IMPACT OF ENVIRONMENTAL CONDITIONS ON THE PHYTOPLANKTON STRUCTURE IN MEDITERRANEAN SEA LAGOON, LAKE BURULLUS, EGYPT

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Abstract. Lake Burullus is one of the northern Delta lakes, connected with the Mediterranean Sea through El-Boughaz opening. The main objective of the present work is to study the physical and chemical properties of the lake and its relation with the phytoplankton communities, chlorophyll-a as well as diversity and Eutrophication index. The studies revealed that, the pH values lie in alkaline side, with wide range of fluctuation (7.15–8.5), the total suspended matter was relatively high (18.2–149 mg l^{-1}), high values of dissolved oxygen (5.17–11.29 ml l^{-1}) and high concentration of nutrient salts, (nitrate ranged between (3.4–44.7 μmole l^{-1}), nitrite (0.42–15.95 μmole l^{-1}), ammonia (1.46–50.60 μmole l^{-1}), phosphate (0.63–14.83 μmole l^{-1}), and silicate (6.54 to 119.3 μmole l^{-1}). Chlorophyll-a concentration showed a wide range of fluctuation (13.8–127.4 μg/l) and the highest value were recorded at the western region of the lake. Phytoplankton counts showed a pronounced increase (1.9×10^6 units l^{-1}) as compared with previous studies, a total of 170 species were identified represented mainly by *Bacillariophyceae* (44.8% to the total community) comprising 68 species, *Chlorophyceae* (39.99%) 54 species, followed by *Cyanobacteria* (9.52%) 26 species, *Euglenophyceae* (5.63%) 15 species. Phytoplankton standing crop attained the highest counts at the western sector particularly at station X during spring and summer (6.7×106 and 4.1×10^6 units l^{-1} respectively) due to the dominance of Bacillariohycean species *Stephanodiscus* phytoplankton diversity was high and showed widely range (1.47–3.66 nats). A series of stepwise regression equations describing the dependence of phytoplankton standing crop, its main groups and diversity index on the changes of the most biotic prevailing conditions were given and discussed. In general, the results showed that the Lake is considered as a eutrophic area. This phenomenon observed in the body of the lake water that receives large influxes of nutrients, which reflects high phytoplankton counts, diversity index and Chlorophyll-a

Keywords: Nutrient salts, Phytoplankton, Diversity index, Chlorophyll-a, Eutrophication index

Introduction

Lake Burullus is a shallow brackish water basin. It lies in the north of the Nile Delta, along the Mediterranean Coast of Egypt between Longitudes 30° 30′ & 31° 10′E and Latitudes 31° 35′ N. It covers an area of about 35 hectare. The lake width varies between 4 and 16 km and its depth from 60 to 150 cm. The lake is connected to the Mediterranean Sea at the northern side through Boughaz El-Burullus. It serves as reservoirs for drainage waters, from agricultural areas through seven drains in addition to the fresh water from Brimbal Canal situated in the western part of the lake.

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The lake receives drainage water at monthly rates, which fluctuated between 78×10^6 and 272×10^6 m^3/ per month during January and July 2002, respectively (Ministry of irrigation). The amount of the drainage water discharged annually into the lake fluctuates from one year to the other, with an average of about 2.5 billion $m^3 year^{-1}$ (Samaan *et al.*, 1989). Lake Burullus suffered from man-made activities and human interferences due to increased rate of development along the Nile Delta. This caused several environmental problems including agricultural, industrial and sewage discharge, land reclamation (35%of the original area decreased) as well as illegal fishing (Ahmed *et al.*, 2001) The lake is influenced by drainage water runoff from land via drains, this water enrich the lake with nutrients (phosphate, nitrate and silicate), the total nitrogen and phosphorus inflow to the lake through drains was 2318 and 558 T/Y, respectively (Abdel_Moati *et al.,* 1990). The inflow of drainage water has increased phosphate levels by four times between 1970 and 1987 and blooms of blue-green algae have been recorded at Baltim, probably linked to sewage outflows (El-badry, 2005). Many investigators had studied the hydrographic and chemical characteristics of Lake Burullus water and sediments as well as phytoplankton community (Abdelmoneim *et al.,* 1990; Moussa, 1984; El-Mamoney, 1988; Okbah, 1991; Radwan, 2000; El-Sherif, 1983 and Radwan, 2002). The objective of the present work was to study the physical and chemical properties of the water and its relation with phytoplankton structure and species diversity as well as to compute an eutrophication status of the lake.

Materials and Methods

Eleven surface water samples were collected seasonally from Burullus Lake during 2003, using plastic Rottener Sampler of 2 liters capacity. Trips for sampled collection were carried out on a boat. Sampling periods were performed in January (winter), April (spring), July (summer) and October (autumn). Sampling stations were chosen covering the different locations of the lake (Figure 1), stations I, II and III were taken from the eastern basin near Boughaz Burullus, four stations IV, V, VI and VII were collected from the middle of the lake, stations VIII, IX, X and XI represented the western part of the lake. As shown in Figure 1, drain3, drain4, drain5 and drain7 drainage in the southeastern region. The highest amount of wastewater discharged by drains 8 & 9 in the middle region, drain 11 and drain 1 as well as Brimbal canal discharge into the western part of the lake.

Nutrient salts (NO_2, NO_3, NH_4, PO_4 and S_iO_4) and chlorophyll-a were measured (Strickland and Parsons, 1972), using a Shimadzu double beam spectrophotometer UV-150-02. Water temperature was measured with an ordinary thermometer; the pH value was measured using a pocket pH meter (model 201/digital pH meter). Water transparency was carried out by a white secchi depth 25 cm in diameter. Water salinity was measured using Bechman salinometer (Model NO. R.S.10). Dissolved oxygen was estimated according to the Winkler method (Strickland and

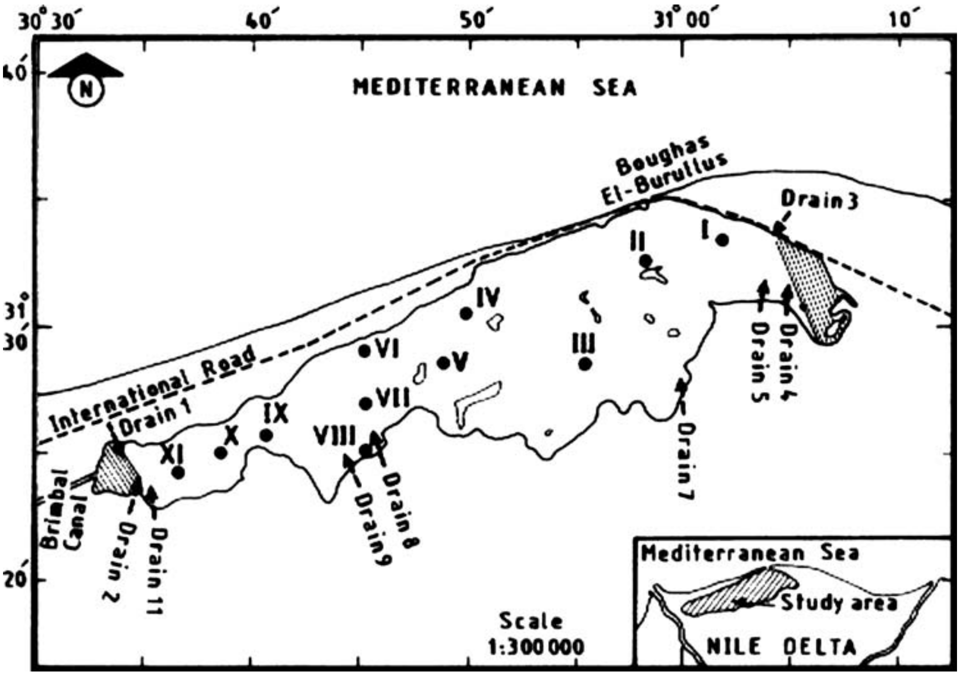

Figure 1. Sampling stations (Lake Burullus).

