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SEASONAL DYNAMICS OF PHYTOPLANKTON COMMUNITY IN THE BITTER LAKES AND TEMSAH LAKE

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ABSTRACT

Water and phytoplankton samples were sampled on a seasonally basis, from autumn 2002 to summer 2003 at five stations located in Bitter Lakes and four at Temsah Lake. A total of 116 taxa were identified, among which 72 taxa of diatoms, 16 dinoflagellates, 14 chlorphytes, 11 cyanophytes, two euglenophytes and one silicoflagellate species. Bitter Lakes were more diversified than Temsah Lake, although the highest population density was recorded at Temsah Lake. A total of 108 taxa were identified in Bitter Lakes among which 68 taxa of diatoms, 15 dinoflagellates, 11 chlorophytes, 11 cyanophytes two euglenophytes and one silicoflagellate species, while 102 taxa were identified among which 60 taxa of diatoms, 14 dinoflagellates, 14 chlorophytes, 11 cyanophytes, two euglenophytes and one silicoflagellate species in Temsah Lake. The very high phosphate and nitrate concentrations in the two lakes are indicators of pollution which may be due to the discharge of agricultural and sewage wastes enriched with nutrients as well as the human activities there. Chlorophyll-*a* content showed similar pattern of changes as that of phytoplankton abundance. It varied between 0.40 mg/m^3 and 1.03 mg/m^3 (Bitter Lakes) and between 0.67 mg/m^3 and 1.54 mg/m^3 (Temsah Lake)with annual average of 0.65 mg/m^3 and 1.02 mg/m^3 , respectively. Diversity values varied between 2.64 nats and 3.92 nats (Bitter Lakes) and between 1.28 nats and 3.78 nats (Temsah Lake), with annual average of 3.3 nats and 2.59 nats respectively. Statistically, positive correlations were found between phytoplankton counts and dissolved oxygen ($r = 0.64$ & 0.93), nitrate ($r = 0.52$ for Bitter Lakes), phosphate ($r = 0.48$ & 0.64)for Bitter Lakes and Temsah Lake, respectively. While an inverse correlation was observed between the phytoplankton abundance and species diversity ($r = -0.75$) in Temsah Lake. In addition the stepwise multiple regression equations were calculated for the biological characteristics in relation to physico-chemical characteristics for each lake. The present study indicates that the phytoplankton in the two lakes of Suez Canal was slightly more diversified than other adjacent areas (Suez and Aqaba Gulfs of the Red Sea as well as the Egyptian waters of eastern Mediterranean). There was a pronounced drop in phytoplankton abundance and high nutrient concentrations in the two lakes when compared with previous studies. Our recommendation is to avoid as far as possible the discharge of oil spills, sewage and agriculture wastes into the water of Suez Canal, specially at Temsah Lake.

1. INTRODUCTION

Although many studies were carried out on Suez Canal, more detailed informations are still required due to the important geographical and economical position and the continuous changes in this area. In addition, the Suez Canal is considered as a transitional zone that connects between two basically different basins, the Indo-pacific Red Sea basin and the Atlanto-Mediterranean basin which in turn influenced the fauna and flora.

The Suez Canal is about 170 km extended from Port-Said at the North to Port Tawfik in the south. It lies between longitudes 32^o 20` and 32° 35` E and between latitudes 29° 55` and 31° 15` N (Fig. 1). Manzallah, Temsah and Bitter Lakes are the most common lakes in the Suez Canal. Temsah Lake lies at 76 km from the northern part of the Canal (Port-Said), with sandy shores and restricted hard bottom of beach-rock type. It is affected by agricultural wastes and land-based activities of Ismailia city. Bitter Lakes lies between Devresoir at 97.5 km and Shandoura at 134.5 km from the north. This area is considered as a transit region for ships passing through the canal. Due to the high salinity of the Bitter lakes, they represent a unique and exceptional habitat which attracted many workers to carry out studies on species composition, total standing crop and diversity of fauna and flora living there. Salinity was 51.84‰ during 1924-25, which declined to 48.84‰ in 1993-34; 47.93‰ in 1954-55; 46.9‰ in 1966 (Morcos 1960 and 1967); 44-47‰ during 1970-71 (Dowidar, 1972) and finally reached between 41.8-42.3 ‰ during 2002-03 (Table 1, Abdel Rahman, personal communication).

From these records it is obvious that Bitter Lakes still represent a unique habitat isolated than the other regions in Suez Canal. On the other hand water salinity in Temsah Lake was lower than Bitter lakes. It has salinity stratification where it receives brackish water from the western lagoon overtopping its high saline water. The lake is polluted due the industrial pollution from shore-line workshops, domestic sewage from unconnected areas adjoining the shore and agricultural drainage water. However, Mac Donald (1933) studied the distribution of phytoplankton and zooplankton in Suez Canal. Ghazzawi (1936) surveyed the phytoplankton in the same area. Halim (1970) carried out a study on phytoplankton of extreme north of Suez Canal, where in this period the salinity of the Bitter Lakes was extremely high and differed completely from Port-Said region which received freshwater discharge from the Nile River, which in turn harbored a diversified flora. He recorded *Ceratium egyptiacum, Peridinium africanoïdes, Peridinium exiquipes, Peridinium nipponicum, Pyrodinium schilleri* in the canal for the first time. Dowidar (1971, 1972) carried out a study on the distribution, ecology and morphological variations of *Ceratium egyptiacum* and its validity as indicator of the current regime. Furthermore, Dowidar (1976) conducted a study on phytoplankton in Suez Canal. Dorgham and Dowidar (1983) conducted a study on seasonal and spatial biometric variation in *Rhizosolenia shrubsolei* from 3 areas in the Suez Canal. Furthermore, Dorgham (1985) investigated the distribution of phytoplankton in spring along the Suez Canal and recorded 102 species of diatoms and 31 of dinoflagellates. Continuous to his investigations, Dorgham (1990) studied in details the phytoplankton of the northern end of Suez Canal in winter. Recently El-Sherif and Ibrahim (1993) studied the phytoplankton production along Suez Canal and recorded 139 species (94 diatoms, 36 dinoflagellates, 5 cyanophytes). Madkour (2000) carried out ecological studies of the phytoplankton of the Suez Canal. In addition Ismael (2005) investigated the phytoplankton of the Gulf of Suez (south part of the canal) and the effect of ship-traffic and recorded 171 species (88 species dinoflagellates, 69 diatoms, 5 chlorphytes, 4 cyanophytes, 2 coccolithophores and one species for crytophytes, euglenophytes and silicoflagellates.

