In regard to major cations, the basic ratio ($Na^+ + K^+$): ($Ca^{2+} + Mg^{2+}$) is generally less than one. The bivalent cation (Mg^{2+}) is positively correlated with the phytoplankton biomass in the lake.

Phytoplankton

Horizontal distributions. The phytoplankton community in Lake Nasser is represented mainly by various algal taxa appertaining to the divisions: Chlorophyta, Bacillariophyta, Cyanobacteria, Dinophyta and Euglenophyta (Table 2). Almost 134 taxa were recorded from the lake during the last two decades. Chlorophyta (54 taxa) contributes more genera to the phytoplankton than any other groups. It is followed by Cyanobacteria (34 taxa), diatoms (33 taxa) and one species of Euglenophyceae. Dinoflagellates are scarce and represented by 12 taxa. Thus, the phytoplankton community structure indicates that it is fairly a diverse community. The most common taxa are those belonging to the genera: *Ankistrodesmus, Lagerheimia* (*Chodatella*), *Crucigenia, Scenedesmus, Desmodesmus, Staurastrum* and *Tetraedron* (Chlorophyceae); *Cyclotella,*

Table 2
List of phytoplankton taxa recorded in Lake Nasser

Cyanobacteria
Anabaena circinalis Rabenhorst ex Bornet et Flahault
Anabaena flos-aquae (Lyngb.) Bréb.
Anabaenopsis circularis (G. S. West) Wołosz. et Miller
Anabaenopsis cunningtonii Taylor
Aphanocapsa elachista W. et G. S. West
Aphanocapsa grevillei (Berkeley) Rabenhorst
Aphanocapsa reinboldii (Richter) Komárek et Anagnostidis
Aphanocapsa sp.
Chroococcus dispersus (Keissler) Lemm.
Chroococcus limneticus Lemm.
Chroococcus minutus (Kütz.) Näg.
Chroococcus turgidus (Kütz.) Näg.
Gomphosphaeria sp.
Merismopedia minima Beck.
Merismopedia punctata Meyen
Merismopedia tenuissima Lemm.
Merismopedia sp.
Microcystis aeruginosa (Kütz.) Kütz.
Microcystis wesenbergii (Komárek) Komárek in Kondrateve
Myxobaktron acicularis Lemm.
Myxobaktron sp.
Planktolyngbya limnetica (Lemm.) Kom. et Cron.
Planktolyngbya sp.
Oscillatoria planctonica Wołosz.
Oscillatoria sp.
Phormidium africanum Lemm.
Phormidium corium (Ag.) Gom.
Phormidium mucicola (Naum. et Huber-Pest.) Schwabe
Phormidium tenue (Ag. ex Gom.) Anag. et Komárek
Phormidium sp.
Snowella lacustris (Chodat) Komárek et Hindák
Spirulina laxissima G. S. West
Spirulina sp.
Woronichinia compacta (Lemm.) Komárek et Hindák
Bacillariophyceae
Amphora ovalis (Kütz.) Kütz.
Aulacoseira distans (Ehr.) Simonsen
Aulacoseira granulata (Ehr.) Simonsen
Aulacoseira granulata var. *angustissima* (O. Müll.) Simonsen
Aulacoseira granulata var. *granulata* f. *valida* (Hust.) Simonsen
Aulacoseira muzzanensis (Meister) Krammer
Cocconeis placentula Ehr.
Cyclotella glomerata Bachmann
Cyclotella kuetzingiana Thwaites
Cyclotella meneghiniana Kütz.
Cyclotella ocellata Pantocsek
Cymbella tumida (Bréb.) Van Heurck
Diploneis sp.

Table 2 (continued)

Epithemia sorex Kütz.
Epithemia sp.
Fragilaria ulna (Nitzch) Lange-Bertalot
Gomphonema gracila Ehr.
Gyrosigma attenuatum (Kütz.) Rabenhorst
Melosira agassizii Ostef var. *malayensis* Hust.
Melosira nyassensis O. Müll.
Melosira nyassensis var. *victoriae* O. Müll.
Navicula pupula Kütz.
Navicula radiosa Kütz.
Navicula sp.
Nitzschia apiculata Greg.
Nitzschia microcephala Grun.
Nitzschia palea (Kütz.) W. Smith
Pleurosigma sp.
Rhopalodia gibba (Ehr.) O. Müll.
Rhopalodia sp.
Stephanodiscus aegyptiacum (Ehr.) S. Meister
Surirella ovalis Bréb.
Synedra tabulata (Ag.) Kütz.
Dinophyceae
Ceratium cornutum (Ehrenberg) Claparède et Lachmann
Ceratium furcoides (Levander) Langhans
Ceratium hirundinella (O. F. Müller) Dujardin
Glenodinium sp.
Gymnodinium lantzchii Utermöhl
Peridiniopsis elpatiewskyi (Ostenfeld) Bourrelly
Peridinium africanum Lemm.
Peridinium pygmaum (Lin.) Bourrelly
Peridinium umbonatum (Stein) Lemm.
Peridinium wierejskii (Wołoszyńska) Lomnickii
Peridinium willei Huitfeld-Kaas
Peridinium sp.
Euglenophyta
Euglena acus Ehr.
Chlorophyta
Actinastrum hantzschii Lagerh.
Ankistrodesmus falcatus (Corda) Ralfs
Ankistrodesmus sp.
Asterococcus limneticus (Cienkowski) Scherffel
Chlamydocapsa planktonica G. et G. S. West
Chlorococcum aegyptiacum Archibald
Closteriopsis longissima (Lemm.) Lemm.
Closterium venus Kütz.
Coelastrum microporum Näg.
Coelastrum reticulatum (Dang.) Senn
Cosmarium contractum Kirchner
Cosmarium depressum Lundell
Cosmarium subtumidum Nadst.
Crucigenia quadrata Morren

Table 2 (continued)

