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SPATIAL VARIATION OF PHYTOPLANKTON AND SOME PHYSICO-CHEMICAL VARIABLES DURING THE HIGHEST FLOOD SEASON IN LAKE NASSER (EGYPT)

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ABSTRACT

Species composition, abundance, and phytoplankton biomass in Lake Nasser were studied during the highest flood season in autumn 1999, and were supported by some physico-chemical environmental parameters. The nutrient salts levels were low to medium, with ranges of 0.96-9.92 μg/L for nitrite, 20.14-72.14 μg/L for ammonia, complete depletion -27.69 μg/L for phosphate, and 5.83-9.00 μg/L for silicate. A total of 71 taxa were identified, of which 46% were chlorophytes, 26% bacillariophytes and 22% cyanophytes. Phytoplankton abundance and biomass values were higher in the northern stations than in the southern, but were lower than previously reported, indicating approaching from oligomesotrophic status, with,respectively, means of 108.9 x 10^4 unit/L and 1.18 mg/L for the main channel, and 712 x 10^3 unit/L and 1.229 mg/L for the khors. Bacillariophyceae was the most important group, constituted 80% and 64% of total abundance and 61% and 51% of total biomass in the main channel and khors, respectively. *Cyclotella* and *Melosira* were the most abundant genera. Cyanophyceae second in importance, forming 11.6% and 16.8% of total abundance and 34.6% and 42.9% of total biomass in the main channel and khors, respectively. *Phormidium* and *Anabaenopsis* were the most frequent genera. Highest species diversity (2.42) and evenness (0.92) were recorded in Tushka, and highest richness (2.52) was recorded in El- Ramla. The statistical regression models performed showed that the most physico-chemical factors affecting the growth of phytoplankton abundance were pH values, dissolved phosphate and reactive silicate.As a whole, a declining in phosphorus concentration, phytoplankton abundance and biomass and development of *Cyclotella* and *Melosira* are approching the lake oligomesotrophic status.

1. INTRODUCTION

Building a dam across a river, and impounding water behind it, may cause profound changes in the limnological regime of the waterbody. These may include chemical and physical changes, in turn affecting the flora and fauna of the regulated waterbody. The trophic conditions of the waterbody may be revealed by the associations of the phytoplankton species (Reynolds, 1997). When these data are related with the environment's abiotic parameters, such as, pH, electrical conductivity, water nutrient concentrations and other external physical disturbances as water mixing, storms and floods, all these must be taken into account when considering the reasons for phytoplankton composition and distribution (Jacobsen and Simonsen, 1993).

The High Dam Lake is one of the largest man-made lakes in Africa and the second in area after Lake Volta in Ghana. It was created after the construction of Aswan High Dam in southern Egypt in 1964. The reservoir consists of two parts, Lake Nasser in Egypt and Lake Nubia in Sudan. Lake Nasser extends for about 300 km in Egypt between 22° 00` to 23° 58` N and 31° 30` to 33° 15` E, constituting about 84% of the surface area of the total High Dam reservoir basin (Fig. 1). One of the main features of Lake Nasser is the presence of side extensions, lagoons, locally named khors. These khors cover about 79% of the total lake surface area. Kalabsha and Tushka are the widest khors with gentle slopes while khor Korosko is steep and relatively narrow (Latif, 1984). The khors play a major role for fishes, in particular, tilapias which use khors as favourite habitats (El-Shabrawy and Dumont, 2003). There is a regular annual rhythmic fluctuation in water level caused by the Nile flood which usually occurs in late summer- early autumn. The water level in Lake Nasser is subjected to dramatic changes from one year to another due to the fluctuations in amount of flood water. During the flood season of 1999, the water level increased remarkably to 181.6 m above sea level, which is considered the highest record since the construction of the High Dam 1964 (Fig. 2). Lake Nasser water level data were kindly provided by the High Dam Lake Authority.

However, little is known about the ecology of phytoplankton as well as seasonal succession along the main channel and the main khors (Samaan and Gaber 1976; Zaghloul 1985; Abd El-Monem 1995 and Touliabah *et al.,* 2000).

The purpose of the present study was to describe quantitatively and qualitatively the phytoplankton abundance and biomass, complemented by some other physical and chemical data during the highest water level reached in a flood period during autumn 1999.

2. MATERIALS AND METHODS

Samples were collected during November 1999, from 7 stations along the main channel and 3 stations were selected in the largest khors: Kalabsha, Tushka and Korosko (Fig. 1). Water samples were collected by Niskin bottles sampler of capacity 3L, attached to a nylon cable at various depths including 0,5,10 and 20m.

Secchi disk of 25 cm diameter is adopted for measuring water transparency. Water temperatures were measured with an ordinary thermometer graduated to 0.01°C fixed in the water sampler. The pH and the electrical conductivity were measured in situ using portable glass electrode pH – conducti – meter (Type: HANAA instrument). Dissolved oxygen was estimated by the modified Winkler method, nitrite, ammonia, phosphate and silicate were determined spectrophotometrically (Strickland and Parson, 1968).

Phytoplankton water samples were immediately preserved in Lugol's iodine solution and were carried out using sedimentation technique as reported in the standard methods (A.P.H.A.1985), and expressed in unit per liter. Phytoplankton biomass was calculated from recorded abundance and specific biovolume estimates, based on simple geometric solids (Rott, 1981) and assuming unit specific gravity.

For phytoplankton identification, the following references were used: Mizuno (1990); Starmach (1974); Khunnach (1967); Huber-Pestalozzi (1938) and Heurck (1896).

The euphotic depth was estimated from Secchi disk reading using the relationship $Z_{eu} = 4.8 \text{ x } Z_s^{0.68}$ computed by Salmaso (2002), where Z_{eu} is the euphotic depth and Z_s is the Secchi disk depth.

Species diversity was estimated by Shannon-Wiener index (Shannon and Weaver, 1963), species richness by Margalef (1968) and equitability by Heip (1974). Statistical analysis including correlation coefficient between phytoplankton abundance, biomass and physico-chemical parameters were calculated (n = 38).

Stepwise multiple regression equations at a confidence limit 95% (P = 0.05) were performed using the statistical computer program Number Crunchier Statistical System (NCSS) by Hintze (1993).