1.1. Aim of work:

The aim of this study is to determine the composition, abundance and distribution of the phytoplankton community in Bitter Lakes and Temsah Lake, to establish its space-time variations, and to search for probable relationships between these parameters and some environmental factors.

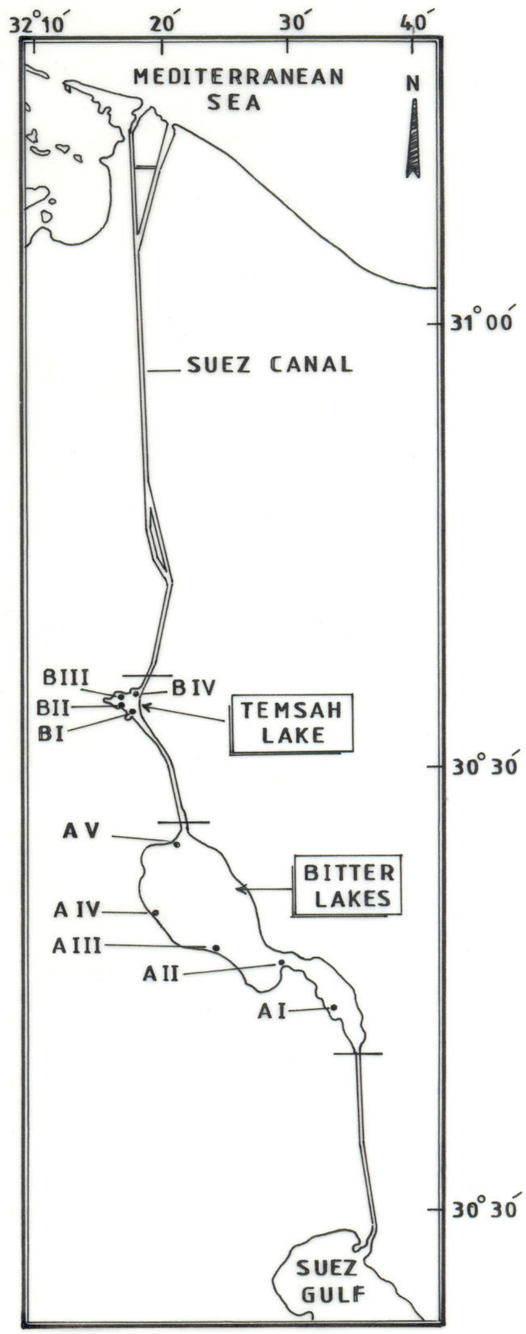

Fig. (1): Positions of the sampling stations

Table (1): The values of salinity in Lake Temsah and Bitter lakes during 2002-2003 (after Abdel Rahman, personal communication)

Months	Lake Temsah			Great Bitter Lake	Small Bitter Lake
	BII	BIII	BIV		
June 2002	38.2	41	42.0	45.0	46.2
July	28	41	43.0	43	43
August	21.4	28.1	33.7	41.0	41.7
Sept.	11	27	32.2	45.3	44
Oct.	23.2	29	32.2	42	42.1
Nov.	33.9	32	37.2	41.8	41.4
Dec.	24	24	35.1	41.1	41.1
Jan.2003	22.4	23.3	30.3	41	40.1
Feb.	6.2	24.6	27.3	41	41
Mar.	13.7	34.2	34.1	41.2	41
April	10.4	16	30.0	42	40.1
May	34.9	31.1	36.2	43	40.2
Average	22.3	29.3	34.5	42.3	41.8

2. MATERIALS AND METHODS

The study area includes Bitter lakes and Temsah Lake. Five stations in Bitter Lakes were sampled namely, shandoura (AI), Kabreit (AII), Fanara (AIII), Fayed (AIV) and Devresoir (AV). In Temsah Lake, four sites were chosen at southern side (BI), southwestern side (BII), northwestern side (BIII) and northeastern side (BIV). Samples were seasonally collected from autumn (2002) to summer (2003).

Water temperature was measured using a simple pocket thermometer graduated to 0.1°C. The pH value was measured in situ using a portable pH meter model Orion 210. Dissolved oxygen determination was carried out according to Winkler method (APHA, 1995), and oxygen percentage saturation was calculated using UNISCO tables (1973).

The phytoplankton abundance was determined using sedimentation method (Ütermohl, 1936) and estimated as number of unit/L (unit comprise cells, filaments, &colonies). Identification of algal taxa followed Peragallo and Peragallo (1897-1908), Lebour (1925), Cupp (1943), Heurk (1962), Sournia (1968, 1986), Tikkanen (1986) and Mizuno (1990). The determination of chlorophyll-*a* was carried out according to the methods described by Parsons *et al.* (1984). Nitrate and phosphate concentrations were obtained by (Hamed, personal communication). Diversity index of phytoplankton community was calculated according to Shannon and Weaver (1963).

Statistical analysis including correlation coefficient between the biological characteristics and physico-chemical parameters were calculated at confidence limit 95% ($P \leq 0.05$) for Bitter Lakes and Temsah Lake (n = 20 & n =16), respectively. Stepwise multiple regression equations were calculated at the confidence limit 95% ($P \leq 0.05$) for Bitter Lakes and Temsah Lake (n = 20 and n = 16), respectively, to quantify the phytoplankton density, chlorophyll-*a* and diversity index in relation to the most correlative environmental factors.

3. RESULTS AND DISCUSSION

3.1. Physical and chemical features:

1) Temperature:

Water temperature did not deviate from the normal seasonal fluctuations of the Egyptian waters (13-32^oC). The lowest values were recorded during winter (17.5-19^oC) and the highest in summer (29.5-31.5^oC) (Table 2). Water temperature showed a close linear correlation with dinoflagellates counts (r = 0.47, $P \leq 0.05$ and n = 20) in Bitter Lakes where the highest counts (average 1041 cell/L) occurred in summer mainly due to *Protoperidinium cerasus* and *Protoperidinium depressum* (Table 4a). These results coincided with that reported by Halim (1969), Ibrahim (1988), Nassar and Hamed (2003).