Desmodesmus communis (Hegew.) Hegew.
Dictyosphaerium ehrenbergianum Näg.
Dictyosphaerium elegans Bachmann
Dictyosphaerium pulchellum Wood
Dictyosphaerium subsolitarium Van Goor
Franceia sp.
Golenkinia radiata Chodat
Kirchneriella microscopica Schmidle
Lagerheimia ciliata (Lagerh.) Chodat
Lagerheimia ciliata var *ciliata* (Lagerh.) Lemm.
Lagerheimia longiseta (Lemm.) Wille
Lagerheimia quadriseta (Lemm.) G. M. Smith
Lagerheimia subsalsa var. *subsalsa* Lemm.
Monoraphidium contortum (Thur.) Kom.-Legn.
Monoraphidium convolutum (Cord) Kom.-Legn.
Monoraphidium griffithii (Berk.) Kom.-Legn.
Monoraphidium komarkovae Nyg.
Monoraphidium minutum (Näg.) Kom.-Legn.
Oocystis borgei Snow
Oocystis elliptica W. West
Oocystis lacustris Chodat
Oocystis parva W. et G. S. West
Oocystis sp.
Pediastrum boryanum (Turp.) Menegh.
Pediastrum duplex Meyen
Pediastrum duplex var. *gracillium* W. et G. S. West
Pediastrum simplex Meyen
Pediastrum simplex var. *biwaense* Fukush.
Pediastrum simplex var. *radians* Lemm.
Planktospheria gelatinosa G. M. Smith
Scenedesmus acutus Meyen
Scenedesmus ecornis (Ralfs) Chodat
Scenedesmus obliquus (Turp.) Kütz.
Schroederia setigera (Schröd.) Lemm.
Staurastrum paradoxum Meyen
Staurastrum tetracerum (Kütz.) Ralfs
Staurastrum uniseriatum Nyg.
Tetraedron minimum (A. Br.) Hansg.
Volvox sp.

Aulacoseira, *Fragilaria* and *Synedra* (diatoms) and *Anabaenopsis, Planktolyngbya, Phormidium, Microcystis* and *Oscillatoria* (Cyanobacteria). The data concerning the spatial distribution of phytoplankton standing crop along the main water body of Lake Nasser in different periods during the last two decades are provided in Fig. 3. The phytoplankton densities tend to show relatively higher values in the 1980s (the years of low water levels, Fig. 2) than those in the 1990s that are characterised by the elevation of water level.

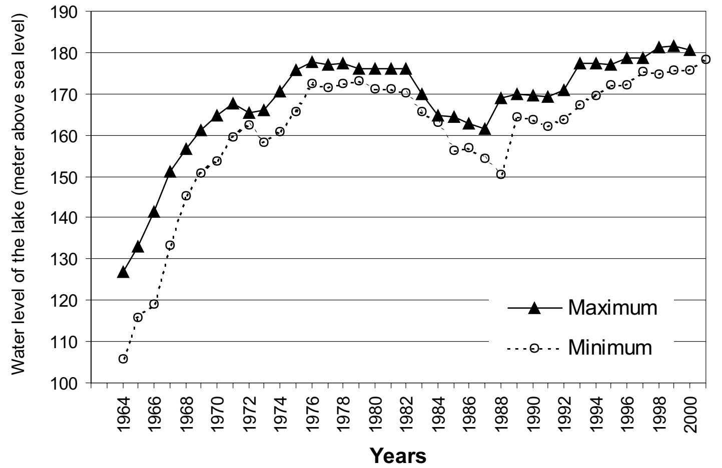

Fig. 2. Maximum and minimum water level (above sea level) between 1964 and 2000 in Lake Nasser

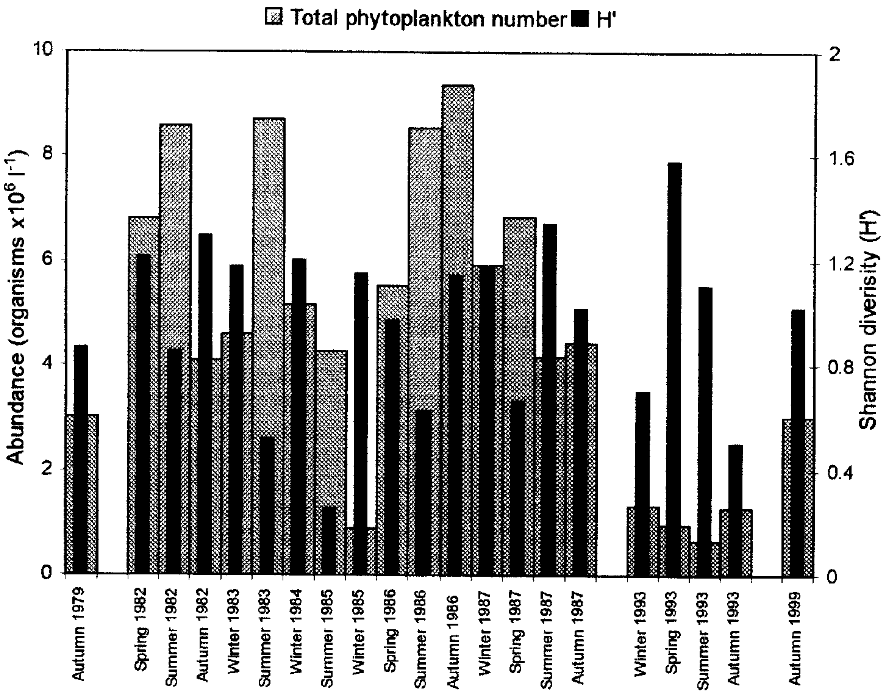

Fig. 3. Changes of the abundance of phytoplankton and Shannon diversity (H′) in different seasons between 1979 and 1999 in Lake Nasser

The Shannon's diversity index did not exceed 1.6 (Fig. 3). Diversity was typically the lowest in summer 1983, 1985, 1986 and 1993, when one or two species of cyanobacteria presented more than 80% of the total counts of organisms. The Shannon index was higher in other seasons, depending on the year. The highest diversity was observed during spring 1993, where the number of individuals was low (Fig. 3).

As far as the seasonal distribution of phytoplankton in the lake is concerned, the main interest is focused on the changes of the relative densities of both diatoms and cyanobacteria. The changes in the phytoplankton of AHDL are shown as variations in the absolute abundance of the phytoplankton groups (Fig. 4). Cyanobacteria presented more than 80% of the total phytoplankton in summer and they were higher than 95% in 1983, 1985 and 1993. Diatoms represented between 60 and 90% of the total counts in springs and winters. In spite of the high number of green algal taxa that exceeded those of any other group of planktonic algae (Table 2), they represented a low number of

Table 3
Time and site of sampling of phytoplankton between 1979–1999 in Lake Nasser