Parson, 1965). Total Suspended matter (TSM) was determined from 100 ml of water sample, filtered through the filter paper (GF/C, 0.45 μm), the TSM value was calculated by the difference between the dry weight of the filter before and after filtration.

Trophic State Index (TSI) was calculated according to Carlson (1977). This index is used as the basis for estimating the trophic status of Burullus Lake. Carlson's TSI is based on the interrelationships of secchi depth reading (TSI_{SD}), Chlorophyll-a concentration μg/l (TSI_{chl}) and Total Phosphorus, μg/l (TSI_{TP}). TSI calculation was done as follows:

$$TSI_{SD} = 10(6 - \ln SD/\ln 2) \qquad SD(m)$$

$$TSI_{chl} = 10((6 - (2.04 - 0.68 \ln chl - a/\ln 2)) \qquad chl - a(\mu g/l)$$

$$TSI_{TP} = 10(6 - \ln(48/TP)/\ln 2) \qquad TP\,(\mu g/l)$$

$$TSI = TSI_{SD} + TSI_{chl} + TSI_{TP}$$

Estimation of the phytoplankton standing crop was carried out by sedimentation method as reported in standard method in American Public Health Association (A.P.H.A., 1985), identification to species and counting will do, and counting was expressed as units. l^{-1}. Species diversity index (H) was estimated according to

Shannon and Weaver (1963) as follows:

$$H = -\sum_{i=1}^{n} Pi \ln Pi$$

Where *P*i = importance probability for each species (*n/N* is the proportion of *i*, the n_i species) to the total number of phytoplankton cells (N), the results were expressed as nats.

Correlation coefficient and stepwise multiple regression equations at a confidence limit 95% were evaluated for the whole year ($n = 44$) to quantize the phytoplankton standing crop, and their dominant groups, as well as diversity index in relation to the most correlative environmental factors.

Results&Discussion

I. HYDROGRAPHIC CONDITIONS

i. *Water Temperature*

Seasonal values of water temperature over the lake varied in the range of 17.00 °C and 29.3 °C. The lowest temperature was recorded in January and increased to reach the highest level in September.

ii. *Total Suspended Matter (TSM)*

Suspended matter consists of lithogenic material and biogenic parts including of plankton and detritus, the value of total suspended matter content (Figure 4) was fluctuated between minimum value of 18.2 mg l^{-1} at station IV in winter and maximum value of 149 mg l^{-1} at station II in summer. In general, the values of TSM in the lake water revealed high levels of organic and inorganic matter produced by living organisms as well as terrigenous particles transported by land run off. The high levels of total suspended matter were observed for drains water, it ranged from 85.0 mg l^{-1} in winter to 225.0 mg l^{-1} in summer (Table I). Their highest values were directly affected on the levels of transparency.

iii. *Water Transparency:*

Secchi depth (Transparency) was recorded in Table IV. It was fluctuated between 15 cm in summer (station V) and 60 cm in winter (station IX). The color of the lake water was usually green, especially at stations III, V, VII, VIII, IX and X in spring and at stations from VI to XI in summer. This may be attributed to the high content of chlorophyll-a, since it ranged from 13.8 to 127.4 μg l^{-1} related to the phytoplankton density.

iv. *Hydrogen ion concentration (pH)*

The values of pH of the investigated area lie on the alkaline side, its values ranging between 7.45 (station VIII in winter) and 8.70 (station IV in spring). The lowest

TABLE I
Physical and chemical parameters value of drains water, Lake Burullus(2003)

Parameter	Winter	Spring	Summer	Autumn
PH	7.35–7.69	7.50–8.30	7.45–8.25	7.75–8.15
D O ml/l	3.2–5.07	4.49–6.14	4.16–6.52	3.97–4.20
Salinity ‰	1.73–2.34	0.42–2.51	1.86–2.78	0.62–3.08
NH4-N mmole/l	9.04–61.70	7.34–34.30	9.21–29.42	20.23–70.45
NO2-N mmole/l	6.42–26.68	4.40–15.07	0.81–15.60	0.25–5.60
NO3-N μmole/l	13.74–56.21	7.41–28.90	7.68–30.75	10.50–51.20
PO4-P mmole/l	6.25–9.55	8.59–24.30	9.47–22.31	5.70–17.31
SiO4 mmole/l	104.00–188.00	18.8–115.60	76.47–117.64	71.60–237.09
Chl-a μg/l	17.30–59.20	42.70–225.20	56.90–295.00	15.20–73.70
SPM mg/l	74.00–195.30	85.00–207.00	64.00–225.00	51.04–176.00

pH value was observed around the middle of the lake, which affected by drains 8 and 9. The pH increased to reach maximum value at near the eastern region of the lake. The pH values of the lake water revealed slightly variation, which may be controlled by the density of phytoplankton count and the water quality inflow to the lake. The pH value of lake water affected with pH value of the drains water, it ranged from 7.35 in winter to 8.30 in spring (Table I)

v. *Water Salinity (S ‰):*
The salinity is an important factor which reflects the changes caused by the mixing of fresh water, drainage water and seawater.

The variation of water salinity was recorded in Figure 2. The lowest value (0.54‰) was recorded at station XI during autumn, while the highest one (21.13‰) was recorded at station II during winter. The low mean value of salinity recorded in autumn season (2.1$\%_o$), it was decreased than that reported in the other season (ranged 3.11–4.38‰).

The present data of water salinity showed wide variations. The highest value was recorded at stations I and II (5.38 to 21.13 ‰).These stations located in the eastern region, which affected with the Mediterranean seawater through the opening of El-Boughaz. On the other hand, the low values of water salinity was reported at the other stations, ranged from 0.74$\%_o$ at station IX in autumn to 3.63‰ at station III in spring.

There is a significant negative relationship between water salinity and temperature ($r = -0.73$). This may be as a result of continuous supply of drainage water discharged into the lake. Seasonal salinity changes of drains water showed lower values during the period of study comparing with the lake water (Table I); it ranged between 0.42‰ in spring and 3.08‰ in autumn.

vi. *Dissolved oxygen (DO):*
The regional value of DO (Figure 2) fluctuated between 5.17 ml l^{-1} (station VI, summer) and 11.29 ml l^{-1} (station II, autumn). During autumn season, the DO