2) PH value:

PH values were always on the alkaline side and oscillated in a narrow range between 7.85 – 8.30. The highest pH values were related to the increased phytoplankton density (14973 unit/L) (Table 2). Significant positive correlation was found between pH values and temperature at confidence limit 95% (r = 0.59 & 0.56 and n = 20, n = 16) for Bitter Lakes and Temsah Lake, respectively, (Table 4a,b). This may be attributed to that the rise in temperature stimulated phytoplankton photosynthetic activity causing more consumption of carbon dioxide and rise of pH. This result coincided with the data reported by Nassar (2000) in Suez Gulf and Nassar and Hamed (2003) in Suez Bay.

3) Dissolved oxygen:

Dissolved oxygen is an important parameter for identification of different water masses. It is needed by aquatic animals in various degrees of which fishes require the highest levels. For a diversified warm-water biota, the optimum concentrations should not be less than 3.5 ml/L, while for a cold-water biota, concentrations at/or near saturation (not lower than 4.2 ml O_2/L) for desirable healthy growth (Grundy, 1971 and Arin, 1974).

High oxygen concentrations occurred in winter with an average of 4.0 ml O_2/L corresponding to 74.4% DO saturation (Table 2). These concentrations coincided with the lowest winter temperature (16.5 – 19^oC), agitation of water by strong wind and the highest abundance of phytoplankton (8533 unit/L). A noticeable increase in the oxygen content was recorded at Temsah Lake at station (BI) during autumn (4.92 ml O_2/L, corresponding to 113% saturation) which coincided with the highest phytoplankton abundance (14973 unit/L). The concentrations decreased to reach 1.7 ml O_2/L at station AI of Bitter Lakes during summer corresponding to 38.6% saturation coinciding with low phytoplankton abundance (3916 unit/L). The annual average of dissolved oxygen in Bitter lakes was 2.84 ml O_2/L, while it attained 3.64 ml O_2/L in Temsah Lake. Dissolved oxygen exhibits a close correlation with phytoplankton abundance and chlorophyll- *a* (both r = 0.64, $P \leq 0.05$, n = 20) for Bitter Lakes and (both r = 0.93, $P \leq 0.05$, n = 16) for Temsah Lake (Table 4a, b). Such result agrees with those obtained by Abdallah *et al.* (1995a), Gharib (1998), Nasser (2000) and Nasser and Hamed (2003).

4) Nutrient salts:

Phosphorus is essential for aquatic life since it is intimately involved in the energy storage and release systems of all organisms and also it is the key element in the water (Stirn, 1988 and Chisholm, 1992).

The nitrogen besides phosphorus is normally utilized by phytoplankton and both elements are considered to be an index of productive capacity of water (Abdellah *et al.* 1995a). Generally, the variations of nitrate content usually reflects an equilibrium between outside inputs of nitrogen salts through sewage and oil effluents, nitrogen fixation, nitrogen salts regeneration from the bottom and the loss of nitrogen by phytoplankton uptake besides bacterial denitrification (Calvert and Price 1971).

The concentrations of dissolved phosphate and nitrate in Temsah Lake were two folds higher than in Bitter Lakes, with annual averages of 5.71 µmol/L and 2.01 µmol/L for nitrate in Temsah Lake and Bitter Lakes respectively.On the other hand the annual averages phosphate attained 0.803 µmol/L in Temsah Lake and 0.374 µmol/L in Bitter Lakes. The values of nitrate fluctuated from 0.82 µmol/L (Station AI, Bitter Lakes) during summer and 8.14 µmol/L (Station BI, Temsah Lake) during spring, coincided with total count of 3916 unit/L and 6484 unit/L, respectively. On the other hand, the values of phosphate fluctuated from 0.14 µmol/L (Station AI, Bitter Lakes) during summer to 1.11 µmol/L (Station BI, Temsah Lake) during winter coincided with total phytoplankton abundance of 3916 unit/L and 12270 unit/L, respectively (Table 2). According to Stirn (1988) soluble phosphorus in usually present in small quantity except the polluted water where the concentrations tend to be high (0.3 to 0.5 µmol/L), and therefore the Bitter Lakes and Temsah Lake are considered polluted area. The high concentrations of the two nutrients (nitrate & Phosphate) in Temsah Lake may be attributed to the agricultural and sewage wastes, land-based activities of Ismailia city and fresh water discharge into the area from Ismailia freshwater canal. Generally, the total average values of dissolved nitrate and phosphate in both Temsah Lake and Bitter Lakes (3.97 and 0.56 µmol/L, respectively) were relatively high comparing with that recorded in Suez Gulf by Nassar (2000), (0.485 and 0.413 µmol/L for the two parameters, respectively).

However, the increase in nitrate content of seawater is followed by an increase in both phytoplankton production and chlorophyll-*a* (Saad and Fahmy, 1984 and Nassar and Hamed, 2003). This agree with the present results, since the most productive station (BI in Temsah Lake) recorded 10349 unit/L coincided with the highest annual average of nitrate and phosphate in this station (7.79 and 0.94 µmol/L, respectively). While the less productive station during the study period (AI in Bitter Lakes) sustained only 4693 unit/L accompanied with the lowest annual average values of both nutrients (0.95 & 0.2 µmol/L, respectively). The same pattern was followed for chlorophyll-*a* where the maximum annual average value of chlorophyll concentration 1.065 mg/m^3 was recorded at station BI (Temsah Lake) while the minimum annual average of chlorophyll-*a* 0.49 mg/m^3 was recorded at station AI (Bitter Lakes).

Table (2): Variations of temperature (°C), pH values, dissolved oxygen (ml O_2/L), phytoplankton density (unit/L) chlorophyll-*a* (mg/m^3), and species diversity (nats) dissolved nitrate & phosphate (µmol/L) in Bitter Lakes and Temsah Lake during 2002-2003.