Site number		1	2	3	4	5	6	7	8	9	10	11
Season		I	II	III	IV	V	VI	VII	VIII	IX	X	XI
1	Autumn 1979	+	–	+	+	–	+	–	+	+	+	+
2	Spring 1982	+	–	+	+	–	+	–	+	+	–	+
3	Summer 1982	+	–	+	+	–	+	–	+	+	–	+
4	Autumn 1982	+	–	+	+	–	+	–	+	+	–	+
5	Winter 1983	+	–	+	–	+	+	–	+	+	–	+
6	Summer 1983	+	–	+	+	–	+	–	+	+	–	+
7	Winter 1984	+	–	+	+	–	+	–	+	+	–	+
8	Summer 1985	+	–	+	+	–	+	+	+	+	+	+
9	Winter 1985	–	–	+	+	+	+	+	+	+	+	+
10	Spring 1986	+	–	–	–	–	–	–	–	–	–	–
11	Summer 1986	+	–	–	–	–	–	–	–	–	–	–
12	Autumn 1986	+	–	–	–	–	–	–	–	–	–	–
13	Winter 1987	+	–	–	–	–	–	–	–	–	–	–
14	Spring 1987	+	–	–	–	–	–	–	–	–	–	–
15	Summer 1987	+	–	–	–	–	–	–	–	–	–	–
16	Autumn 1987	+	–	–	–	–	–	–	–	–	–	–
17	Winter 1993	+	+	+	–	+	+	+	+	+	+	+
18	Spring 1993	+	+	+	–	+	+	+	+	+	+	+
19	Summer 1993	+	+	+	–	+	+	+	+	+	+	+
20	Autumn 1993	+	+	+	–	+	+	+	+	+	+	+
21	Autumn 1999	+	–	+	+	+	+	+	+	+	+	+

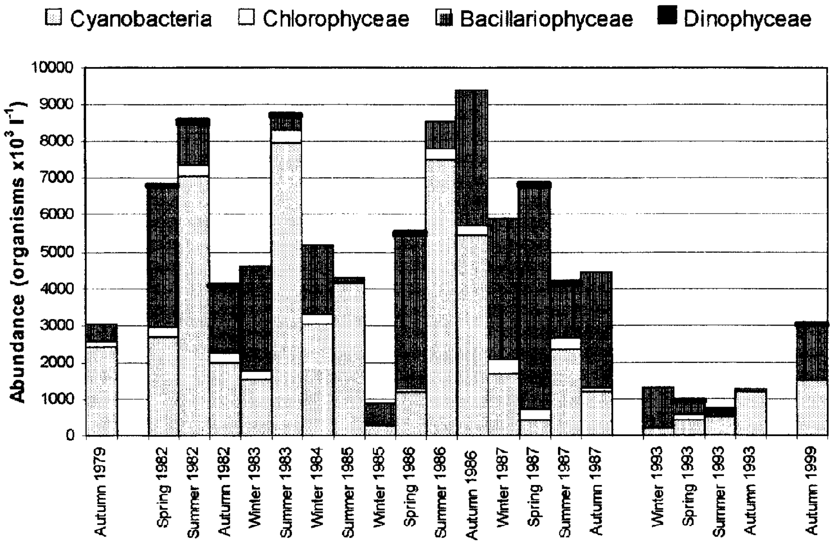

Fig. 4. Changes in the percentage abundance of the different phytoplankton groups in various seasons between 1979 and 1999 in Lake Nasser

organisms, between 2 and 13%. Figure 6 shows that diatoms and cyanobacteria are the dominant groups of the phytoplankton in different seasons

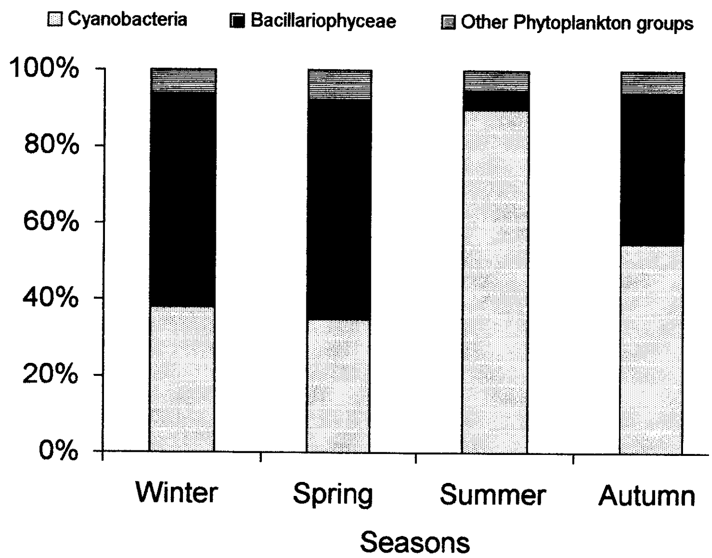

Fig. 5. Seasonal changes of the average of percentage abundance of diatoms, cyanobacteria and other groups of phytoplankton (data is the average of all the investigated seasons from 1979 to 1999)