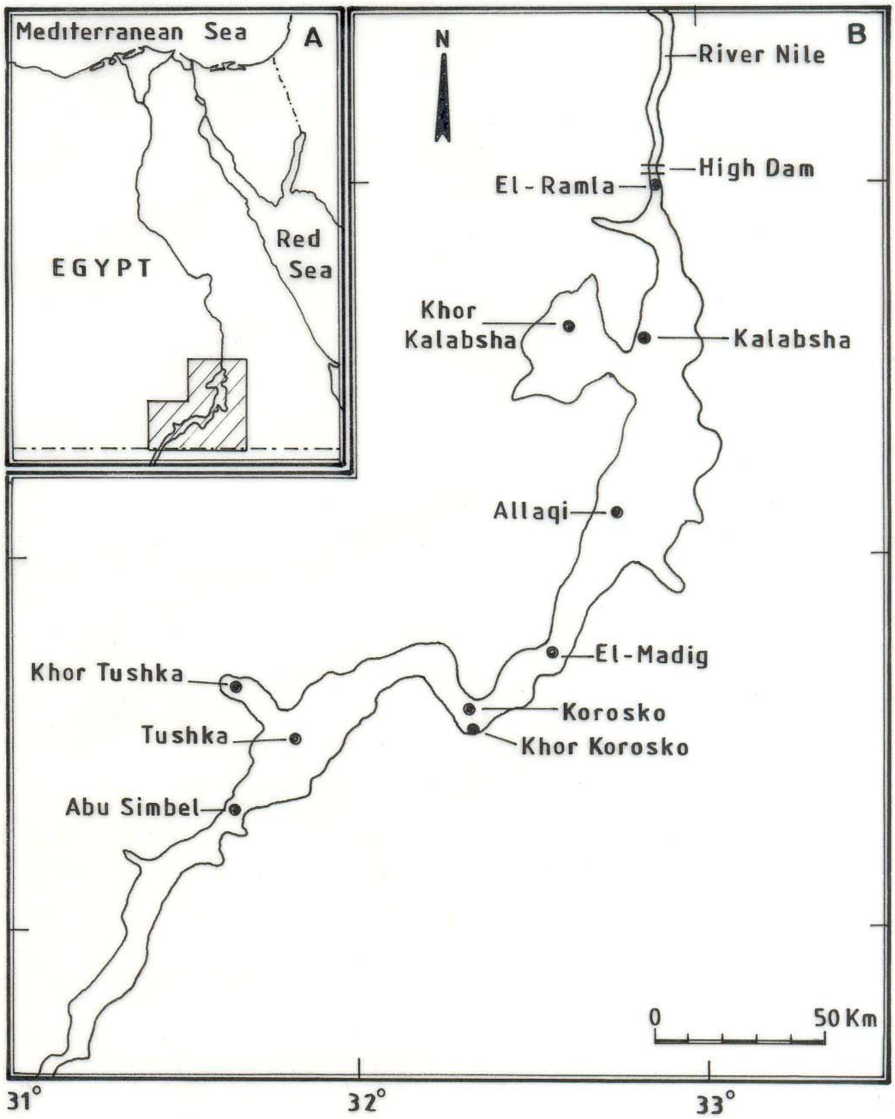

Fig. (1): A. Site of Aswan High Dam reservoir in Egypt and Sudan.
B. Lake Nasser, identifying the sampling locations.

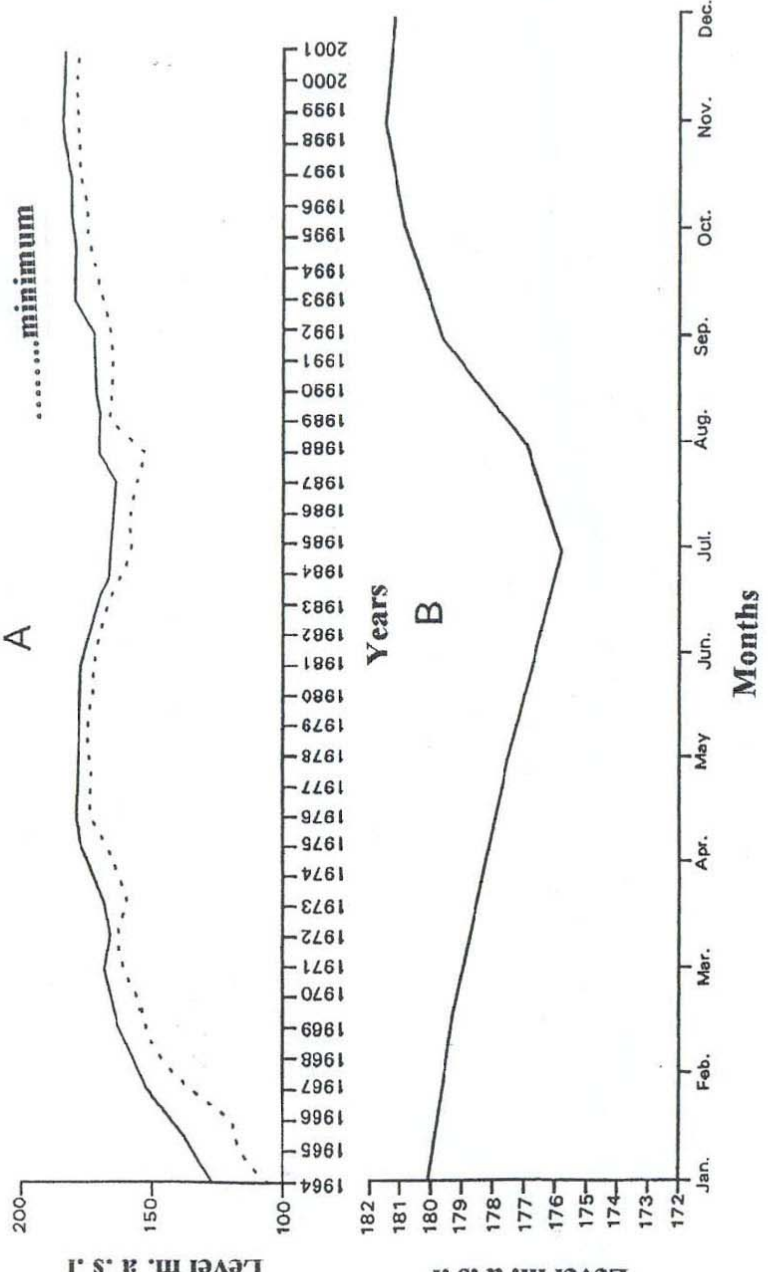

Fig. (2): Water level in Lake Nasser. A : Annual fluctuations during the period 1964-2001, B: Monthly fluctuations during 1999.