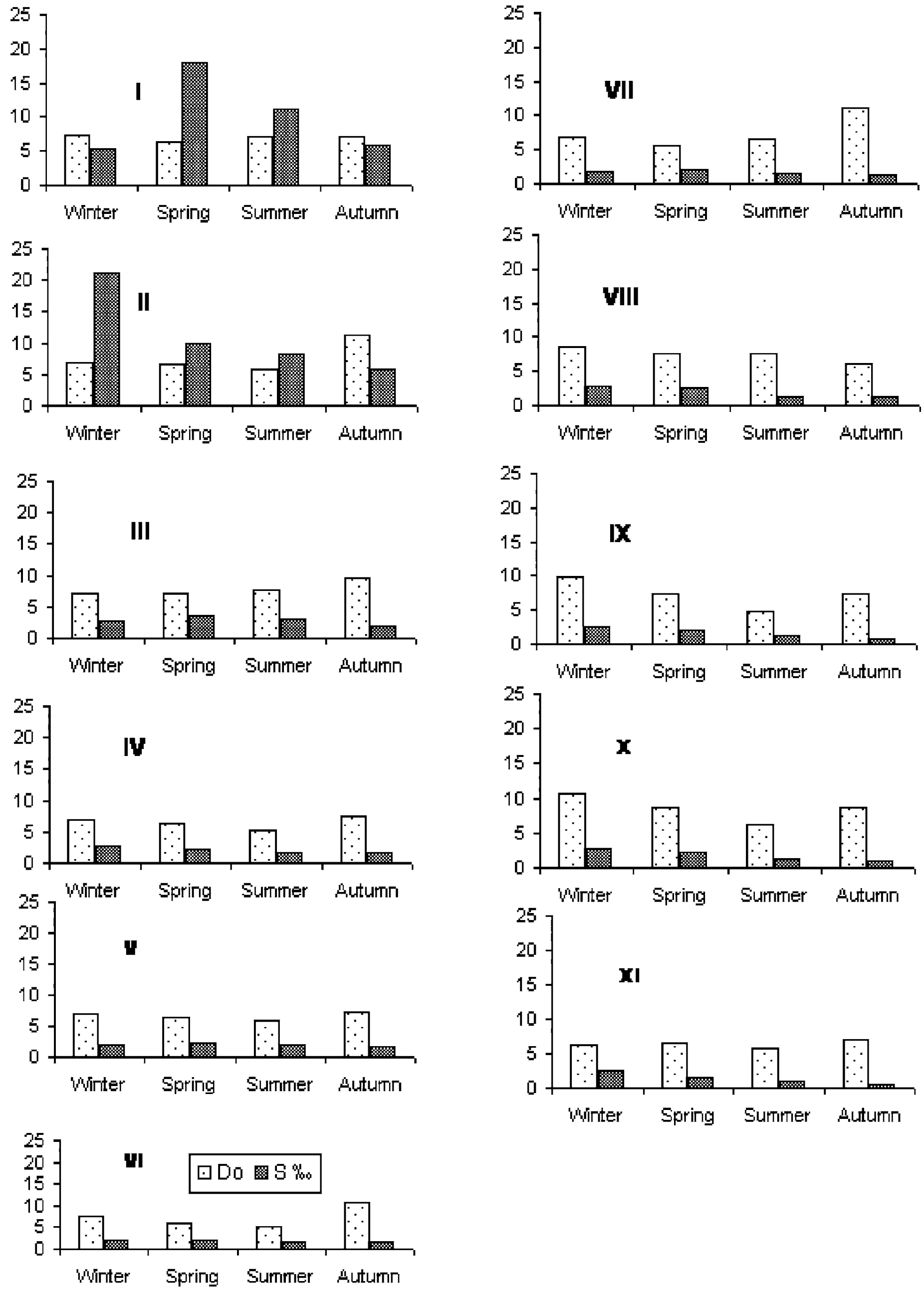

Figure 2. Seasonal variations of dissolved oxygen (ml/l) and water salinity(‰)values at different stations in Lake Burullus during 2003.

content of the lake water was relatively high comparing with the other seasons (Figure 2). Generally, the increasing of water temperature leads to the decreasing of DO. This confirmed with a significant negative correlation ($r = -0.56$). This may be due to several factors, the rise in temperature increased biological activity, respiration of organisms and increased rate of decomposition of organic matter. The level of dissolved oxygen concentration of drains water was low (Table I), it ranged from 3.20 to 4.05 ml l^{-1}. The difference level of DO between the drains and the lake water reflects the conditions and the effect of the inflow of drain water on the water quality of the lake.

II. NUTRIENT SALTS

i. *Dissolved Inorganic Nitrogen (DIN):*
Dissolved inorganic nitrogen content (the sum of ammonia, nitrite and nitrate) in the lake water is relatively high.

Generally, high level of DIN was found in the middle basin compared with that reported in the eastern and western basins. This basin is affected directly by the discharge water of drains No, 8 & 9, which are mainly contain amount of agricultural fertilizers. The drainage water discharged through these drains amounted to more than 960 million cubic miters per year (Okbah, 2005).

The absolute values of ammonia, nitrite and nitrate revealed wide variation as shown in Figure 3. Ammonia was fluctuated between 1.46 μmole l^{-1} (station VII, autumn) and 50.60 μmole l^{-1} (station VIII in winter). Nitrite ranged between 0.42 μmole l^{-1} in spring at station XI and 15.95 in summer at station VIII, while nitrate distribution in the lake water varied from 3.41 μmole l^{-1} in spring (station X) to 44.70 μmole l^{-1} in summer (station VIII).

The regional variations of dissolved inorganic nitrogen showed that, the minimum mean concentration was 3.70 μmole l^{-1} for NH_4; 1.20 μmole l^{-1} for NO_2 and 6.57 μmole l^{-1} for NO_3. On the other hand, the maximum mean values of NH_4-N (12.33 μmole l^{-1}); NO_2-N (10.93 μmole l^{-1}) and NO_3-N (30.49 μmole l^{-1}) were found at stations XI; IV and VIII, respectively.

The relatively high concentration of NH_4-N, NO_2-N and NO_3-N may be due to the large amounts of drainage water from the agricultural areas through the drains, which are contaminated by anthropogenic material. The dissolved inorganic nitrogen of drain water (Table I) showed high levels of DIN in winter and autumn seasons (ranged from 9.04 to 70.45 μmole l^{-1} for NH_4-N and from 10.5 to 56.21 μmole $^{-1}$ for NO_3-N. The concentrations of NH_4-N and NO_3-N decreased in spring and summer seasons may be related to the high growth of phytoplankton.

The relative decrease of NH_4, NO_2 and NO_3 in summer and spring may be as results of nutrients consumption by phytoplankton and aquatic plants which are density populating during these seasons (Abdel-Moati *et al.*, 1990). This illustrated as a result of the high levels of chlorophyll-a concentrations during these seasons, it ranged from 49.8 to 70.7 μgl $^{-1}$ in spring and summer seasons.

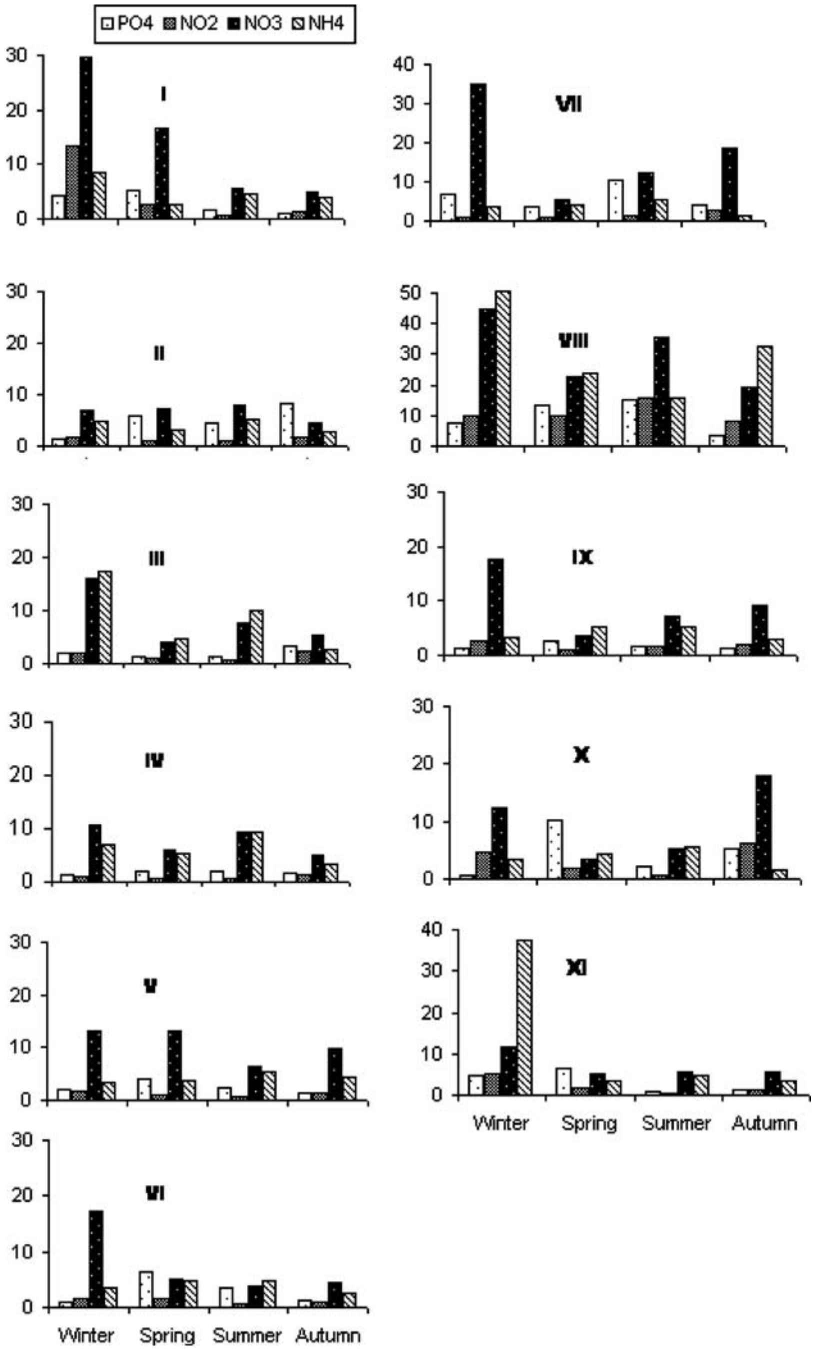

Figure 3. Seasonal Variations of Reactive Phosphate,Nitrite,Nitrate and Ammonia Concentrations at the Different Stations in Lake Burullus during 2003.