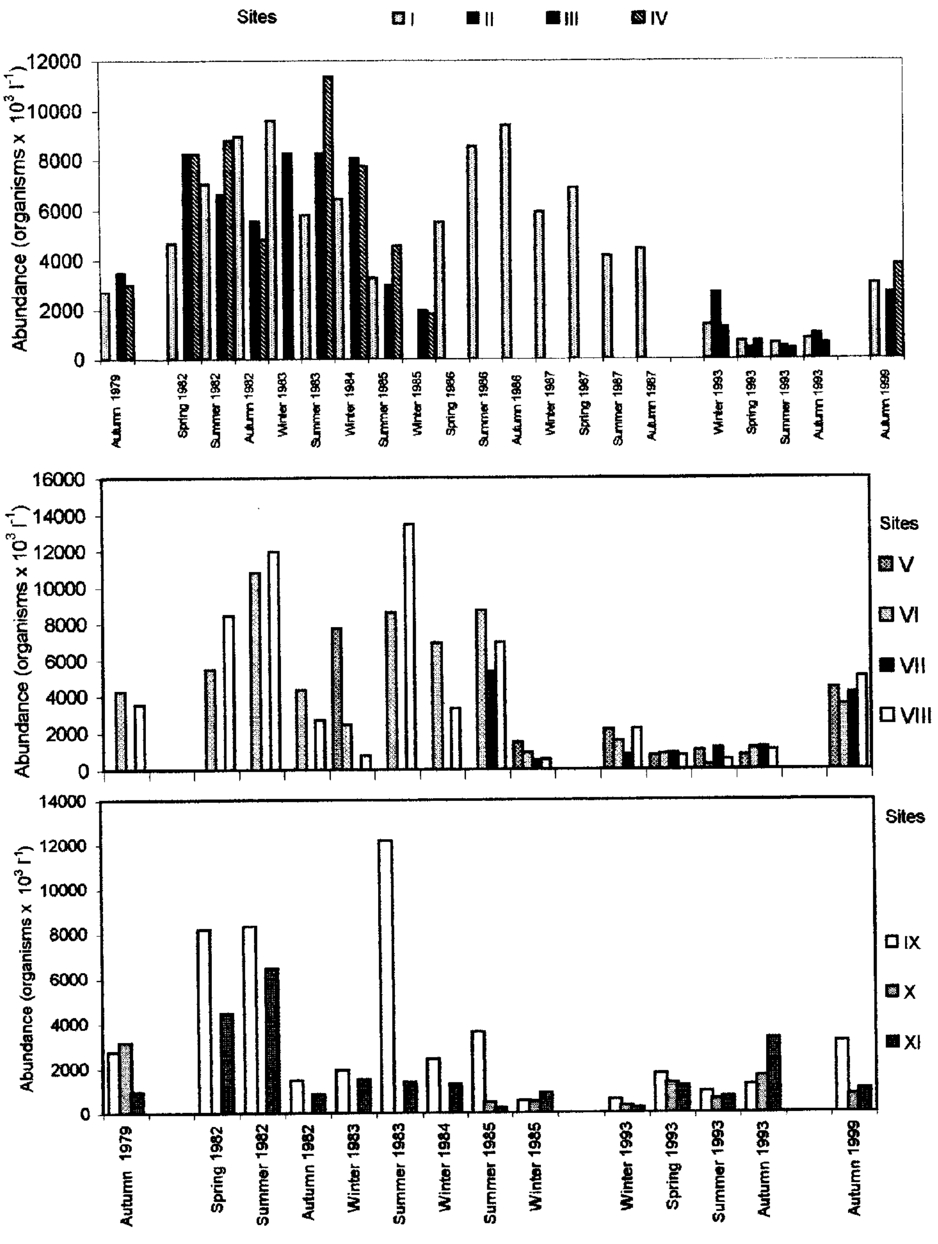

Fig. 6. The distribution of phytoplankton (abundance of organisms $\times 10^3\ l^{-1}$) at different sites in different seasons between 1979 and 1999 in Lake Nasser

(average of all available data during the last two decades). Diatoms tend to be dominant in cold winter and cyanobacteria in summer seasons. This pattern of variations in the phytoplankton composition could be regarded as a possible link to the water temperature. Dinophyceae, if found, was very rear and it was never more than 2% of the total counts of phytoplankton.

In the northern and middle sections of the lake (200 km south to AHD) the phytoplankton densities are always recorded to be of relatively high values (Fig. 6 top and middle). High number of organisms characterised the summer periods with low diversity throughout the lake (Figs 6 and 7) as a result of dominance of genus *Anabaenopsis cunningtonii* (around 85% of Cyanobacteria) in all summer seasons except of summer1993 where *Microcystis aeruginosa* was the dominant species. The counts of organisms were lower in other seasons (Fig. 7A). Slight decreases in the phytoplankton population density could be observed in the southern region (200–300 km south of the AHD, sites IX, X and XI), except spring 1982 and summer 1982 and 1983 (Fig. 6 bottom). The Shannon's diversity values were relatively high in these sites in most seasons (Fig. 7B).

In the samples collected during the flood season of 1999, the spatial distributions of phytoplankton reveal that diatoms and cyanobacteria alternated the dominance of the phytoplankton along the main water body of the lake (Fig. 8). In the northern and middle sections (sites I–V), high relative densities of the cyanobacteria (*Anabaenopsis cunningtonii* 58% and *Phormidium* sp. 33% of the total Cyanobacteria) was observed with a decreasing tendency southward. Conversely, diatoms are the dominant phytoplankton group in the middle-southern section (sites VI–X). *Aulacoseira* (*Melosira*) *granulata* was the dominant species in this section (70% of the total counts of diatoms), whereas it tends to be somewhat of low relative densities in the northern (sites I and III), where *Cyclotella meneghiniana*, *A. cunningtonii* and *Phormidium* sp. were dominant in site I (Fig. 9, left).

Vertical distributions

Concerning the vertical distribution of the phytoplankton standing crop, it is of a special importance to mention that pronounced vertical variations appear during the periods of thermal stratification particularly in spring and summer seasons. Owing to the breakdown of the thermal stratification in winter seasons, only slight irregular variations appear in the vertical distribution with no wide differences between the surface and other depths of water down to a depth of 20 m. Maximum counts of phytoplankton were subsurface (1–3 m depth) in spring and summer seasons. While, the maximum counts of algal species were found at the surface layer of the lake in autumn and winter seasons (Fig. 10). Diatoms and cyanobacteria remain the most influential groups also in the vertical distribution of the phytoplankton in different seasons. In addition, *Cyclotella* and *Anabaenopsis* seem to be the most abundant genera that can influence the depth distribution of the phytoplankton populations in different seasons. *A. cunningtonii* is the main representative taxon of the genus *Anabaenopsis*. *C. meneghiniana* and *C. ocellata* mainly represent the small centric diatom. However, in the samples collected during the flood season of 1999 some spatial variations in the vertical distribution of phytoplankton (Fig. 10, right side) can be observed along the main water body of the lake. It should be noticed that sometimes the diatoms represent the predominant planktonic algae in the southern region of the lake. In this case, chains of the centric diatom *A. granulata* mainly represent the main bulk of the predominant diatom assemblages. This region is significantly affected by floodwater that pushes ahead a great amount of the planktonic diatom *A. granulata* towards the southern part of the lake.

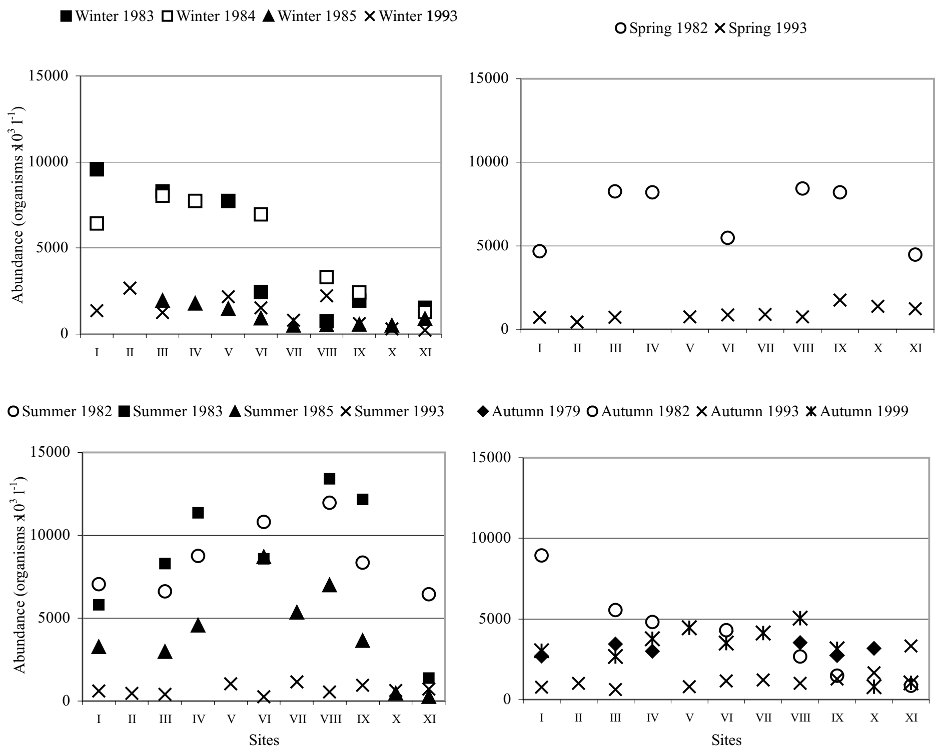

Fig. 7A. Distribution of phytoplankton at different sites in various seasons between 1979 and 1999: (◆) 1979, (❍) 1982, (■) 1983, (❑) 1984, (▲) 1985, (x) 1993 and (Ж) 1999