3.RESULTS AND DISCUSSION

3.1. Physical and chemical features

Lake Nasser is a warm monomictic with a single circulation period during winter between November and March (Entz, 1976). A thermocline becomes established in summer, with a maximum vertical difference of 13°C (Abd Allah, 1994). Homothermy, with temperatures around 2.7°C on the whole water column (Fig. 3). The water of the downstream stations (El-Ramla and Kalabsha) was more transparent than that upstream (Abu Simbel and Tushka) because the southern stations were mostly affected by the turbidity of the flood season. Transparency depth ranged between 1.5m (Abu Simbel) and 3.55 m (Allaqi). The transparency in the khors is normally slightly less than in adjacent open water areas due to abundant suspended organic materials. Khors Tushka and Korosko were highly affected by the turbid flood water than khor kalabsha. The thickness of the euphotic zone was usually less than 10 m, except for Kalabsha, Allaqi and khor kalabsha where the euphotic zones were about 11 m.

PH values were always on the alkaline side and varied from 8.04 to 8.98. The highest pH value was recorded at El-Madiq and was related to the increased phytoplankton density (273.7 x 10^4 unit/L). PH values showed no major variations from surface to bottom (Fig. 3).

Lake Nasser was well oxygenated from surface to bottom. The euphotic zone usually exhibited dissolved oxygen (DO) above 7 mg/L (Fig. 3). In the main channel, DO ranged between 9.8 mg/L (El-Madiq) and 6.96 mg/L (Tushka), and in the khors DO ranged between 9.24 mg/L (khor korosko) and 6.91 mg/L (Khor Tushka). Due to their common dependence on photosynthetic processes, dissolved oxygen and pH showed a close linear correlation ($r = 0.76$, $P < 0.001$). Furthermore, oxygen exhibits a close correlation with phytoplankton abundance ($r= 0.71$, $P < 0.001$) and phytoplankton biomass ($r = 0.54$, $P < 0.001$). A similar relationship was also observed between pH and phytoplankton abundance ($r = 0.84$, $P < 0.001$) and phytoplankton biomass ($r = 0.58$, $P < 0.001$).

Lake Nasser is fed by River Nile water heavily loaded with inorganic clay, silt, sand and organic detritus and therefore increasing conductivity. The highest conductivity (250 µS/cm) was measured at Kalabsha and the lowest (230 µS/cm) at Abou-Simbel. Average conductivity values showed increasing trend northward. The same observation was recorded by Latif (1984) and Touliabah *et al.* (2000). The decrease in conductivity is linked to the precipitation of calcium carbonate which is mainly caused by algal CO_2 depletion and secondarily, by higher temperatures (Salmaso and Decet, 1998). Latif (1984) recorded conductivity up to 300 µS/cm at the High Dam and Kalabsha in November 1970.

In the upper 10m., nitrite concentrations ranged between 0.96 and 9.92 µg NO_2/L, with a mean of 3.98 µg NO_2/L for the main channel and between 2.24 and 7.04 µg NO_2/L, with a mean of 4.56 µg NO_2/L for the khors (Fig. 3). The mean nitrite value for the main channel was 10 µg NO_2/L during 1988 (Ali *et al.*, 1995) and 3.4 µg NO_2/L during autumn 1993 (Abd El-Monem, 1995). As for ammonia, the highest absolute value (72.14 µg NH_4/L) was recorded at Allaqi and the lowest (20.19 µg NH_4/L) at Tushka , with a mean of 37.82 µg NH_4/L for the main channel and between 24.29 µg NH_4/L (Khor Tushka) and 78.57 µg NH_4/L (Khor Korosko), with a mean of 45.1 µg NH_4/L for khors.

In the upper 10 m, soluble reactive phosphate concentrations ranged between compete depletion (El-Ramla and Kalabsha) and 27.69µg PO_4/L (Abu-Simbel), with a mean of 7.24 µg PO_4/L for the main channel, and between complete depletion and 21.54 µg

PO_4 /L, with a mean of 11.54 μg PO_4/L for khors. Generally, phosphate concentrations increased southward and showed a weak negative correlation with phytoplankton biomass ($r = -0.36, P \leq 0.05$).

Soluble reactive silicate concentrations were always above 6.0 μg SiO_4/L, but with a narrow oscillation between different stations and through the water column (Fig. 3). The concentrations of silicate are likely to the intense assimilation by diatoms which strongly developed in the euphotic zone ($r = -0.49, P \leq 0.05$).

The concentrations of reactive phosphate and silicate were much reduced when compared with previous data collected during 1981 by Zaghloul (1985) that found reactive phosphate ranged between 70 and 520 μg PO_4/L and reactive silicate between 10 and 35 mg SiO_4/L; and data collected during 1988 by Ali *et al.* (1995) that found reactive phosphate ranged between complete depletion and 1200 μg PO_4/L, with a mean of 160 μg PO_4 /L.

3.2. Phytoplankton density and species composition

Seventy one taxa belong to five divisions of phytoplankton were identified from samples at seven stations and four different depths in the main channel of Lake Nasser, during autumn 1999 (Table 1). Chlorophyta was the most diversified group (33 taxa), followed by Bacillariophyta (19), Cyanophyta (16), Dinophyta (2) and only one species belong to Euglenophyta.

The number of taxa in the three selected khors (Kalabsha, Tushka and Korosko) decreased to 58 taxa, out of these, 25 belong to Chlorophyta, 16 to Bacillariophyta, 15 to Cyanophyta and 2 to Dinophyta. The present results exhibited higher species diversity than that reported in the four seasons of 1981 (45 species) by Zaghloul (1985) and lower than that recorded (116 species) over three seasons (winter, summer and autumn) during 1998 by Touliabah *et al.* (2000).

The phytoplankton density in the euphotic zone of the main channel ranged from 245 x 10^3 unit/L (Toushka at 5m.) to 273.7 x 10^4 unit/L (El-Madiq, surface layer) with a mean of 108.9 x 10^4 unit/L, and in terms of biomass ranged from 0.107 mg/L (Toushka at 5m) to 1.937 mg/L (Kalabsha, surface layer), with a mean of 1.180 mg/L.