ii. *Phosphorus compounds:*
The mean concentration of PO_4-P (Figure 3) reveled that, the lowest value (0.63 μmole l^{-1}) was recorded at station X in winter and the highest concentration of PO_4-P in the study area was recorded in spring (13.52 μmole l^{-1}) and summer (14.83 μmole l^{-1}) at station VIII. This may be related to the high content of waste water discharges from drains 8 and 9. The level of PO_4-P content of the drains ranged from 5.7 to 24.30 μmole l^{-1}.A significant negative correlation between salinity and PO_4-P was found, ($r = -0.35$). The reverse relationship between salinity and PO_4-P can be interpreted on the basis of the reactive phosphate is allochthonous. Total phosphorus concentration in the lake showed a wide range of variation Table IV. The absolute value of total phosphorus fluctuated between 3.40 (mole l^{-1} at Station II in winter and 21.42 μmole $^{-1}$ at Station VIII in autumn. Generally, the concentration of total phosphorus was relatively high; this may be related to the huge amounts of wastewater drainage into the lake.

iii. *Silicate (SiO_4):*
The seasonal distribution of silicate concentration in Lake Burullus water showed a wide range of variation (Figure 4). It ranged from 6.54 μmole l^{-1} in spring (Station X) to 119.3 μmole l^{-1} in autumn (Station X). The lower silicate was recorded during spring and summer; this may be due to the high level of phytoplankton growth (Chl-a was 57.53 and 75.49 μg l^{-1}, respectively). In general, the results revealed that the minimum value of silicate was recorded in the western regions, while the high content was found in the middle and eastern regions of the lake. The regional variations of silicate content were related to the amounts of drainage water discharged through the drains (Figure 1).The results showed greater amount of silicate concentrations of drains water, it ranged between 18.8 and 237 l^{-1} (Table I)

III. CHLOROPHYLL-a (Chl-a):

Chlorophyll-a concentration is considered as a good indicator of the phytoplankton biomass. The distribution of Chl-a in the investigated area during the year 2003 is presented in Figure 4. The mean concentration of Chl-a was exhibited lower value at station III (13.80 μg l^{-1}), while the highest value at station VIII (127.4 μg l^{-1}). Depending on the regional distribution of Chl-a, the station VIII, which was under a higher influence of wastewater, exhibited Chl-a contents between 71.1 and 127.4 μg l^{-1}. The results as shown in Table I revealed high concentration of Chl-a in drains water, ranged from 15.2 to 295.5 μg l^{-1}. The simple regression analysis between Chl-a and both PO_4 and NO_3 indicated a poor linear relationship ($r = 0.34$ for PO_4 and $r = 0.294$ for NO_3). This may be related to the rapid utilization of NO_3 and PO_4 by phytoplankton (James and Head, 1972). On the other hand, there is a significant positive relationship between ammonia and Chl-a content; ($r = 0.5$). This may reflect the role of ammonia content in the growth of phytoplankton and the biological processes

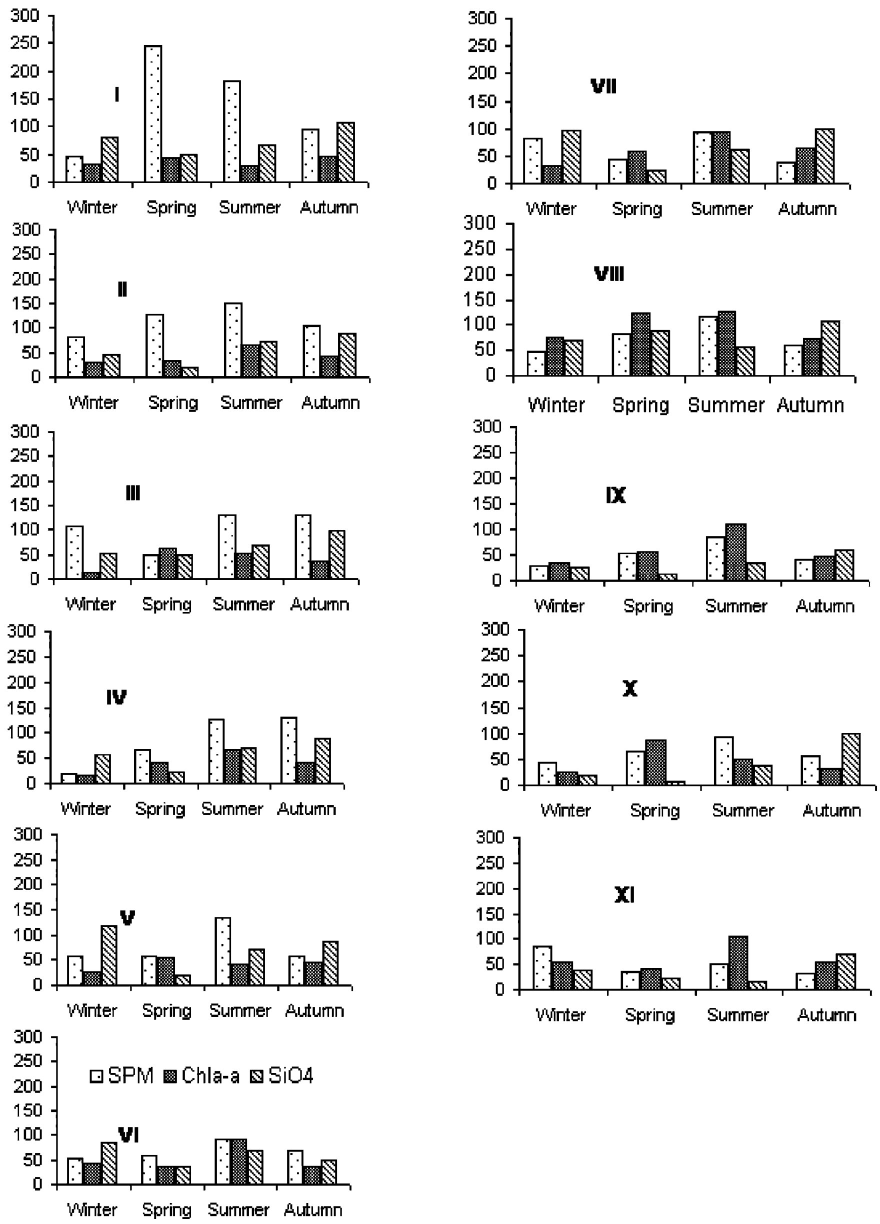

Figure 4. Seasonal Variations of Total Suspended Matter, Chlorophyll-a and Silicate Concentrations at the Different Stations in Lake Burullus during 2003.

IV. Phytoplankton count

Community composition

A total of 170 taxa have been identified, comprising 68 Bacilloriophyceae, 54 Chlorophyceae, 26 Cyanobacteria, 15 Euglenophyceae, beside 6 species Dinophyceae and one silicoflagellate, as shown in Table II.

The phytoplankton community represent a high diversified flora, included both fresh and brackish water species as well as some scattered marine forms.