		Bitter Lakes					Temsah Lake			
		AI	AII	AIII	AIV	AV	BI	BII	BIII	BIV
Temp.	Autumn2002	25.5	26.5	29	30	28.5	28	29	29	29
	Winter 2003	17.5	18	18.5	19	18	17.5	17	16.5	16.5
	Spring	19	20	21	22	21	20	20.5	20	19.5
	Summer	29	29.5	30	31	31	31	30.5	31.5	31.5
PH	Autumn 02	8.01	8.04	8.05	8.18	8.06	8.12	8.1	8.06	8.03
	Winter 03	7.94	7.94	8.01	8.15	8	7.85	8.03	8.09	8.06
	Spring	8.08	8.15	8.13	8.27	8.08	8.21	8.05	8.03	8.05
	Summer	8.18	8.21	8.26	8.3	8.22	8.15	8.15	8.22	8.23
DO	Autumn 02	2.4	2.47	2.83	2.73	2.5	4.92	4.6	3.84	3.88
	Winter 03	3.2	3.14	3.84	3.28	4.16	4.83	4.23	4.6	4.7
	Spring	2.6	2.78	3.27	3.1	2.85	2.69	3.22	3.11	3.36
	Summer	1.7	1.9	3.14	2.6	2.24	2.63	2.51	2.65	2.48
Phytoplankton	Autumn 02	3839	4361	5953	5532	4354	14973	13936	10496	10594
	Winter 03	4944	4676	8070	5326	8972	12270	9578	11601	11666
	Spring	6077	6891	9077	8327	7167	6484	8837	8348	9463
	Summer	3916	4485	10045	7699	6035	7742	7233	7890	7131
Chl-a	Autumn 02	0.42	0.45	0.61	0.57	0.45	1.54	1.44	1.08	1.1
	Winter 03	0.51	0.48	0.83	0.55	0.92	1.26	0.99	1.18	1.2
	Spring	0.62	0.71	0.93	0.86	0.74	0.67	0.91	0.86	0.98
	Summer	0.4	0.46	1.03	0.79	0.62	0.79	0.74	0.81	0.73
Diversity	Autumn 02	2.92	2.75	2.85	2.64	3.62	1.56	1.68	1.34	1.28
	Winter 03	3.52	3.67	3.88	3.92	2.64	2.81	2.7	2.56	2.23
	Spring	3.16	3.43	3.18	3.25	3.56	3.78	2.8	2.92	3.18
	Summer	3.63	3.55	3.12	3.38	3.39	3.36	3.15	2.9	3.17
Nitrate	Autumn 02	0.88	1.12	2.98	2.56	2.35	7.71	7.32	3.47	3.64
	Winter 03	1.14	1.29	2.58	3.41	2.91	8.14	7.9	3.95	4.24
	Spring	0.82	0.99	2.21	2.75	2.7	7.45	7.33	3.22	3.88
	Summer	0.95	1.04	2.43	3.11	2.88	7.85	7.61	3.6	4.11
Phosphate	Autumn 02	0.18	0.3	0.58	0.48	0.33	1.11	0.93	0.66	0.71
	Winter 03	0.28	0.4	0.7	0.56	0.48	1	0.91	0.78	0.84
	Spring	0.14	0.25	0.44	0.4	0.29	0.86	0.77	0.66	0.85
	Summer	0.20	0.29	0.51	0.35	0.31	0.79	0.82	0.6	0.54

There was a positive significant correlation coefficient between nitrate and total phytoplankton abundance and chlorophyll-*a* for Bitter Lakes (both r = 0.52 at $P \leq 0.05$, n = 20) while insignificant correlation was found between nitrate and phytoplankton abundance and chlorophyll-*a* in Temsah Lake. Correlation between phosphate and phytoplankton abundance and chlorophyll-*a* for Bitter Lakes (both r = 0.48 at $P < 0.05$, n = 20) and for Temsah Lake (both r = 0.64 at $P \leq 0.05$, n = 16) (Table 4a,b). Stepwise multiple regression models were calculated to show the relationship between phytoplankton abundance and the most effective physico-chemical parameters for each lake.

For Bitter Lakes:Total phytoplankton abundance = -94155.6 + 2816 dissolved oxygen + 11396 pH . (r = 0.86 at $P \leq 0.05$, n = 20).

For Temsah Lake: Total phytoplankton abundance = -3848 + 2918 dissolved oxygen + 129 pH.

(r = 0.93 at $P \leq 0.05$, n = 16).

From the two equations it was obvious that dissolved oxygen and pH were the most effective parameters for the two lakes.

3.2. Biological studies:

1) Community composition:

A total of 116 taxa comprising 72 diatoms, 16 dinoflagellates, 14 chlorophytes, 11 cyanophytes, two euglenophytes and one species of silicoflagellates, were collected from both Temsah Lake and Bitter Lakes during the course of the present study. Out of these 7 and 14 species were specific to Temsah Lake and Bitter Lakes, respectively, whereas 95 taxa (57 diatoms, 13 dinoflagellates, 11 chlorophytes, 11 cyanophytes, 2 euglenophytes and one silicoflagellates) were common to both Temsah Lake and Bitter Lakes. The greatest majority of the recorded species (89) showed seasonal occurrence, however, 15 diatoms, 8 dinoflagellates, 3 chlorophytes and one cyanophyte were perennial. Diatoms contributed 60 & 68 taxa, dinoflagellates 14 & 15 taxa, chlorophytes 14 & 11 taxa, cyanophytes 11 taxa for each, euglenophytes 2 taxa for each and 1 silicoflagellate for Temsah Lake and Bitter Lakes, respectively, to a total taxa content of 102 in Temsah Lake and 108 in Bitter Lakes (Table 3).