In the khors, the phytoplankton density ranged from 25.1 x 10^4 unit/L (Khor Toushka at 5m.) to 136.6 x 10^4 unit/L (Khor Korosko, surface layer), with a mean of 71.2 x 10^4 unit/L, and in terms of biomass ranged from 0.251 mg/L (Khor Toushka, surface layer) to 2.527 mg/L (Khor Korosko, surface layer), with a mean of 1.229 mg/L. The phytoplankton abundance and biomass showed pronounced high occurrence in the euphotic zone than in the non euphotic layer (Figs. 4, 5, 6).

Although the water transparency in the selected stations was less than 3.5 m, and the Secchi depth is about one third of the euphotic zone (Salmaso, 2002), phytoplankton distributed throughout the water column and some groups can change their positions within their environment in a variety of ways.

As previously recorded by Zaghloul (1985), seasonal phytoplankton abundance and biomass values in the main channel during 1981 were, respectively, 601.6 x 10^4 unit/L, 27.26 mg/L in winter; 386 x 10^4 unit/L, 15.75 mg/L in spring; 849.1 x 10^4 unit/L, 15.12 mg/L in summer; and 544.9 x 10^4 unit/L, 7.95 mg/L in autumn. The abundance of phytoplankton decreased during 1993 to an average of 132.7 x 10^4 unit/L in winter; 92.9 x 10^4 unit/L in spring; 75.9 x 10^4 unit/L in summer and 139.8 x 10^4 unit/L in autumn (Abd El-Monem, 1995). These values were reduced to 108.9 x 10^4 unit/L and 1.180 mg/L in the present study (autumn, 1999).

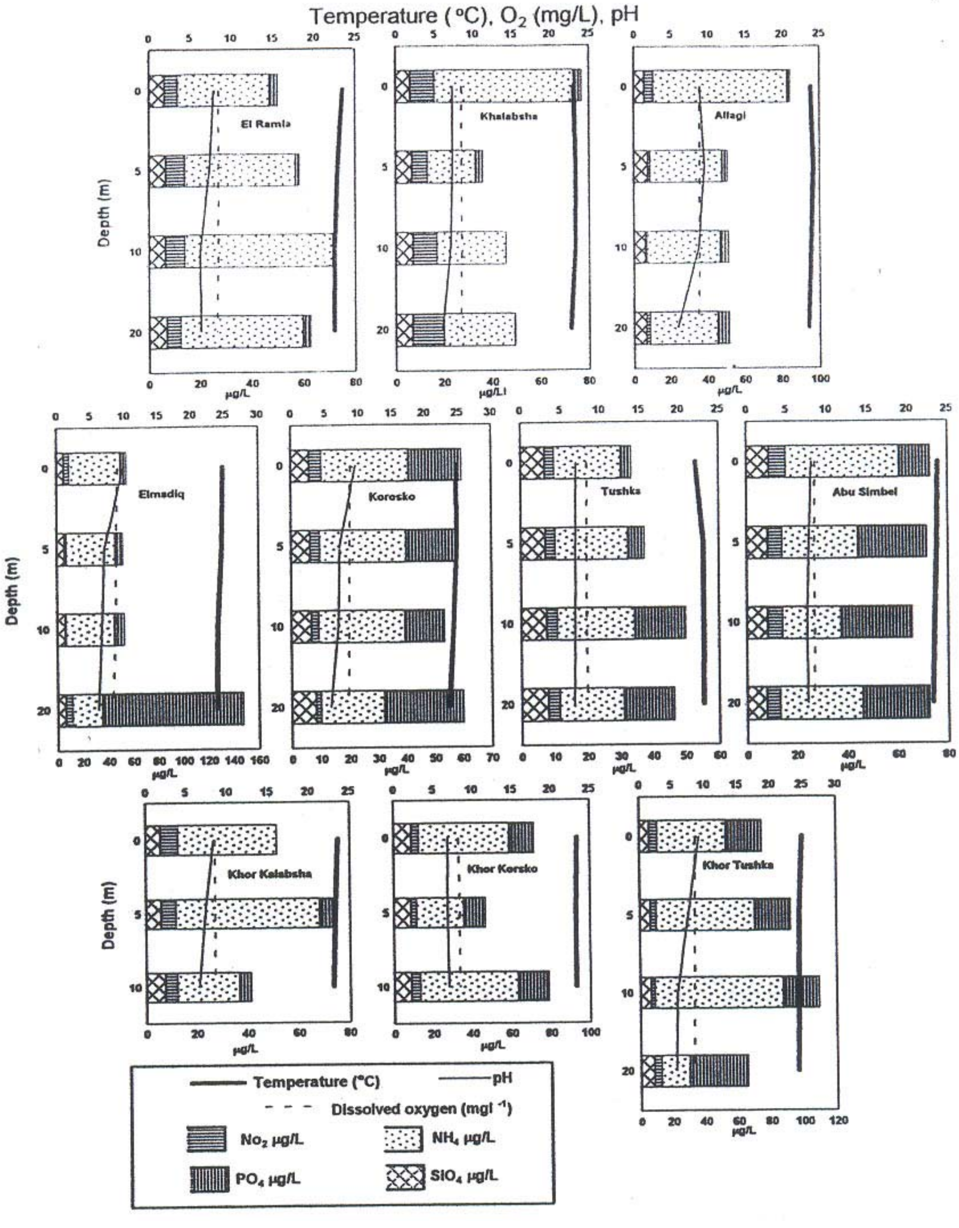

Fig. (3): Vertical profiles of temperature, pH, dissolved oxygen, nitrite, ammonium, reactive phosphate, and soluble silicate in the different stations of Lake Nasser during Autumn, 1999.

Table (1): List of phytoplankton taxa identified in the main channel and khors of Lake Nasser during autumn 1999 (+ present, - absent).