Bacillariophyceae was the most dominant group, forming 44.826% of the total phytoplankton count, with an average of 850.3×10^3 cells l^{-1}. Diatoms appeared more dense in the western sector, particularly at Station X which harbored the maximum density (2.1×10^6 cells l^{-1}), this accompanied by levels high of nutrient salts 4.6 μmol l^{-1} phosphate, 39.7 μmol l^{-1} silicate, 9.69 μmol l^{-1} nitrate, 3.32 μmol l^{-1} nitrite and also high dissolved oxygen level was recorded (8.58 ml l^{-1}). Chlorophyll-a was sustained often remarkably high concentrations, in the whole area fluctuating between 17.3 μg l^{-1} (station IV, winter) and 127.4 μg l^{-1} (station VIII, summer). It met with high counts of standing crop (0.8×0^6 units l^{-1} and 1.7×10^6 units l^{-1} respectively). The most dominant diatoms species were *Stephanodiscus* sp. (15.2% by number to the total phytoplankton count), *Nitzschia* spp. (12.1%), *Navicula* spp. (5.8%), *Melosira* spp. (5.7%) & *Cyclotella* spp. (3.9%). High counts of diatoms may be attributed to the high silicate concentration resulted from drainage water, which considered the main component of diatom frustules, coincided with Donoso & Phinnes, 1988 and Gouni & Tsekos 1989. While the lower dense were recorded at the middle sector particularity at Station V (0.15×10^6 cells l^{-1}).

In this work correlation matrix showed that diatoms were negatively correlated with silicate and SPM ($r = -0.4$ & -0.27, $P < 0.05$ respectively).

Chlorophyceae was the second dominant group and formed about 39.99% to the total phytoplankton count, with an average count of 758.6×10^3 units l^{-1}. It dominated by the genera *Scenedesmus* (14.4% to the total phytoplankton standing crop) and *Ankistrodesmus* (10.8%). The highest counts of Chlorophyceae were recorded at western sector at stations X & XI (1.6x 10^6 & 1.1×10^6units.l^{-1} respectively), as well as at the station VI (1.2×10^6 units l^{-1}). Chlorophycean group was negatively correlated with TSM ($r = -0.37$ $p = 0.002$) and positively one with water transparency ($r = 0.25$ $p = 0.045$).

Cyanobacteria showed irregular production, constituting about 9.52% to the total phytoplankton count with an average 180.5×10^3 units l^{-1} and represented mainly by *Merismopedia* and *Anabaenopsis* during autumn, *Anabaena* during summer. Cyanophycean group was positively correlated with water transparency ($r = 0.28$, $p = 0.021$).

Euglenophyceae constituted about 5.63% to the total phytoplankton standing crop, with an average 106.7×10^3 cells l^{-1}. It represented by *Euglena* (8 spp.) and *Phacus* (6 spp.) and one *Trachalomonos* sp., it's negatively correlated with TSM ($r = -0.24$, $p = 0.048$).

TABLE II

The annual average number (units l^{-1}) of the different phytoplankton groups, number of species their percentage frequencies, and diversity range (nats) during 1987–1988 (El-Sherif, 93), during 97–98 (Radwan, 2002) and during 2003 (present work) in lake Burullus.

	During 87–88 El-Sherif, 1993			During 97–98 Radwan, 2002			During 2003 Present work		
Groups/Year	Average No	No of ssp.	%	Average No	No of ssp.	%	Average No	No of ssp.	%
Bacillariophyceae	511×10^3	52	49.1	42×10^3	22	59.5	850×10^3	68	44.826
Chlorophyceae	329×10^3	38	31.6	151×10^3	37	21.2	759×10^3	54	39.992
Euglenophyceae	27×10^3	2	2.6	39×10^3	8	5.4	107×10^3	15	5.626
Cyanobacteria	18×10^3	15	1.7	85×10^3	14	11.9	$180.\ 10^3$	26	9.515
Dinophyceae	23×10^3	2	2.2	14×10^3	2	2	0.8×10^3	6	0.04
Cryptophyceae	132×10^3	1	12.7	0	0	0	0	0	0
Silicoflagellates	0	0	0	0	0	0	0.018×10^3	1	0.001
Total phytoplankton.	1040×10^3	110	100	713×10^3	83	100	1897×10^3	170	100
Diversity range	0.38–2.93 (nats)			0.21–1.06 (nats)			1.47–3.66 (nats)		

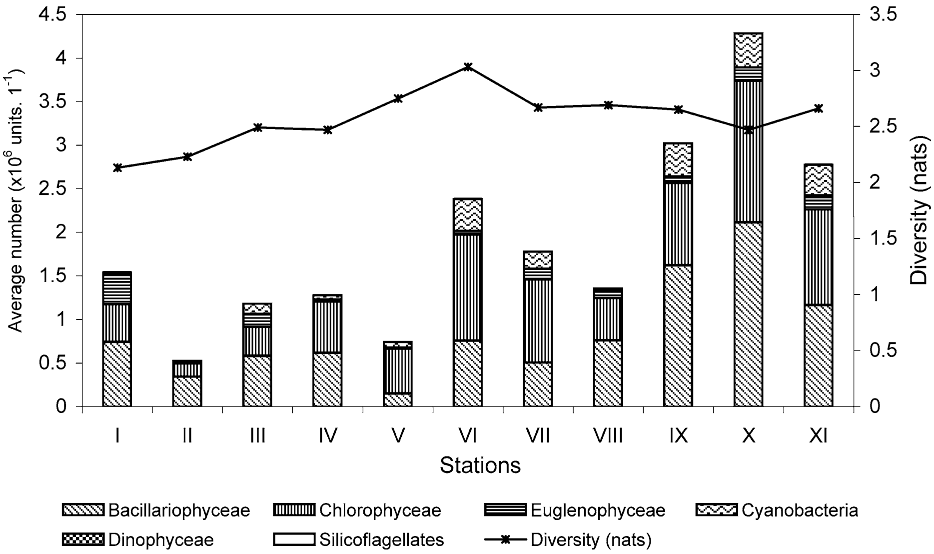

Figure 5. Distribution of total phytoplankton standing crop and its main components (x106 units l^{-1}) at different stations and diversity values in Lake Burullus during the year 2003.

Dinophyceae was rarely occurred at some stations during some months never exceeded 0.04% to the total community. Silicoflagellates appeared once at (Station I) near El-Boughaz area.

This work showed that, the lake harbored high phytoplankton standing crop and more diversified during the year 2003, when compared with that previously recorded during the 1987 (El-Sherif, 1993) and during 1997 (Radwan, 2002) as shown in Table II. Phytoplankton count was extremely up, when compared with the previous work. This is attributed to a direct effect of the increased amounts of drain water flowing into the lake, as result of the increased annual Nile flood during 2003.

Spatial distribution of the total phytoplankton

The average annual numbers of the phytoplankton community was 1.9×10^6 unit.l^{-1}. The highest counts appeared at western region at (stations IX, X, XI and reached 3.0×10^6, 4.3×10^6 and 2.8×10^6 units l^{-1} respectively) and decreased gradually toward eastern region (stations I & II) as shown in Figure 5.

The western region sustained a heavy phytoplankton growth as a result of continuous discharge of nutrients and organic load from several drains located there. The highest average count was recorded at station X (4.3×10^6 units l^{-1}), due to the increased numbers of diatoms (49.28%), which were represented by *Stephanodiscus* sp. (26.79%), *Navicula* spp. (11.12%) and to less extent of *Melosira* spp., *Nitzschia* spp. and *Cyclotella* spp. Chlorophyceae was the second dominant group (38.02%), represented by *Scenedesmus* spp. (15.09%), *Ankistrodesmus* spp. (12.5%). Cyanobacteria contributed about (9.19%) and dominated by *Merismopedia* spp. (4.47%), *Anabaenopsis* (2.28) and Anabaena (1.09%). Euglenophyceae shared by 3.49% to the total community, represented by *Euglena* spp. and *Phacus* spp. (2.33% & 1.03% respectively).

These results coincided with relatively high chlorophyll-a value (average of 47.41 μg l^{-1}) and dissolved oxygen (average of 8.58 ml.l^{-1}), as well as nutrient salts, silicate (39.7 μmole l^{-1}) phosphate (4.62 μmole l^{-1}), and nitrate (9.69 μmole l^{-1}), also high value of TSM was recorded (63.77 mg l^{-1}).