2) Phytoplankton distribution:

In Bitter Lakes, phytoplankton counts fluctuated between 3839 unit/L (Station AI, autumn 2002) and 10045 unit/L (Station AIII, summer 2003) with an annual average of 6286 unit/L. This value was lower than that recorded in Temsah Lake, where phytoplankton abundance ranged between 6484 unit/L (Station BI,spring 2003) and 14973 unit/L (Station BI, autumn 2002) with an annual average of 9871 unit/L (Table 2 & Fig. 2a,b). The dominant species in Bitter Lakes was *Protoperidinium cerasus* (70.52% to total dinoflagellates and 32.63% to the total counts), followed by *Nitzschia sigma* (21.36% to total diatoms and 13% to total counts), while in Temsah Lake the leader species was *Skeletonema costatum* which contributing 81.22% to total diatoms and 73.46% to total counts. The blooming of *Skeletonema costatum* reflected the effect of freshwater which agreed with Abdallah *et al.* (1995b) who recorded the species as one of the dominant species in the Eastern Harbour and was mainly related to low salinity affinity and was negatively correlated with the salinity. The dominance of any species in polluted water for one season or more constituting about 10% of the total community may be considered as pollution indicator species (Mihnea, 1985) and therefore *Skeletonema costatum* may be considered as one of these species. Our results agreed with El-Sherif (1993 & 1994), El-Sherif and Gharib (1994) and Nassar (2000) who reported that *Skeletonema costatum* is a pollution tolerant and indicator species of eutrophication.

Table (3): Number of genera and species of different groups and relative abundance in Bitter Lakes and Temsah Lake of Suez Canal during 2002-2003.

	Bitter Lakes				Temsah Lake				Total				Suez Canal 1991 (El-Sherif and Ibrahim, 1993)			
	Genera	species	Total abundance (u/L)	% to total abundance	Genera	species	Total abundance (u/L)	% to total abundance	Genera	species	Total abundance (u/L)	% to total abundance	Genera	species	Total abundance (u/L)	% to total abundance
Bacillariophyceae	35	68	4725	75.16	30	60	7967	80.71	37	72	6166	78.25	40	94	15895	97.3
Dinophyceae	9	15	955	15.20	9	14	608	6.16	10	16	801	10.16	11	36	401	2.45
Chlorophyceae	8	11	230	3.66	9	14	741	7.51	9	14	457	5.80	3	3	46	0.3
Cyanophyceae	7	11	330	5.25	7	11	474	4.80	7	11	394	5.0	4	5		
Euglenophyceae	2	2	34	0.54	2	2	68	0.69	2	2	49	0.62	-	-		
Silicoflagellates	1	1	12	0.19	1	1	13	0.13	1	1	13	0.17	1	1		
Total	62	108	6286	100	58	102	9871	100	66	116	7880	100	59	139	16342	100

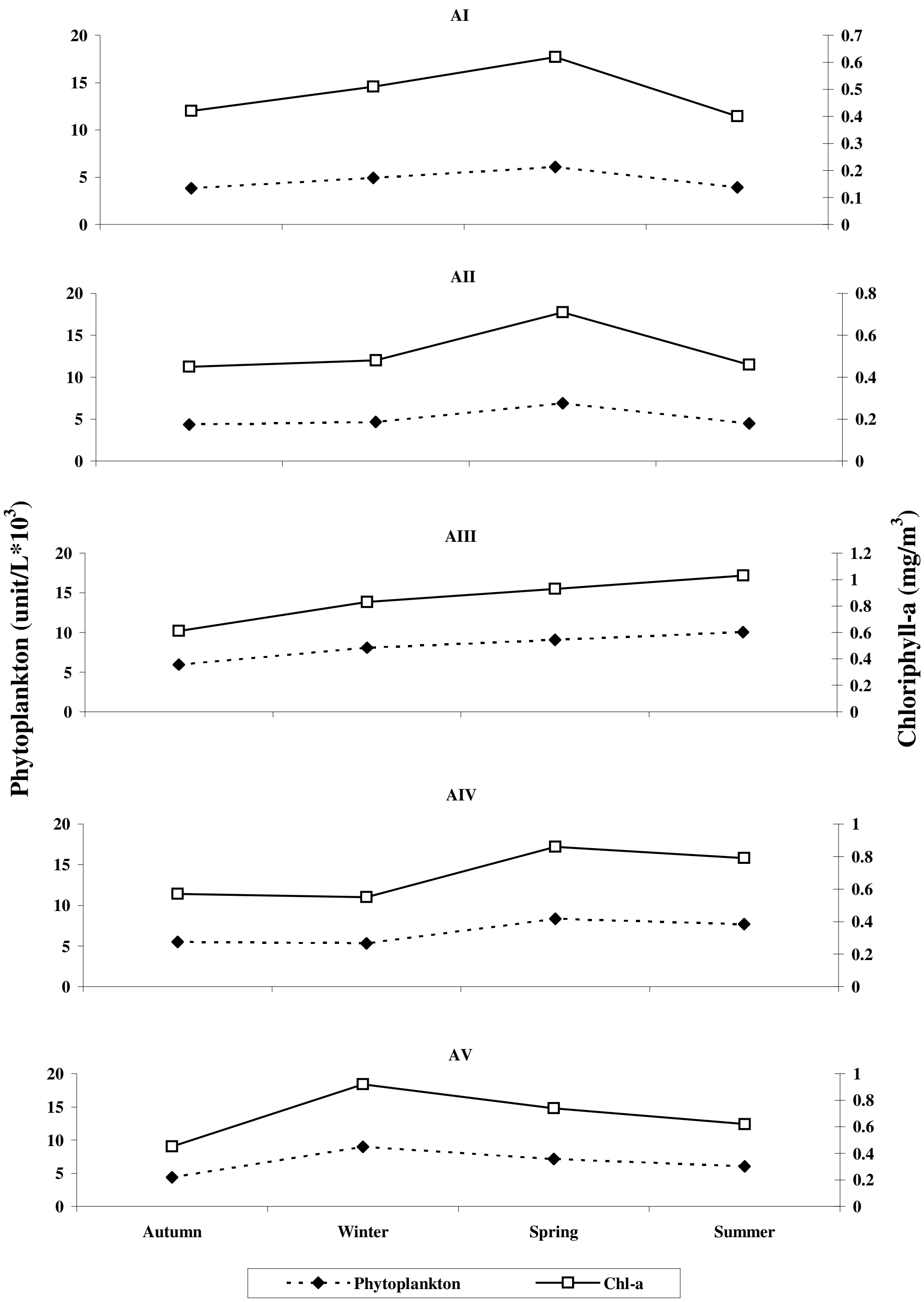

Fig. (2a): Phytoplankton abundance (unit/L x 10^3) and chlorophll-a in (mg/m^3) each station in Bitter Lakes during 2002-2003.