To determine groups of similar sites and seasons hierarchical classification of the sites and for seasons were performed. The resulting dendrogram of the two decades is shown in (Figs 11 and 12) separates the main water body of the lake into three sections: north (sites I and III), middle (sites IV–IX) and south (sites X and XI). The analysis of sites 2, 5 and 7 (X) gave foul results because the sampling was not done in all investigated seasons (see Table 3, Fig. 11). The resulting dendrogram for seasons (Fig. 11) shows three groups of season: group A, before the flood (summer seasons); group B, between two floods (winters and springs) and group C, time of flood or just after it (autumn periods).

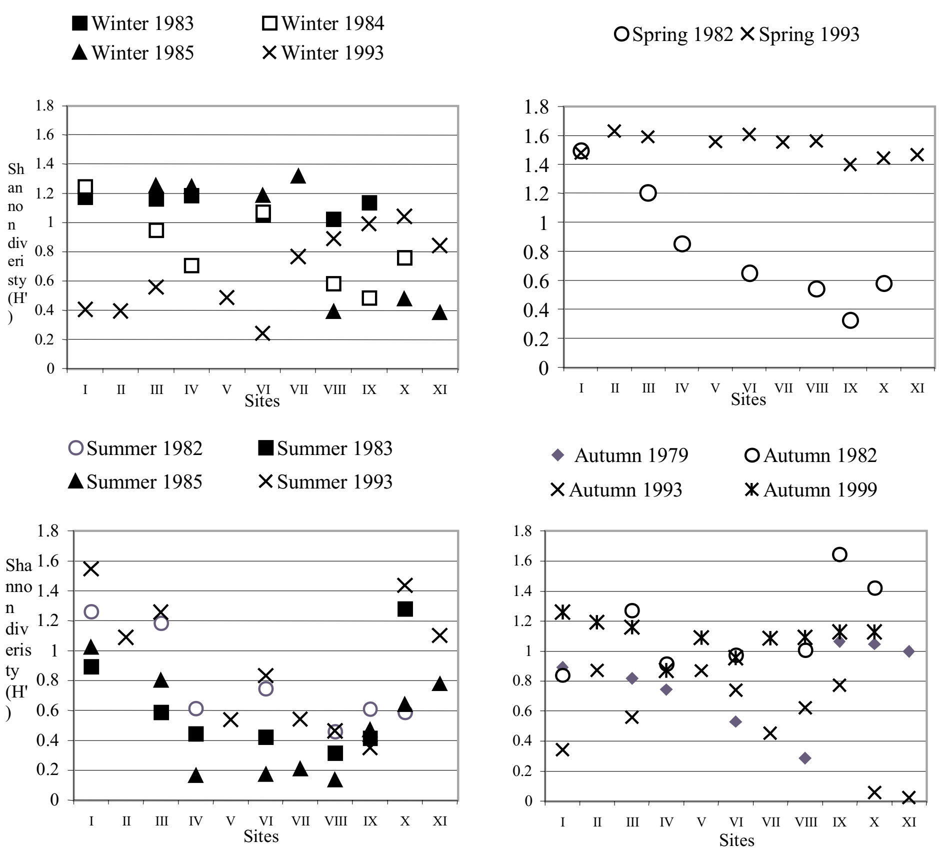

Fig. 7B. Shannon diversity (H′) at different sites in various seasons between 1979 and 1999: (◆) 1979, (❍) 1982, (■) 1983, (❑) 1984, (▲) 1985, (x) 1993 and (Ж) 1999

DISCUSSION

Lake Nasser is a monomictic subtropical lake with a single period of turnover (Entz 1997). The onset of thermal stratification is recorded in the late spring months (Ahmed *et al*. 1989). Pronounced thermal stratification appears in summer seasons (Nessim 1972, Elewa 1976) and in the early autumn months. This stratification is completely destroyed in winter (El-Otify 1991, Abd El-Monem 1995). Water temperature of the lake is less than usual ranges in temperate lakes (Entz 1997).

The water transparency of Lake Nasser is affected by different factors (Ahmed *et al*. 1989) including the floodwater loaded with silt, the development of phytoplankton and wind action. Thus, wide range of variations of water transparency is recorded depending mainly on season and region (Zaghloul 1985). The transparency values were ranged between 30 and 70 cm from 1969 to 1974. In the last two decades the transparency increased in the northern section of the lake. The decrease in transparency in late summer could be due to the increased silt load carried by flood. However, the increase in transparency in the north might be due to the sedimentation and the horizontal currents induced by the transflowing Nile (usually decreasing to 5 cm sec^{-1} or less by the AHD).

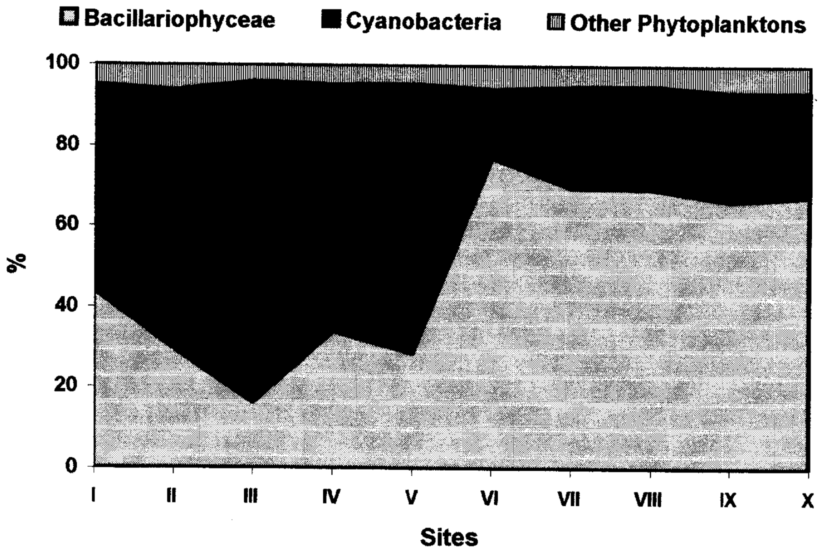

Fig. 8. Percentage contribution of the dominant phytoplankton groups at different sites in Lake Nasser in 1999