The western station IX also harbored high count (3×10^6 units l^{-1}). Bacillariophyceae was dominant contributed about (53.64%) followed by Chlorophyceae (31.24%) and Cyanobacteria 12.65% to the total community there *Nitzschia* spp. was the most dominant one 32.08% followed by *Ankistrodesmus* spp. formed (8.81%), *Carterias* sp. (6.4%), while *Cyclotella* spp. and *Melosira* spp. Were frequent (6.16 & 4.28%, respectively), *Scenedemus* spp. and *Kirchneriella* spp. (3.24% & 3.22% respectively), and *Navicula* spp. (1.9%). Cyanobacteia formed 12.65% represented by *Anabeana* spp., *Merismopedia* spp. and *Dactylococcopsis* sp. (2.52%, 2.5% & 1.29 to the total community respectively). Euglenophyceae formed about 2.4% represented by *Euglena* spp. and *Phacus* spp. (1.63% & 0.74%, respectively).

Chlorophyll-a at this station reached an average of 61.85 μg l^{-1}. It was higher than recorded at station X. This is may be due to the size of phytoplankton species. This accompanied with high values of nutrient salts, Silicate (32.76 μmol l^{-1}), phosphate (1.71 μmol l^{-1}) and Nitrate (9.35 μmol l^{-1}), as well as dissolved oxygen (7.27 ml l^{-1}) and TSM (51.38 mg l^{-1}).

The phytoplankton count at station XI attained 2.8×10^6 units l^{-1}. It dominated by *Stephanodiscus* sp. (16.22%), *Ankistrodesmus* spp. (14.47%), *Melosira* spp. (11.13%) and *Scenedesmus* spp. (9.95%), while *Cyclotella* spp. (7.94%) *Carteria cordiformis* (3.64%), *Chlorella vulgaris* (3.41%), *Chlamydomonas* spp. (3.19%), *Euglena* (3.16%), *Phacus* (2.58%) were recorded as frequent and rare forms. Moderate value of silicate (36.16 μmole l^{-1}) was recorded as it consumed by diatoms (41.97%), while relatively high values of PO_4 (3.26 μmole l^{-1}), NO_3 (6.96 μmole l^{-1}) & NH_4 (12.33 μmole l^{-1}). Chlorophyll-a attained high value (63.21 μg l^{-1}) and DO (6.42 ml l^{-1}).

The lower count values were recorded at stations II & V (0.5×10^6 & 0.7×10^6 units l^{-1} respectively). These wide variations reflect the environmental conditions prevailing in each station. The minimal value of diatoms was recorded at stations V & II (0.15×10^6 and 0.34×10^6 units l^{-1}, respectively). This coincided with higher value of silicate (73.29, 56.23 μmole l^{-1} respectively). Also, station II located near by Boughaz (lake sea connection), sea water may invade this area, so some marine plankter were occasionally observed there and coincided with higher water salinity value (11.25‰), as well as TSM (115.85 mg l^{-1}).

Seasonal variations

Phytoplankton counts attained high values all the year round particularly during spring (2.5×10^6 units l^{-1}) as shown in Figure 6.

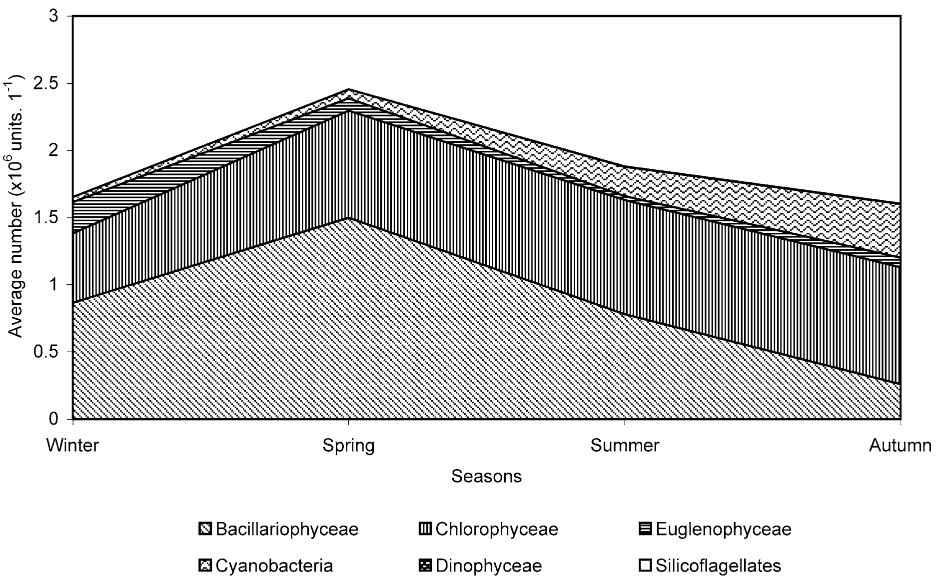

Figure 6. Seasonal average variations of the total phytoplankton standing crop and its main components (x106 units l^{-1}) in Lake Burullus during the year 2003.

Bacillariophyceae appeared more dominant during winter and spring (52.36% & 60.99 to the total community for each respectively). A moderate peak was observed during spring particularly at station. X (6.7×10^6 units l^{-1}), Figure 7, where 78 species were recorded. Bacillariophycean species *Stephanodiscus sp.* (65.77% by number to the total phytoplankton count during this season), coincided with low S_iO_4 concentration (6.54 μ mol l^{-1}) high content of Chlorophyll-a value (85.75 $\mu g\, l^{-1}$) and high DO (8.72 ml l^{-1}) followed by *Ankistrodesmus* spp. 14.74%, *Scenedemus* spp. formed 5.84%, *Nitzschia spp.* 3.43%, *Melosira* spp. 2.22% and *Navicula* 1.25%, while the other 48 species recorded as scarce form contributed about 5.26% to the community there.

During summer and autumn Chlorophyceae (45.13%, 54.35%, respectively to the total number for each) became dominant instead of Bacillariophyceae (41.56%, 16.12%, respectively).

Its variability was caused by significant input of nutrient rich effluent into the lake, which induced ecosystem modification on the level of community structure and species abundance; agree with Annika Stahl *et al.*, 2003. This phenomenon appeared mainly during summer and autumn at stations V, VI Figure (7). The most dominant Chlorophycean genera was *Scenedesmus* (5 species) constituted about 42.28% & 25.18% to the total community at stations V & VI respectively during summer and (43.21% & 23.28%, respectively) during autumn. The development of such genus may be attributed to the high level of organic matter and phosphate discharged with the drainage water. This is agreeing with the observations of Munawar (1970) and Radwan (2002).