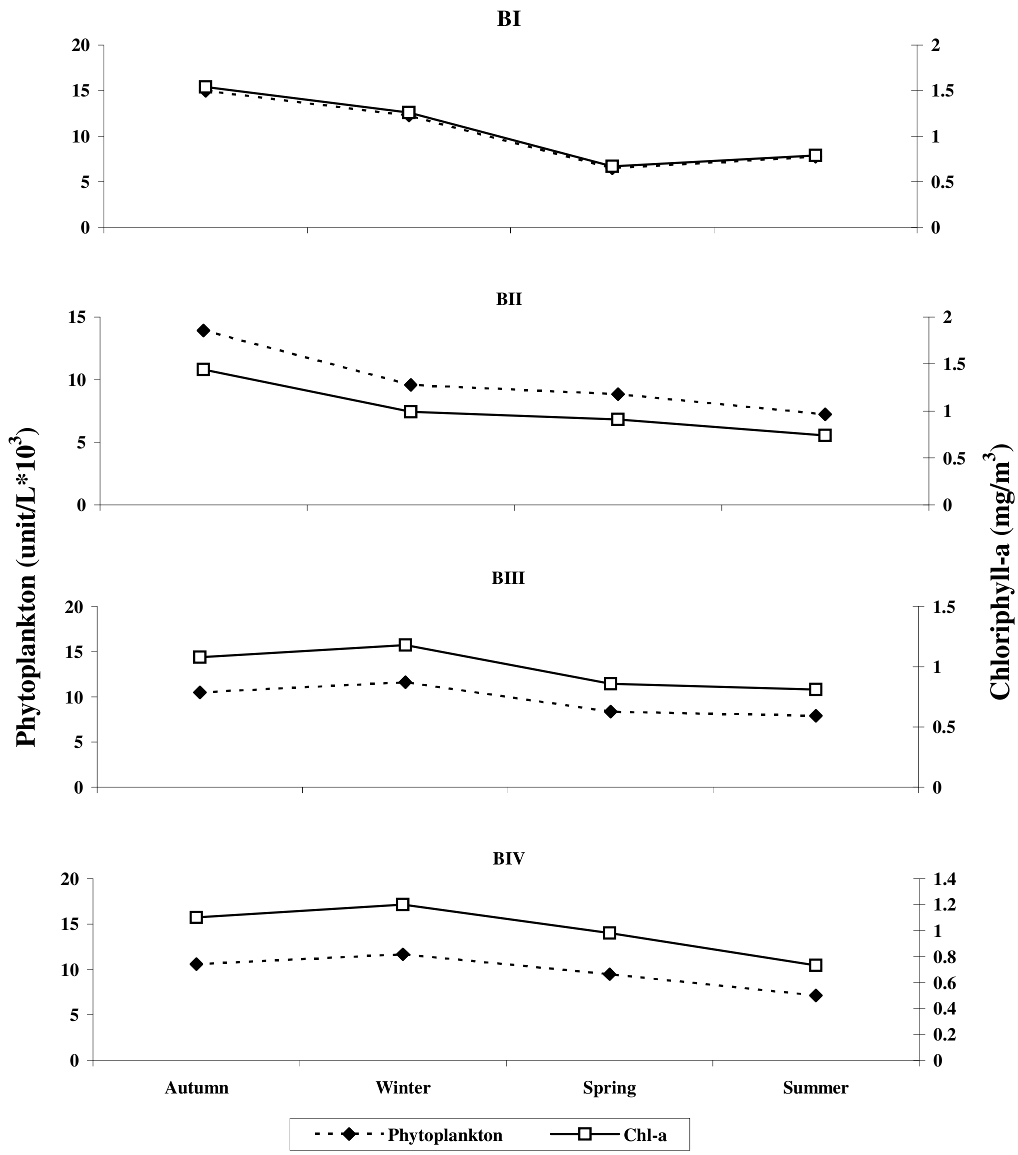

Fig. (2b): Phytoplankton abundance (unit/L x 10^3) and chlorophll-a (mg/m^3) in each station in Temsah Lakes during 2002-2003.

The relatively average values in the different stations of Bitter Lakes were 8285, 6720 and 6632 unit/L at stations AIII, AIV and AV, respectively, (Fig. 3). These values were coincided with average concentration of chlorophyll-*a* 0.85, 0.69, and 0.68 mg/m^3, respectively (Table 2). While in Temsah Lake the values were 10349, 9879, 9563 and 9694 unit/L at stations BI, BII, BIII and BIV coincided with average concentration of chlorophyll-*a* 1.065, 1.02, 0.98 and 1.002 mg/m^3, respectively. The lowest counts of phytoplankton (average of 5102 and 4693 unit/L) were found at station AII and AI accompanied with the lowest average concentrations values of chlorophyll-*a* 0.52 and 0.49 mg/m^3 respectively. This may be due to the lowest average concentrations of phosphate and nitrate which in turn affected the phytoplankton growth (0.89 and 0.95 µmol/L for nitrate and 0.31 and 0.2 µmol/L for phosphate, respectively).

The regional and seasonal variations of chlorophyll-*a* followed a similar pattern of distribution to that of phytoplankton abundance (Fig.2a,b). For Bitter Lakes the highest concentration (1.03 mg/m^3) was recorded at station AIII and the lowest (0.40 mg/m^3) at station AI, both recorded during summer and had an annual average of 0.65 mg/m^3. The concentrations of chlorophyll-*a* in Temsah Lake fluctuated between 0.67 mg/m^3 (Station BI, spring) and 1.54 mg/m^3 (Station BI, autumn) with an annual average of 1.02 mg/m^3. For the trophic characterization of lakes reported by OECD (1982), Bitter Lakes and Temsah Lake are characterized among oligotrophy. A positive correlation was observed between chlorophyll-*a* and reactive phosphate ($r = 0.48$ at $P \leq 0.05$, $n = 20$) and dissolved nitrate ($r = 0.52$ at $P \leq 0.05$, $n = 20$) in Bitter Lakes. While a positive correlation was observed between chlorophyll-*a* and phosphate ($r = 0.64$ at $P \leq 0.05$, $n = 16$) in Temsah Lake (Table 4a,b). In addition stepwise multiple regression models were calculated for each lake to show the relationship between chlorophyll-*a* and the physico-chemical parameters.