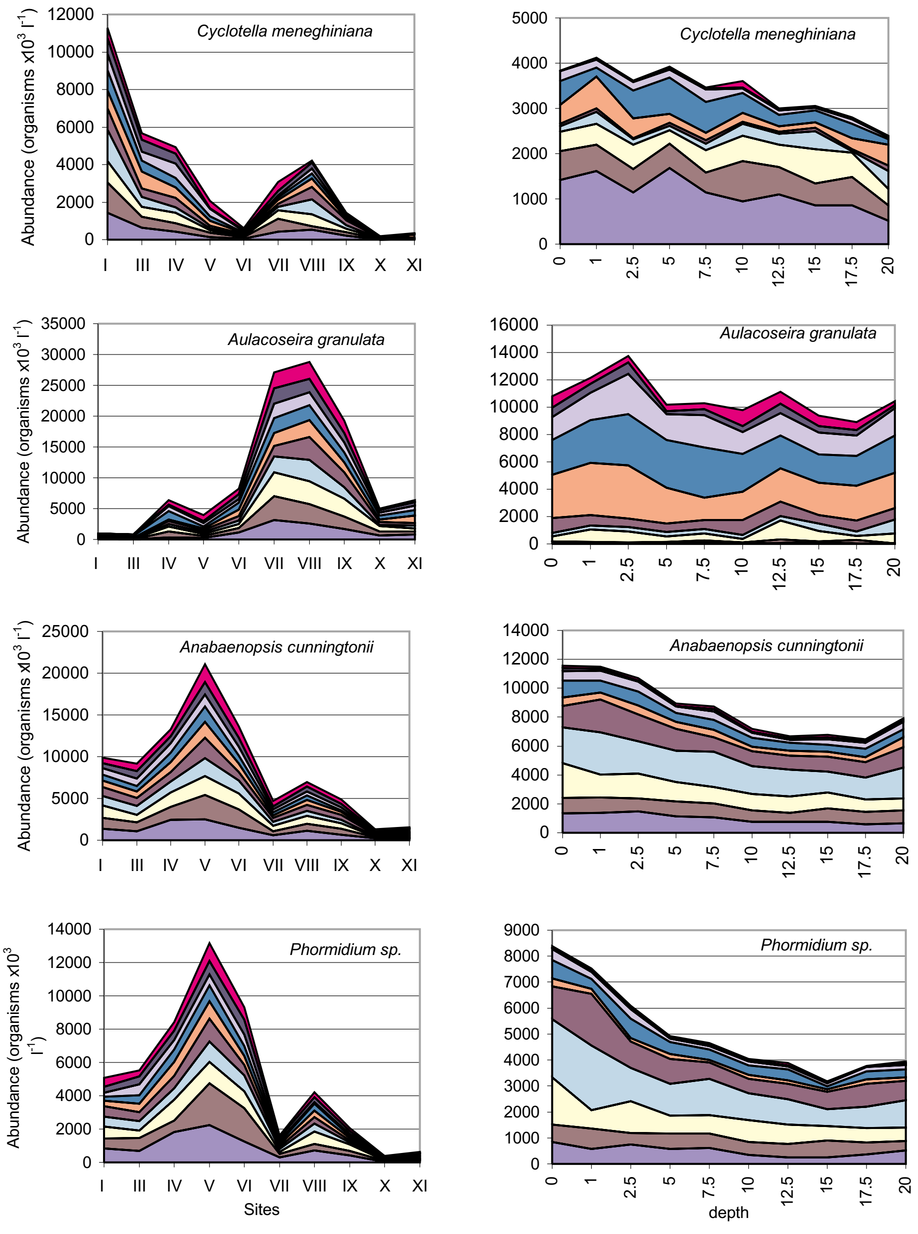

Fig. 9. Spatial horizontal and vertical distribution of the most dominant species of phytoplankton in 1999. In the left-side group, each layer gives the abundance of the indicated species at different depth between 0 and 20 m in each site; and in the right-side group, each layer gives the abundance of the indicated species in sites I, III, IV, XI. at different depth