Phytoplankton taxa	main channel	Khors
Chlorophyceae		
Ankistrodesmus falcatus (Corda) Ralfs	+	+
Ankistrodesmus falcatus (Corda) Ralfs var.*mirabile*W. & G.S. West	+	-
Ankistrodesmus setigerus (Schrod) G.S. West	+	+
Ankistrodesmus spiralis (Turpin) Lemm.	+	+
Characium sp.	+	+
Chodatella subsala Lemm.	+	+
Chloroccum sp.	+	+
Closterium acutum Breb.	+	-
Closterium parvulum Naeg.	+	+
Coelastrum microporum Naeg.	+	+
Cosmarium polygonum Naeg.	+	-
Crucigenia rectangularis (A. Braum) Gay.	+	+
Crucigenia quadrata Morren.	+	+
Gloeocystis gigas (Kutz) Lag.	+	+
Golenkinia radiata Chodat.	+	+
Gonium sociale Warm.	+	-
Kirchneriella lunaris (Kirch.) Moeb.	+	+
Micractinium radiatum (Chodat) Wille	+	-
Micractinium sp.	+	-
Oocystis borgei Snow	+	+
Oocystis solitaria Wittr.	+	+
Pandorina morum (Mull.) Bory.	+	-
Pediastrum clathratum (A. Braun) Lag.	+	+
Pediastrum simplex Meyem	+	+
Planktosphaeria gelatinosa G.M.Smih.	+	-
Scenedesmus dimorphus Turp.	+	+
Scenedesmus quadricauda (Turp.) Breb.	+	+
Schroederia setigera (Schroed.) Lemm.	+	+
Selenastrum gracile Reinsch.	+	+
Sphaerocystis schroeteri Chodat.	+	+
Staurastrum tetracerum Ralf.	+	+
Tetraedron minimum (A. Br.) Hansg.	+	+
Tetraedron muticum A. Braun.	+	+

Table (1): continued

Bacillariophyceae:		
Achnanthes lanceolata Breb.	+	+
Amphora ovalis Kutz	+	+
Bacillaria paradoxa G.F. Gmel.	+	-
Cocconeis placentula Ehr.	+	+
Cyclotella meneghiniana Kutz.	+	+
Cyclotella ocellata Pantocsek.	+	+
Cymbella turgida Greg.	+	+
Gomphonema olivaceum (Lyngybe) Kutz.	+	+
Melosira crucipunctata Bachm.	+	+
Melosira granulata (Ehr.) Ralfs	+	+
Melosira granulata Kutz var.*angustissima* Muller	+	+
Navicula cryptocephala Kutz.	+	+
Navicula placentula Ehr.	+	+
Navicula sp.	+	-
Nitzschia palea (Kutz) Wm.	+	+
Nitzschia sigma Wm. Sm.	+	-
Rhopalodia gibba Ehr.	+	+
Synedra acus kutz	+	+
Synedra ulna (Nitzsch.) Ehr.	+	+
Cyanophyceae:		
Anabaenopsis cunningtonii Taylor.	+	+
Aphanocapsa pulchra (kg.) Rbh., Pl. G.M. Smith.	+	+
Chroococcus dispersus (Kelssl.) Lemm.	+	+
Chroococcus dispersus var. *minor* G.M. Smith.	+	+
Chroococcus turgidus (kg.) Naeg., G.M. Smith.	+	+
Goelosphaerium sp.	+	+
Gomphosphaeria lacustris Chod., G.M. Smith	+	+
Lyngbya limnetica Lemm.	+	+
Merismopedia punctata Meyen	+	+
Microcystis aeruginosa kg.	+	+
Microcystis sp.	+	+
Oscillatoria limnetic Lemm.	+	+
Phormidium tenue Menegh.	+	+
Phormidium sp.	+	+
Raphidiopsis curvata Fritsch & Rich.	+	+
Spirulina laxissima G.S. West.	+	-
Dinophyceae		
Ceratium hirundinella (O.F. Mull.) Bergh.	+	+
Peridinium sp.	+	+
Euglenophyceae		
Euglena granulata (Klebs.) Lemm.	+	-