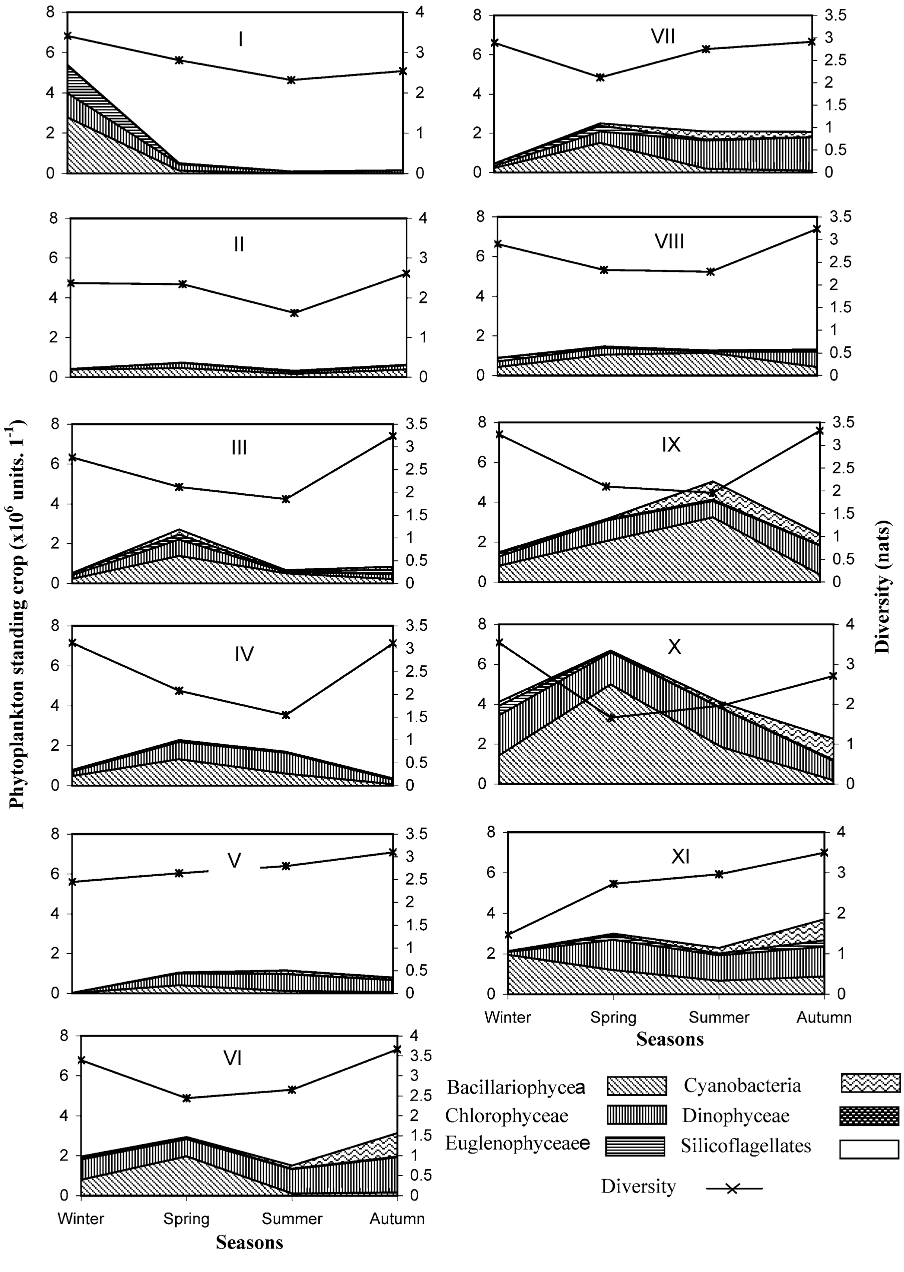

Figure 7. Seasonal variations of phytoplankton standing crop, its main compononts (x10^6 units 1^{-1}) and diversity values at the different stations in Lake Burullus during the year 2003.

At station X during autumn, the most dominant genus was the Cyanobacterian *Merismopedia* (2 species) and reached about 32.43% to the total community, this agreement with the results recorded by Radwan (2002), followed by chlorophycean genera *Scenedesmus* (6 species) constituted about 17.52% to the total community there *Ankistroduesmus* (4 species) formed about 11.8%, *Crucigenia* (3 species) reached 4.93%, *Anabaena* (2 spp.) 4.54%, *Oscillatoria* 4.04%, *Pediastrum* (4 spp.) 3.93% and *Anabaenopsis* sp. formed 3.12%. During autumn, station IX dominated by Chlorophyceae, the most dominant genera was *Ankistrodesmus* spp. (29.74%), *Pediastrum* (2 species) 10.44%, *Carteria cordiformis* (8.96%) and *Kirchneriella obesa* (6.74%), while station XI dominated by Chlorophyceae, *Ankistrodemus* (3 spp.) 14.98% to the total community there, *Chlorella* (6.43%) & *Carteria* 5.79% and by Cyanobacteria; *Merismopedia* (2 spp.) 12.07%, *Anabaenopsus* 5.73%, *Spirulina* (5.27%) & *Oscillatoria* 3.03% this may be attributed to the high load of drainage and nutrient salts discharged. So high silicate values were recorded at stations IX, X & XI (58.52 μ mol. l^{-1}, 98.56 μmol. l^{-1} & 69.52 μmol. l^{-1} respectively). Also, low water salinity values were recorded (0.74‰, 0.95‰ & 0.54‰ respectively) and high pH values (8.1, 8.05 & 8.31, respectively.). This is in agreement with the results recorded by Zafar (1964) and Radwan (1994) at the same area of investigation and moderate Chlorophyll-a value (47.92, 30.4 & 55.07 μg l^{-1} respectively). Phytoplankton growth actually regulate silicate level, so during summer and autumn silicate concentration were moderately high due to the domination of Chlorophyceae and Cyanobacteria particularly at stations X and XI, which do not need silicate for growth.

The extremely high phytoplankton count in the lake all the year round indicated a dramatic increase in the eutrophication level during the year.

Species diversity

Generally, Lake Burullus showed a pronounced increase in the diversity during the year 2003, (1.47–3.66 nats) when compared with the previously recorded during 1987–1988 (0.38–2.93 nats) by El-Sherif, (1993) and during 97–98 (0.21–1.06 nats) by Radwan, (2002), as shown in Table II. The diversity index depend on the dominance of species not on the total phytoplankton counts i.e. when many species shared in the phytoplankton bloom, higher values of diversity were recorded and vice versa

The diversity varied from one station to the other within the same season, (Figure 7). The average diversity values fluctuated between 2.13–3.03 nats (Stations I & VI respectively). Generally the average values of species diversity (2.87, 2.31 & 2.25 & 3.08 nats for winter, spring, summer & autumn, respectively) and phytoplankton density relatively higher in spring than the other seasons (2.5×10^6 units l^{-1}) and the species richness were nearly similar for the all seasons (119, 113,104 & 114 respectively). The high diversity values are attributed to the dominance of several species.

The absolute value of species diversity during winter fluctuated between 1.47 (station XI) and 3.54 (station X) as shown in Figure 7. The lowest value was attributed to the dominance of two species; *Stephanodiscus* sp., constituting about

65.9% and *Melosira varians* 16.7% by number to the total count, at this station, species number reached 40 species, while the highest value was recorded at station X was accompanied with high number of species (67 species) and the dominancy was shared by more than one species *Ankistroduesms falcatus var. spiriliformis*, *Melosira varians* (11.2%), *Scenedesmus quadricanda* 8.4%, *Ankistrodesmus falcatus var. acicularis* 4.3% *Ankistrodesmus falcatus var. mirabile* 3.3% to the total count there.

During spring, diversity ranged between 1.7 nats (station X) and 2.8 nats (station I) as shown in Figure 7. The lowest one was due to the dominance of *Stephanadiscus* spp. 65.8% & *Ankistrodesmus* spp. 14.7% since the species richness were 78 species and phytoplankton count reached 6.7×10^6 units l^{-1}. On the other hand, the highest one was attributed to the dominance of more than one species, *Ankistrodemus* spp. (22.6%) *Carteria cordiformis* (11.2%), *Melosira* spp. (8.2%), *Scenedesmus* spp. (10.9%), *Nitzschia* spp. (7.0), *Euglena* spp. (5.8%), *Chlamydomonas* spp. (5.7%) and *Navicula* spp. (5.5%). Phytoplankton count attained 0.5 $\times 10^6$ units l^{-1} and number of species reached 36 species at the same time.

The lowest diversity value during summer was recorded at station IV (1.55 nats) where 32 species were recorded and total phytoplankton count reached 1.7×10^6 units l^{-1}, the dominant species were *Scenedesmus quadricanda* (39.4% to the total phytoplankton count at this station), *Stephanodiscus* sp. (19.2%), *Nitzschia microcephala* (12.8%) and *Scenedesmus bijugatus* var. *atternas* (10.9%). While the highest diversity summer value was recorded at station XI (2.96 nats), the most dominant species were *Melosira varians* (7.4%), *Ankistrodemus falcatus* var. *mirabile* (5.1%), *Stephanodiscus* sp. (5.0%), *Scenedesmus quaricauda* (4.0%), *Scenedesmus bijugatus* var. *alternans* (3.4%) and *Ankistrodesmus falcatus* (2.7%). During autumn, the minimum value (2.53 nat) recorded at station I, and the phytoplankton count was low 0.2×10^6 units l^{-1} and species richness was relatively low (41 species) and the dominancy was shared by many species, *Scenedesmus quadricauda* (27.1%), S*cenedesmus acutus* (15.8%) and S*cenedesmus bijugatus* (14.2%), *Ankistrodesmus falcatus* (9.7%), *Ankistrodesmus falcatus* var. *mirabile* (6.3%), *Ankistroduesms falcatus* var. *acicularis* (4.2%) and *Chlorella vulgaris* (3.0%).