For Bitter Lakes:
chlorophyll-*a* = -9.52535 + 0.287 dissolved oxygen + 1.15 pH.
($r = 0.86$, $P \leq 0.05$, $n = 20$).
For Temah Lake:
chlorophyll-*a* = -0.39957 + 0.301 dissolved oxygen + 0.0133 pH.
($r = 00.93$, $P \leq 0.05$, $n = 16$).

The equations showed that for chlorophyll-*a*, as for phytoplankton abundance, dissolved oxygen and pH were most effective factors for the two lakes.

3) Seasonal variations:

The highest density of phytoplankton was recorded during autumn 2002 and winter 2003 in Temsah Lake with averages of 12500 unit/L and 11279 unit/L, respectively. *Skeletonema costatum* was the dominant species in autumn contributing 82.66% to total diatoms and 74.4% to total counts, while *Chaetoceros anastomosans* was the leader during winter contributing 63.24% to total diatoms and 45.88% to total phytoplankton abundance. While in Bitter Lakes the highest total average phytoplankton counts was 7508 unit/L recorded during spring. *Asterionella japonica* was the dominant contributed 17.71% to total diatoms and 15.08% to total counts. *Chaetoceros curvisetus* was second forming 11.39% to total diatoms and 9.7% to phytoplankton abundance. The third species was *Hemiaulus heibergii* contributing 10.03% to total diatoms and 8.54% to total phytoplankton abundance.

Finally, in this study comparison between the Bitter Lakes and Temsah Lake showed differences in phytoplankton abundance, the dominance of species and the seasonal distribution in addition to phytoplankton composition.

Table (4a): Correlation matrix of some measured items in Bitter lakes during 2002-2003.

	Temp.	pH	DO	Phyto	Chl-a	Diversity	Nitrate	Phosphate
Temp.	1							
pH	0.59	1						
DO	-0.67	-0.37	1					
Phyto	-0.18	0.33	0.64	1				
Chl-a	-0.18	0.33	0.64	1	1			
Diversity	-0.25	0.02	-0.06	-0.15	-0.16	1		
Nitrate	0.13	0.32	0.45	0.52	0.52	0	1	
Phosphate	-0.1	-0.02	0.67	0.48	0.48	0.03	0.7	1

N=20, p>0.05, r>0.42 is significant

Table (4b): Correlation matrix of some measured items in Temsah lake during 2002-2003.

	Temp.	pH	DO	Phyto	Chl-a	Diversity	Nitrate	Phosphate
Temp.	1							
pH	0.56	1						
DO	-0.44	-0.62	1					
Phyto	-0.15	-0.47	0.93	1				
Chl-a	-0.15	-0.48	0.93	1	1			
Diversity	-0.21	0.3	-0.65	-0.75	-0.75	1		
Nitrate	-0.04	-0.1	0.12	0.12	0.12	0.22	1	
Phosphate	-0.34	-0.4	0.64	0.64	0.64	-0.16	0.71	1

N=16, p>0.05, r>0.43 is significant

In Bitter Lakes (Table 5) about 12 species of diatoms and two of dinoflagellates were recorded and completely missed in Temsah Lake. The diatoms species were *Climacospheria moniligera, Climacodium bicocavum, Striatella unipunctata, Laudrea borealis, Rhizosolenia alata* form *indica, Rhizosolenia stolterforthii, Biddulphia farus, Guinardia flaccida, Licmophora gracilis, Licmophora abbreviata, Licmophora flabellata* and *Pleurosigma angulatum* and the dinoflagellates were *Phalacroma rapa* and *Ceratium tripos*.

On the other hand, four species of diatoms (*Chaetoceros coarctatus, Biddulphia auriata, Rhabdonema adriacticum* and *Bellarochea* sp.), three of chlorophytes (*Pediastrum boryanum, Pediastrum tetras* and *Oocystis borgei*) and one of dinoflagellates (*Goniaulax minuta*) were restricted only to Temsah Lake.

The phytoplankton species in the Bitter Lakes belong to 62 genera, while in Temsah Lake they belong to 58 genera (Table 3).

Some of these species as *Ceratium egyptiacum, Rhizosolenia spp. and Hemiaulus heibergii* are littoral forms with tropical and/or subtropical affinities and widely distributed in the neritic waters of the Mediterranean Sea and Indian Ocean (Sournia, 1968 and Dowidar, 1974). Several other species as *Pediastrum tetras, Chroococus turgidus , Oscillatoria limnetica, O. tenuis, Phormidium sp.*and *Spirulina platensis* are freshwater inhabitants were previously observed in Suez Canal, Suez Gulf and the northern part of the Red Sea (El-Sherif and Ibrahim, 1993, El-Sherif and Abo El-Ezz, 2000 and Nassar and Hamed, 2003).

4) Species Diversity:

Diversity index was employed as parameter to define the structure of the phytoplankton community in the study area. However spacial and seasonal variations in number of species or richness reflected on the diversity index. Generally, The Shannon-Wiener diversity indices in Bitter Lakes were usually higher than that recorded in Temsah Lake and having a narrow range of variation. It was found to be between 2.64 nats (Sts. AIV & AV, autumn and winter, respectively) and 3.92 nats (St. AIV, winter), with a mean of 3.30 nats. The high value of diversity was associated with large number of taxa (57 taxa), i.e., the community was shared by several taxa. While in Temsah Lake, diversity index had wider range of variation and fluctuated between 1.28 nats (St. BIV, autumn) and 3.78 nats (St. BI, spring) with a mean of 2.59 nats. The low value was met with low number of taxa (33 taxa) and the peak was mainly caused by the development of single or few dominant species. The leading diatom *Skeletonema costatum* formed about 77% of the total phytoplankton counts. On the other hand, diversity index in Bitter Lakes and Temsah Lake during spring 2003 (3.32 & 3.17 nats) were associated with large number of taxa (61 & 62 taxa), respectively. While the low values in Bitter Lakes and Temsah Lake during autumn 2002 were met with low number of taxa (47 taxa for each).However the reduction in both the number of dominant species and diversity index and the appearance of one or two resistant algae in considerable numbers in Temsah Lake are indicators of domestic and industrially polluted environment (Umamaheswara Rao and Mohanchand, 1988 and Nassar, 2000). On the other hand diversity values in the study area are relatively higher than that previously recorded in the Suez Canal (0.7 – 2.72 nats) by El-Sherif and Ibrahim (1993). Species diversity in Temsah Lake was negatively correlated with phytoplankton abundance and chlorophyll-*a* (both $r = -0.75$, $P \leq 0.05$, $n = 16$) while no significant correlation was found in Bitter Lakes (Table 4a,b). This was supported by stepwise multiple regression equations which were calculated to show the relationship between diversity and the most effective physico-chemical parameters for each lake.