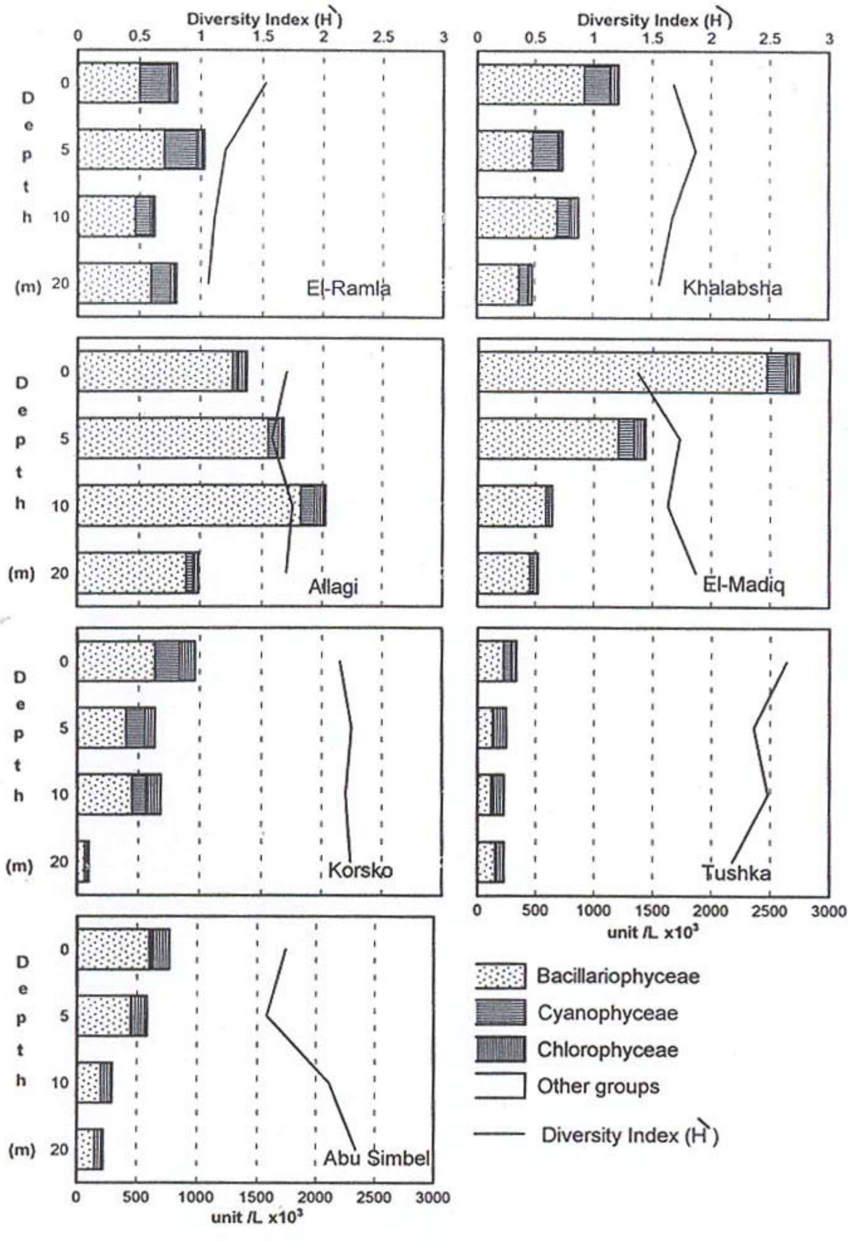

Fig. (4): Vertical profile of phytoplankton abundance (unit/L x 10^3) subdivided by algal groups and species diversity index of the different station of the main channel of Lake Nasser during Autumn 1999.

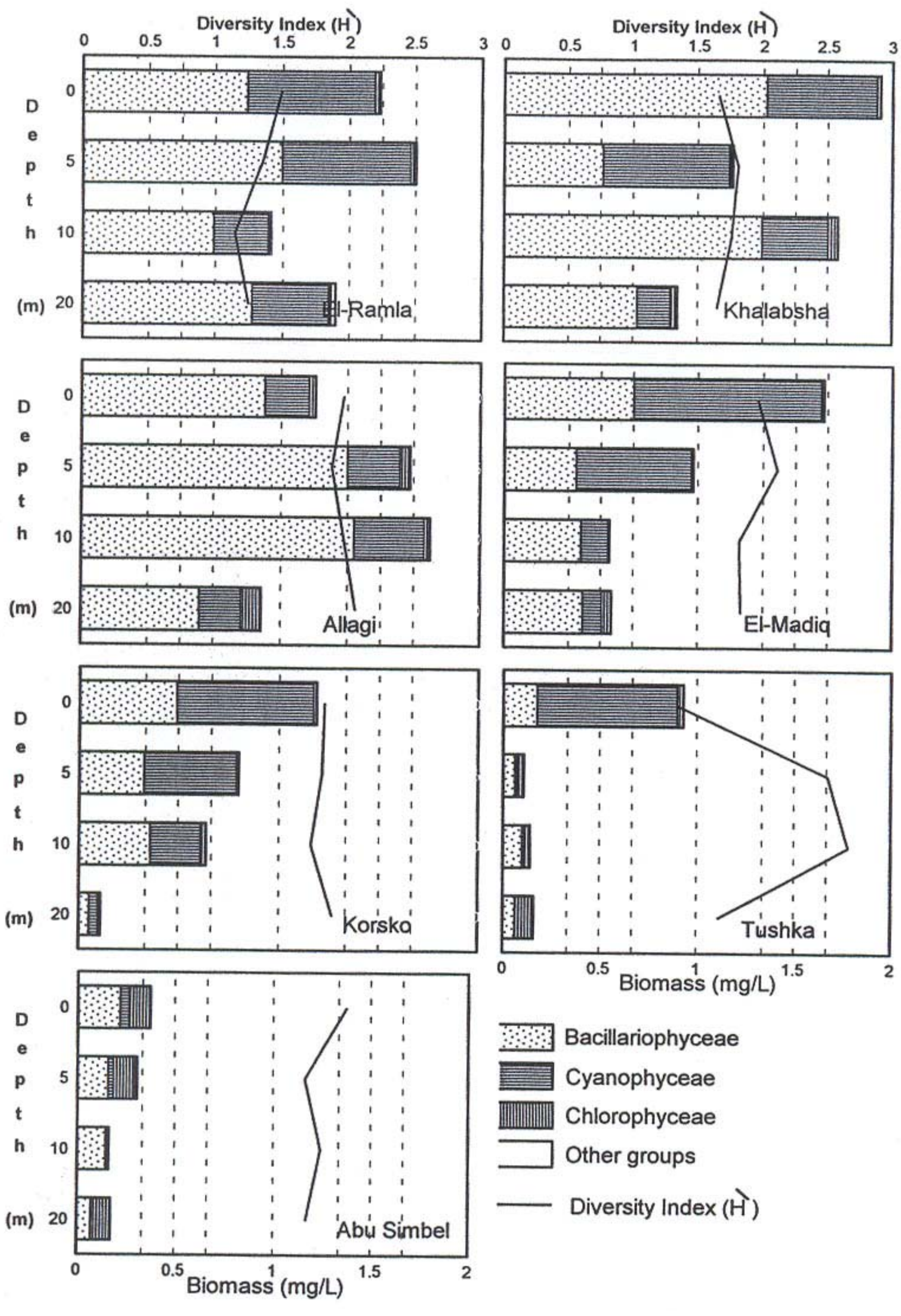

Fig. 5: Vertical profiles phytoplankton biomass (mg/L) subdivided by algal groups and species diversity index of the different station in the main channel of Lake Nasser during Autumn 1999.