The highest diversity value recorded during autumn (3.66 nats) at station VI, also high number of species was recorded (65 species) and harbored high phytoplankton count (3.1×10^6 units l^{-1}) and Cyanobacteia and Chlorophyceae were the dominant group, representing by *Oscillatoria limnetica* (9.2%), *Dactylococcopsis irregulus* (6.1%), *Spirulina major* (5.1%), *Merismopedia minima* (6.1%), *Scenedesmus bijugatus* (4.9%), *Carteria cordiformis* (5.0%), *Sc. quadricauda* (4.1%), *Sc. bijugatus* var. *atternans* (4.1%), *Lyngbya limnetica* (4.0%), *Chlamydomonas reinhardii* (4.1%), *Chlamydomonas snowii* (2.9%) and *Chlamydomonas ehrenbergii* (2.5%).

Phytoplankton structure and environmental conditions:

The correlation coefficient of phytoplankton count, its main groups with some physical and chemical parameters are given in Table III.

TABLE III

Significant correlation coefficient at $P \leq 0.05$ of biological factors with some physical and chemical environmental factors in Lake Burullus during 2003

Parameters/Groups	pH	Temp.	TSM	Salinity	NO_2	NO_3	SiO_4	Trans.
Phytoplankton	0.5086		−0.4286	−0.3162			−0.3775	
Bacillariophyceae	0.2865		0.2713				−0.4010	
Chlorophyceae	0.2528		−0.3712	0.3472				0.2481
Cyanobacteria	0.2886	0.3141						0.2845
Euglenophyceae	–	0.2471	−0.244		0.2987	0.2448		

As shown in Table III, pH values are significantly positively correlated with all biological factors, due to consuming CO_2 by phytoplankton photosynthesis (Raymonat, 1980 and Shiyu and Zhaowen, 1996). While phytoplankton count was negatively correlated with both TSM and water salinity, so the most phytoplankton community was fresh or brackish forms and with silicate concentration. Bacillariophyceae showed positive correlated with TSM and negatively correlated with silicate concentration.

Stepwise multiple regression models showed the dependence of phytoplankton count, Bacillarophyceae, Chlorophyceae on the most correlative environmental factors are as follows.

$$\text{Total phytoplankton} = -1.0467069 + 0.309\,\text{pH} - 0.333\,\text{TSM} - 0.265\,\text{SiO}_4 \quad (\text{MR} = 0.63)$$

$$\text{TotalBacillarophyceae} = 2107890 - 0.4013\,\text{SiO}_4 - 0.272\,(TSM) \quad (\text{MR} = 0.48)$$

$$\text{T.Chlorophyceae} = -8985461 + 0.495\,\text{pH} - 0.218\,\text{TSM} \quad (\text{MR} = 0.60)$$

$$\text{T.Cynobacteria} = -1398833 + 0.315\text{temp.} + 0.191\text{trans.} - 0.149\,\text{TSM} \quad (\text{MR} = 0.47)$$

$$\text{T.Euglenophyceae} = 214160.1 - 0.254\,\text{temp.} + 0.221\,\text{Trans.} \quad (\text{MR} = 0.33)$$

$$\text{Diversity} = 5.524763 - 0.417\,\text{TSM} + 0.311\,\text{OOM} - 0.140\,\text{pH} - 0.247\,\text{NH}_4 + 0.21\,\text{NO}_3 \quad (\text{MR} = 0.48)$$

Eutrophication Index:

The trophic state index (TSI) is a valuable tool in determining the condition of a lake or in comparing the present condition to the past.

The TSI values calculated from Chlorophyll-a ($\mu g\,l^{-1}$), secchi depth (m) and total phosphorus ($\mu g.\,l^{-1}$). The original intent of Carlson's TSI (Carlson, 1977) was to provide a numerical scale, lakes with TSI values of 0–40 are generally considered oligotrophic, and those with a TSI of 40–50 are mesotrophic and above 50 indicate eutrophy. According to the trophic index reported by Carlson (1977) and based on our data, TSI indicates that all stations of Lake Burullus were found in the eutrophic state.

The mean values of TSI (Table IV) for Lake Burullus water ranged from 74 (station XI) to 84 (station VIII). Station VIII revealed to be highly eutrophied

TABLE IV

Total phosphorus chlorophyll-a, secchi depth and Trophic State Index (Carlson, Index) of Lake Burullus during 2003

	Total phosphorus (mmole l^{-1})				Chlorophyll-a ($mg.l^{-1}$)				Secchi depth (m)				
Stations	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Average of Trophic State Index (TSI)
I	8.52	8.9	12.73	5.63	30.8	42.16	30.24	47.4	0.35	0.25	0.25	0.3	76
II	3.4	9.3	15.4	13.5	28.9	32.43	65.16	42.66	0.35	0.22	0.23	0.25	77
III	6.64	8.87	10.5	6.34	13.8	62.13	51.53	35.6	0.4	0.32	0.25	0.25	75
IV	3.8	7.48	9.49	10.29	17.3	42.25	67	40.6	0.4	0.24	0.17	0.25	76
V	7.6	8.13	7.56	5.54	26.1	55.29	42.1	43.4	0.35	0.24	0.15	0.4	76
VI	4.4	11.61	8.5	7.06	42.2	35.71	90.65	37.26	0.45	0.3	0.23	0.4	76
VII	11.3	9.91	8.11	15.38	31.8	58.1	94.35	62.8	0.45	0.17	0.21	0.3	78
VIII	16.7	18.79	17.68	21.42	76.3	121.79	127.4	71.1	0.45	0.2	0.22	0.2	84
IX	4.2	6.96	5.38	6.17	35.6	54.83	109.05	47.92	0.6	0.22	0.23	0.45	75
X	4.8	19.3	8.19	9.3	23.7	85.73	49.8	30.4	0.5	0.25	0.2	0.35	76
XI	12.9	11.47	4.55	4.28	52.2	42.45	103.11	55.07	0.55	0.29	0.3	0.5	74

Oligotrophic (TSI from 40)
Mesotrophic (TSI 40 to 50)
Eutrophic (TSI > 50)
Hypertropic (TSI > 70)

(hypertrophic) is affected with wastewater drainage from drain 8 and drain 9 located in the Southern region of the lake which reflects relatively high phytoplankton count (1.4×10^6 units l^{-1}) and Chlorophyll-a value (99.15 $\mu g\, l^{-1}$), were recorded at this station.

The trophic status throughout the lake varied spatially and temporally. Generally, the TSI usually shifts from eutrophic to mesotrophic or to hypertrophic conditions depending on the dynamic of water, density flow characteristics and watershed runoff.

Conclusion

The investigated area received huge amounts of drainage water enriched with agricultural fertilizers in addition to domestic industrial effluents and sewage effluents. Beside the invasion of submerged hydrophytes which covered a wide area, as well as decrease amount of fresh water and sea water interring to the lake through El-Boughaz opening. These conditions affected directly and/ or indirectly the water quality of the lake, causing eutrophication state, such as increasing amount of dissolved inorganic nitrogen, phosphate and silicate concentrations. These causes higher phytoplankton count, diversity index and chlorophyll-a content. Such situation provides a warning alarm against the increased pollution in the lake. It is recommended to control discharge of drainage and sewage water into the lake or at least minimize the usage of fertilizers in agricultural lands, or treatment of drainage water is essential to hurry its recovery and improving water quality.

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