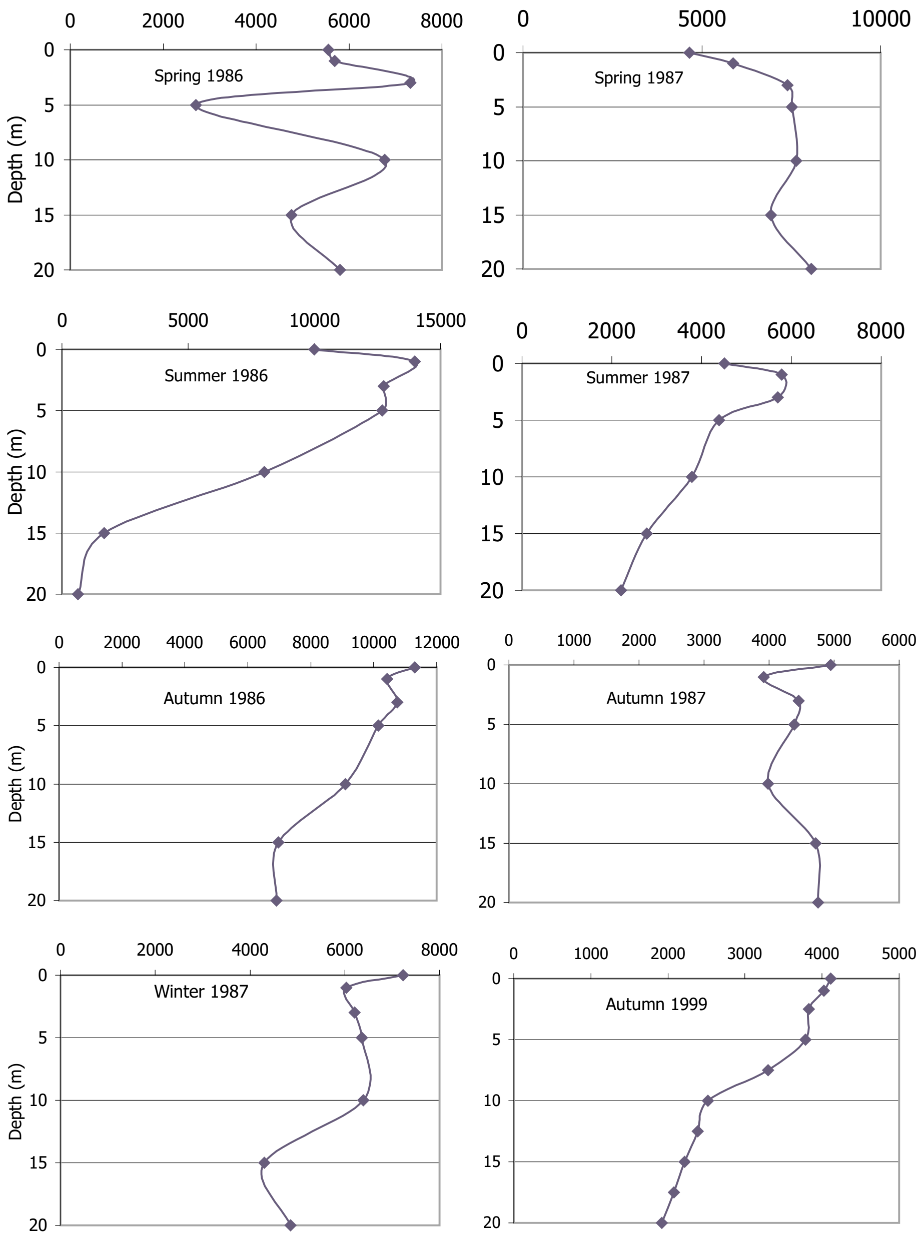

Fig. 10. Seasonal vertical distribution of the abundance of phytoplankton (organism $\times 10^3$ l^{-1}) in years 1986, 1987 and 1999 at site I

Distribution of the dissolved oxygen content varies seasonally, horizontally and vertically (Latif 1984). From April to July under stratified conditions the epilimnion usually shows oxygen supersaturation (up to 160 or 200%) in the lacustrine part of the lake (Entz 1997). Mohammed *et al.* (1989) suggested that oxygen concentrations above the saturation level are often resulted by the assimilation activity of the existing phytoplankton. Thermal stratification coincides with the formation of well-oxygenated epilimnion and an oxygen-free hypolimnion layer (Elewa 1980, Latif and Elewa 1980). Such variations could be attributed mainly to the activity of biological processes that consume or release oxygen. There is a lack of oxygen at the bottom and the deep-water layers for five or seven months.

It seems that Lake Nasser can be classified among lakes with moderate conductivity (Abd El-Monem 1995). The relatively low electric conductivity may be attributed to the low conductivity of the floodwater (El-Shahawy 1975).

The dynamics of the nitrogen cycle in Lake Nasser are complex due to the existence of different forms of dissolved inorganic nitrogen (NH_4, NO_2 and

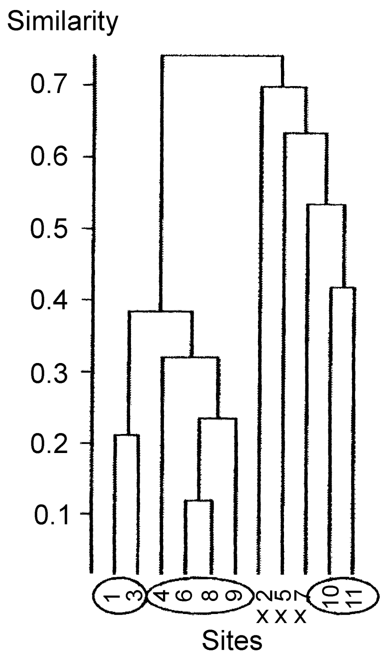

Fig. 11. Dendrogram representing similarity relationships among sites. The three discriminated groups (oval shape) are indicated three various sections in north, middle and south of the two decades in Lake Nasser. The analysis of sites 2, 5 and 7 (X) gave foul results because the sampling was not done through all investigated seasons (see Table 3)

NO_3) which can be interconverted either by bacteria or within other living cells. The floodwater is the main source of nitrate (Talling and Rzóska 1967) which is the predominant form of inorganic nitrogen in the water of Lake Nasser. Spatial and temporal distribution of nitrate-nitrogen are correlated mainly to the incoming flood (Zaghloul 1985) and the phytoplankton development (Mohammed *et al*. 1989). The distribution of the other inorganic nitrogen forms (NH_4 and NO_2) is attributed mainly to nitrification processes that lead to oxidation of ammonia into nitrite and nitrate. In addition, the nitrite concentrations increase as a result of the partial reduction of nitrate by phytoplankton (French *et al*. 1983, Abd El-Monem 1995). Furthermore, the total organic nitrogen contents increase in winter and decrease in summer. This phenomenon is mainly related to the direct fixation of nitrogen gas by the nitrogen fixing bacteria and cyanobacteria as well.

Sulphate concentrations correlated significantly with the chlorophyll *a* contents in Lake Nasser (Abd El-Monem 1995). The deep-water layers have low sulphate levels due to the low oxygen contents that lead to the sulphate reduction into H_2S by bacteria.

Bishai *et al*. (2000) recorded 134 taxa in the lake during the last two decades. The euglenoid algae are very rare occurred and represented only by one species (Zaghloul 1985).

The results show that diatoms and cyanobacteria are the dominant groups of the phytoplankton in different seasons. Indeed, relatively high temperature

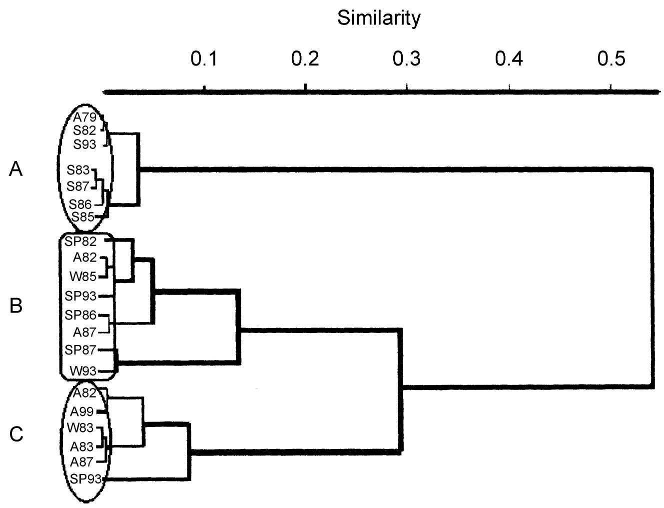

Fig. 12. Dendrogram representing similarity relationships among seasons. The three discriminated groups: group A, summer seasons (S); group B, winter (W) and spring (SP) seasons and group C, autumn seasons with some exception in each group (arrows)

is more suitable for cyanobacteria than for the other groups of phytoplankton (Shafik *et al*. 1997, 2001). Therefore, cyanobacteria are dominant as the water temperature increases in the summer seasons. Many African lakes and reservoirs are dominated by cyanobacteria over extended of the year, possibly due to the "endless summer" conditions typical of Africa (Kilham and Kilham 1990). Diatoms tend to alternate dominance with cyanobacteria (usually *Microcystis*) either seasonally or annually (Talling 1986). Examples are Lake Malawi (Patterson and Kachinjika 1993) and Lake Victoria (Hecky 1993).