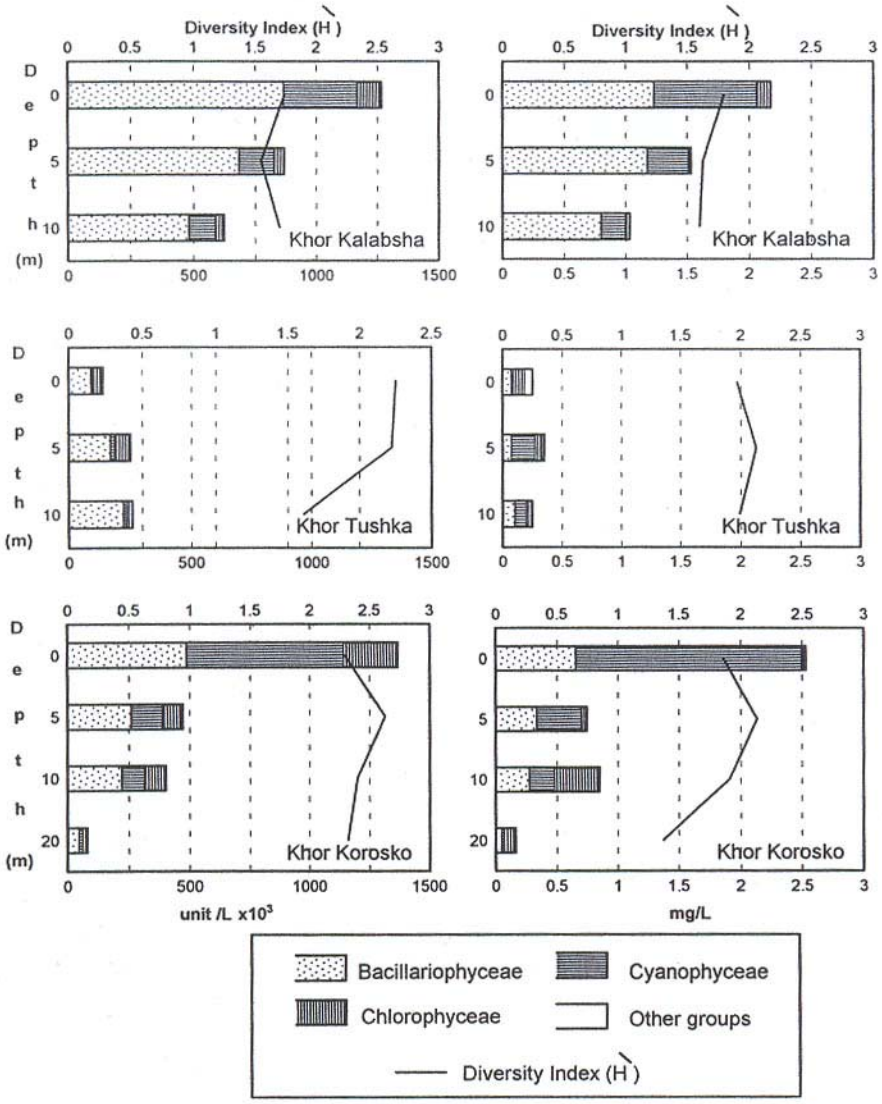

Fig. (6): Vertical profiles of phytoplankton abundance (unit/L x 10^3) and biomass (mg/L) subdivided by algal groups and species diversity index in different Khors of Lake Nasser during Autumn 1999.

At khors, the seasonal abundance and biomass values during 1981 (Zaghloul 1985) were, respectively, 413.4 x 10^4 unit/L, 4.68 mg/L in winter; 558.5 x 10^4 unit/L, 135.36 mg/L in spring; 690.9 x 10^4 unit/L, 5.99 mg/L in summer and 51.7 x 10^4 unit/L, 5.54 mg/L in autumn. The values reduced to 71.1 x 10^4 unit/L and 1.229 mg/L in the present study.

It is important to notice that the trend followed the total phytoplankton shows relationship with water level fluctuations of any reservoir (Carvajal-Chitty, 1993; Descy, 1993). In particular, high values of phytoplankton density correspond to the minimum level phase, while low density takes place during the maximum level phase (Barone and Flores, 1994). This fact seems to be related to the low phytoplankton abundance and biomass at the highest water level during the present study.

Bacillariophyceae:

The main channel: Bacillariophyceae were the most abundant division in the euphotic zone, comprising 80% and 59% of total density and biomass, respectivity. Maximum density (247.3 x 10^4 cells/L) occurred at El-Madiq and that of biomass (1.37 mg/L) at Allaqi (Figs. 4 & 5). *Melosira granulata* and *M. granulata* var. *angustissima* were the dominant taxa. There was a spatial tendency towards an increase in abundance upstream. The two taxa contributed 94% to diatom densities (El-Madiq) and 78% to diatom biomass (Allaqi). The periodicity of *Melosira* in temperate lakes is mainly connected with periods of turbulence of the lake water (Petrova 1986). . *Melosira granulata* var. *angustissima* was positively correlated with pH ($r = 0.64$, $p < 0.001$), DO ($r = 0.54$, $P < 0.001$), Secchi depth ($r = 0.34$, $P \leq 0.05$) and negatively correlated with silicate ($r = -0.36$, $P \leq 0.05$).

Contrary to *Melosira*, *Cyclotella ocellata* was strongly represented in the downstream and decreased towards the south. Highest density was recorded at El-Ramla, contributing, respectively, 92% and 83% to total diatom densities and biomass. *Synedra* spp. contributed 11.4% to diatom biomass, but numerically showed negligible value (0.6%).

According to the standard of the National Environment Committee Announcement (Ministry of Science and Technology, 1994), *Cyclotella* and *Melosira* might be used as bioindicators of the oligo-mesotrophic status, and generally, diatoms are species with low nutrient requirements and low temperature optima (Reynolds 1986 and Brettum 1989).

Khors: Bacillariophyceae dominated the phytoplankton with maximum average abundance of 679 x 10^3 cell/L (74%) and average biomass of 1.08 mg/L (68%) recorded at khor kalabsha (Fig. 6). The percentage decreased to 44% to total abundance and 31% of total biomass at Khor Korosko. The centric diatom *Cyclotella ocellata* was clearly dominant in Khor Kalabsha (527 x 10^3 cell/L and 0.70 mg/L) with relative abundance and biomass 78% and 65% to total diatoms, respectively. *Synedra* spp. contributed 15% to total diatom biomass.

Cyanophyceae:

The main channel: The cyanophyceaen community contributed 12% and 35% to total phytoplankton densities and biomass, respectively. There was an increase in abundance and biomass downstream. El-Ramla had the highest abundance (195 x 10^3 unit/L, 24% to total phytoplankton abundance) and Abu Simbel had the lowest (Figs. 4, 5). El-Madiq had the highest biomass (0.45 mg/L). *Phormidium* sp. was the most common species (average 87 x 10^3 unit/L, 67% of total cyanophytes). In terms of biomass, the species had an average of 0.18 mg/L, with a relative biomass of 40%.

Highest density was recorded at El-Ramla (116 x 10^3 unit/L), decreased to reach 861 unit/L at Abu Simbel. It is worth mentioning that, the comparatively large-sized *Microcystis aeruginosa* played a significant role in the formation of cyanophytes biomass (54%), but numerically showed negligible value (1.5%). The species was positively correlated with pH (r= 0.65, $P < 0.001$), DO (r = 0.59, $P < 0.001$). Some species of Cyanophyta can adapt by using intracellular structures as gas vacuoles for vertical moving and others can move by using flagella (Graham and Wilcox, 2000). This may illustrated the presence of *Microcystis aeruginosa* at 20m. depth.