Dinophyceae was never more than 2% of the total counts of phytoplankton, i.e. Dinophyceae distinctly missing or quantitatively minor components of Lake Nasser as well as in most lakes of the African Rift Valley (Hecky and Kling 1987). They tend to dominate the less-enriched African water bodies (Zohary *et al*. 1996). Grigorszky *et al*. (2003) suggested that the temperature and organic matter content are the most important factors controlling the distribution of Dinophyceae species.

In general, the diversity index of Lake Nasser was low compared to the shallow, non-stratifying lakes, e.g. Lake Balaton, Hungary (Padisák 1993) and Lake Lobardzu, Latvia (Trifonova 1993). The Shannon index was lower in summer seasons than all other seasons. The highest diversity was observed during spring 1993, where the number of individuals was low (Fig. 3). According to the definition of the equilibrium state (Padisák, in press), the phytoplankton community of the lake might have been in equilibrium state in summer seasons where one or two species represented more than 80% of the total phytoplankton biomass and the Shannon index was low.

The southern region (sites IX–XI) is characterised by somewhat riverine conditions particularly during the flood seasons (Entz 1976). The nutrient-enriched water of Lake Nasser may increase in this part particularly in the regions that are adjacent to the new established project (Abu-Simbel, Tushka region). This enrichment of the water ecosystem can exhibit nuisance blooms. Similarly, some spatial differences in the population type are evident even if the spatial variation in terms of the phytoplankton population density is not significant.

Mass occurrence of cyanobacteria (water blooms) is observed intermittently in Lake Nasser since the early years of its formation. During the 1970s, water colouration due to the extensive water blooms caused mainly by *M. aeruginosa* became common annually for several months before the flood period particularly in the southern area of the lake (Entz 1976, Hamed 2000). The water temperatures exceed 27 °C and the relatively high light intensity may stimulate the bloom forming algae (Resson *et al*. 1994). These conditions may also favour the growth of *Microcystis* (Ha *et al*. 1999). The cell structure of having gas vacuoles enables them to be buoyant during the periods of high water temperature and calm weather (Carmichael 1991). In the 1980s, systematic surveys on the phytoplankton of Lake Nasser have revealed that *M. aeruginosa* was one of the infrequent species (Zaghloul 1985, Mohammed *et al*. 1989, El-Otify 1991). Recently, remote sensing of the surface of the phytoplankton (Landsat 7 Thematic Mapper data of March, 25, 2000 based on GIS) and the spatial data analysis of the satellite image were used for monitoring of water blooms in Lake Nasser (Hamed 2000). It was found that a total area of 169 km^2 was covered by bloom forming cyanobacteria, *M. aeruginosa* was the major species. *Microcystis* is one among the nuisance genera of most problematic and notorious cyanobacteria blooms (Paerl 1996). Extensive surface blooms pose serious water quality and fisheries resource problems, including deoxygenation of hypolimnetic waters, leading to toxicity (H_2S build-ups). It is accompanied by foul odours, undesirable tastes and fish kills in affected water. Nuisance strains can be toxic to algal consumers in the aquatic habitats and animals as well as man utilising affected water for drinking purposes (Carmichael 1991). Food webs in freshwater can be negatively affected due to poor edibility and food quality of bloom species (Holm *et al*. 1983).

A. granulata is an abundant diatom species in the headwater lakes (Lake Victoria, Lake Kiago, Lake Albert and Lake Tana) and also in the White Nile and Blue Nile (Talling 1976). For this reason, the floodwater comes from these headwater lakes is carried high counts of diatoms, especially *A. granulata* which were the dominant species in late autumn and winter at the southern region of the lake. During winter seasons the diatoms were the dominant phytoplankton group in site I. In this site the predominant diatoms were represented by some taxa related to the genus *Cyclotella*. The dominant of genus *Cyclotella* may be a result of high transparency, i.e. high light intensity. Shafik *et al*. (1997) found that high irradiance does not inhibit the growth of *Cyclotella meneghiniana*, while inhibit the growth of some cyanobacteria (Shafik *et al*. 2001). For this reason, the phytoplankton may be growing at the surface of the lake (the maximum counts of phytoplankton were recorded) in autumn and winter seasons (Fig. 10).

The cluster analysis of the results of spatial and temporal distribution of the phytoplankton of the lake separates the main water body into three sections: north (sites I and III), middle (sites IV–IX) and south (sites X and XI). The last section has somewhat riverine conditions, especially during the flood seasons, while the other two sections have lacustrine conditions. Sites I and III more deeper than that sites of middle section (sites IV, VI, VIII and IX) and characterised by good light conditions where the transparency is mostly higher. This gives advantage for the growth of diatoms over cyanobacteria. The analysis of sites 2, 5 and 7 (X) gave foul results because the sampling was not done in all investigated seasons (see Table 3, Fig. 11). In addition, there were some exceptional seasons included in each group. Such spatial variations can be related to different environmental factors such as current speed, grazing by zooplankton, fish and other animals as well as variations in nutrient contents.

The resulting dendrogram for seasons (Fig. 12) shows three groups of season: group A, before the flood (summer seasons); group B, between two floods (winters and springs) and group C, time of flood or just after it (autumn periods).

CONCLUSIONS

The dominance of phytoplankton groups is mainly between cyanobacteria and diatoms. Chlorophyta and Dinophyta never presented more than 14% of the total phytoplankton. The main factors effecting the distribution of the phytoplankton standing crop are 1: the floodwater comes from the head water lakes, 2: the seasonal change of the temperature water and 3: the water level in the lake, which is mainly effected by the floodwater.

Accordingly, the distribution of phytoplankton can be classified to three periods:

1 – before the flood (summer season) – most part of the lake is covered by Cyanobacteria and the major species are *Microcystis aeruginosa*, *Anabaenopsis cunningtonii* and *Phormidium* sp.

2 – during the time of flood (late summer and autumn) – the lake can be divided into four mean sections: (i) sites just behind the AHD show a balance between diatoms (*Cyclotella* spp.) and Cyanobacteria (*Anabaenopsis cunningtonii* and *Phormidium* sp.); (ii) the north section (100 km from the dam) is characterised by dominance of Cyanobacteria; (iii) the middle section (100–200 km) shows alternation in prevalence between diatoms (*Aulacoseira granulata*) and cyanobacteria (*Anabaenopsis* sp.); and (iv) the south section where the diatom *Aulacoseira granulata* is the abundant species.

3 – after the flood (winter and spring seasons) – diatoms (*Aulacoseira* spp. and *Cyclotella* spp.) group is more abundant than other groups of phytoplankton.

The diversity index in Lake Nasser is low compared to other lakes especially in summers.

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