Khors: Fifteen cyanophycean species, ranged between 5.4% and 38.6% to total densities and between 28.7% and 57% to total biomass with a mean of 16.8% and 42.9% to total abundance and biomass, respectively. Khor Korosko had the highest density (224 x 10^3 unit/L) and Khor Tushka had the lowest (12 x 10^3 unit/L) (Fig. 6). *Phormidium* sp. was the leader, contributing 49% and 48% to total cyanophytes densities and biomass, respectively. *Microcystis aeruginosa* formed significant contribution to cyanophyte biomass (34%). *Anabaenopsis cunningtonii* was weakly represented in the main channel, formed in the khors 26.8% and 16.3% to total cyanophyte densities and biomass, respectively. Cyanophyceae had a relatively higher proportion in khors than in main channel because these diets are unsuitable food for large herbivores zooplankton and fishes which use khors as favourite habitats (Garibaldi *et al.*, 2003).

Many African freshwater lakes and reservoirs are dominated by cyanophytes over extended parts of the year, possibly due to the "endless summer" conditions typical of Africa (Kilham and Kilham, 1990). Blooms of N_2-fixing cyanophytes are common (e.g. Lake Malawi, Patterson and Kachinjika, 1993 and Lake Victoria, Hecky, 1993). However, the non-N_2-fixing *Microcystis aeruginosa* is by far the most common bloom-forming cyanophytes in Africa (Zohary *et al.*, 1996).

Chlorophyceae:

In spite of Chlorophyta contributed more taxa to the phytoplankton than other groups during the last two decades (El-Otify *et al.,* 2003), their contribution to total phytoplankton was fairly low, even though they represented 7.5 and 11% to total abundance in the main channel and khors, respectively. *Crucigenia rectangularis* and *Ankistrodesmus spiralis* constituted, respectively, 17.5% and 14.4% to total chlorophytes.

3.3. STATISTICAL ANALYSIS

3.3.1.Species richness and other diversity indices:

Species diversity and evenness were negatively correlated with phytoplankton abundance (r = -0.47, $P \le 0.05$ and r = -0.43, $P \le 0.05$, respectively) and no significant correlation was found between diversity and phytoplankton biomass.

The main channel: Highest species richness (56 taxa) was found in El-Ramlah, while Abu-Simbel had the lowest (34 taxa). However, Tushka showed the highest diversity and evenness, 2.42 and 0.92, respectively. El-Ramla had the highest richness value (2.52) while the lowest (1.81) was at Allaqi (Table 2). The prevalence of *Cyclotella ocellata* (60% to total count), and *Phormidium* sp. (22.8% to total count) was associated with low diversity in El-Ramla. Wide oscillation was evident in Tushka through water column, due to the frequent changes in dominance occurring in the community and the absence of dominant species. In terms of biomass, diversity ranged between 1.31 (El-Ramla) and 0.05 (Tushka). Biomass peaks were mainly caused by the development of single or few dominant species belonging to Bacillariophyceae and Cyanophyceae.

Khors: The highest number of taxa (46) was recorded in khor kalabsha; it was met with lowest diversity index value (1.66) and lowest evenness (0.63). Khor Korosko had highest diversity and evenness values (2.41 and 0.92 , respectively). In terms of biomass, Khor Tushka had the highest diversity and lowest of 1.68 in Khor Kalabsha. The present study showed that the largest species had a strong impact on the evolution of phytoplankton diversity. In particular, the high development of the large diatoms and cyanophytes caused a decrease in the diversity values.

3.3.2. Regression models:

A series of simple statistical regression models were calculated according to Hintze (1993) describing the dependence of phytoplankton abundance on the measured physico-chemical factors in Lake Nasser.

Phytoplankton abundance (unit/L) = -175.337 + 22.83 pH + 0.04646 PO_4 – 1.66 SiO_4 (R^2= 0.795).

The importance of the physico-chemical factors were: pH contributing 59.68% of the variations of the total phytoplankton abundance followed by PO_4 (28.52%) and silicate (11.80%).

Bacillariophyceae(cell/L) = -200.051 – 0.00069 NH_4 + 24.13 pH + 0.057 PO_4 (R^2= 0.730).

The importance of the physico-chemical factors were: NH_4 contributing 56.79% of the variations of the total Bacillariophyceae, followed by pH (27.82%) and PO_4 (15.39%).

Cyanophyceae (unit/L) = 4.53 – 0.00874 NH_4 + 0.2896 DO – 0.00423 PO_4 -0.725 SiO_4 (R^2 = 0.42).

The importance of the physico-chemical factors were: NH_4 contributing 42.38% of the variations of the total Cyanophyceae followed by DO (23.80%), PO_4 (21.24%) and silicate (12.58%).

Chlorophyceae (cell/L) = 6.46 + 0.0036 NH_4 + 0.356 DO -1.003 pH (R^2 = 0.475).

The importance of the physico-chemical factors were: NH_4 contributing 61.62% of the variations of the total Chlorophyceae followed by DO (32.04%) and pH (6.34%).

As a whole, a declining in phosphorus concentration, phytoplankton abundance and biomass are approaching the lake oligomesotorophic level. This status is supported by some characteristic of the phytoplankton assemblage, like the development of the diatoms, *Cyclotella* and *Melosira*, that might be used as bioindicators of the oligo-mesotrophic status.

Table (2): Average diversity measures of the phytoplankton of the sample stations of Lake Nasser

Station	No. of taxa	Diversity index based on abundance	Diversity index based on biomass	Evenness	Richness
El-Ramla	56	1.22	1.31	0.46	2.52
Kalabsha	51	1.70	1.72	0.64	2.47
Allaqi	38	1.68	1.97	0.64	1.81
El-Madiq	46	1.65	1.93	0.63	2.07
Korosko	46	2.21	1.83	0.84	2.31
Tushka	41	2.42	2.05	0.92	2.11
Abu-Simbel	34	1.94	1.85	0.74	2.01
Khor Tushka	40	2.03	2.03	0.77	2.01
Khor Korosko	43	2.41	1.82	0.92	2.18
Khor Kalabsha	46	1.66	1.68	0.63	2.34

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