For Temsah Lake: diversity = 6.687 – 0.8 dissolved oxygen – 0.076 temperature + 0.112 nitrate.

($r = 0.91$ at $P \leq 0.05$, $n = 16$).

Comparison between observed and calculated values of phytoplankton abundance, chlorophyll-*a* and diversity showed a small average error, which may be due to the interference of the factors that were not included in the model equations (Fig. 4a,b).

Table (5): List of the recorded species of phytoplankton in Bitter Lakes and Temsah Lake of Suez Canal 2002-2003.

Class	B. Lakes	T. Lake	Aut. 2002	Win. 2003	Spr.	Sum.
Bacillariophyceae						
Asterionella japonica Cleve	+++	+++	+++	-	+++	+
Amphora marina Smith	+	+	+	+	+	+
Amphiprora paludosa W. Smith	++	+	+	+	+	++
Amphiprora alata Kütz	++	+	+	-	+	++
Bacillaria paradoxa (Gmel.) Grun.	+	+	+	+	+	++
Bellarochea sp.	-	+	-	-	+	-
Biddulphia longicruris Grev.	+	+	-	+	+	-
Biddulphia farus Her.	+	-	-	-	-	+
Biddulphia obtusa Kütz	+	+	-	-	+	+
Biddulphia mobiliensis Bail.	+	+	-	-	+	+
Biddulphia auriata (Lyng.) Breb.	-	+	+	-	+	+
Campylodiscus noricus var. hibbernica Ehr	+	+	+	+	+	-
Cerataulina bergonii H.Pergallo	+	+	-	++	-	-
Chaetoceros decipiens Cleve	++	+	+	-	++	+
Chaetoceros curvisetus Cleve	+++	+	+	+	+++	++
Chaetocerus tortissimus Gran.	++	+	++	-	+	-
Chaetoceros lorenzianus Grun.	+	+	-	+	+	-
Chaetoceros peruvianus Brightwell	+	+	+	-	+	-
Chaetoceros anastomosans Grun.	++	+++	+	+++	+	-
Chaetoceros coarctatus Lauder	-	+	-	-	-	+
Climacodium biconcavum Cleve	+	-	-	-	+	-
Climacosphenia moniligera Ehr.	+	-	+	-	+	+
Cocconeis placentula Ehr.	+	+	+	+	-	-
Coscinodiscus granii Gough	++	+	-	++	-	+
Coscinodiscus radiatus Ehr.	+	+	+	++	+	++
Cyclotella meneghiniana Kütz	+	+	+	+	+	+
Cymbella ventricosa Kütz	+	+	+	+	+	+
Diploneis interrupta Kütz &Cleve	+	+	+	-	-	-
Fragillaria sp.	+	+	++	+	-	+
Guinardia flaccida H.peragallo	+	-	-	-	+	-
Gyrosigma attenuatum Ehr.	+	+	+	++	++	++
Gyrosigma balticum Ehr.	+	+	+	+	+	+
Hemiaulus heibergii Cleve	++	++	-	-	+++	-
Lauderia borealis Gran.	+	-	-	-	+	-
Leptocylindrus danicus Cleve	+	+	-	-	++	++
Licmophora gracilis Ehr (Grunow)	+	-	+	+	-	+
Licmophora abbreviata Ag.	+	-	-	+	-	-
Licmophora flabellata (Gran) Ag.	+	-	-	+	-	-
Melosira granulata Ehr.	+	+	+	+	+	-
Melosira sulcata (Her.) Kütz	+	+	-	+	+	+
Melosira varians C.A. Ag.	+	+	-	-	-	+
Navicula gracilis Cleve	+	+	+	+	++	+
Navicula cryptocephala Kütz	+	+	+	-	+	+
Navicula placentula Ehr.	+	+	+	+	+	-
Navicula cuspidata Kütz	+	+	+	+	+	-
Navicula dicephala Ehr.	+	+	+	-	-	-

Table (5) Continued

	B.	T.	Aut.	Win.	Spr.	Sum.
	Lakes	Lake	2002	2003		
Nitzschia sigma Kütz	+++	+	+	++	+	+++
Nitzschia longissima Her.	++	++	+	++	++	++
N. pungens var. atlantica Cleve	++	+	-	++	+	++
N. pacifica Cupp.	+	+++	-	-	-	+++
N. seriata Cleve	+	+	-	-	-	++
N. closterium (Ehr.) W. Smith	+	++	-	++	-	-
N. Kützingiana Hilse	++	+	-	++	-	-
Pleurosigma angulatum Quekett W. Smith	+	-	-	-	+	-
Rhabdonema adriaticum Kütz	-	+	-	-	-	+
Rhizosolenia alata f. gracillima (Cleve) Grun.	++	++	-	++	+++	+
R. alata f. indica H. Peragallo	+	-	+	-	+	-
R. imbricata (Cleve) Schroder	+	+	-	-	+	-
R. calcar avis M. Schultz	+	+	-	-	+	-
R. stolterfothii H. Peragallo	+	-	-	-	+	-
R. styliformis Brightwell	+	+	-	-	+	-
Schroderella delicatula H. Peragallo	+	++	+	+	+	++
Skeletonema costatum (Greville) Cleve	++	+++	+++	++	+++	+
Stephanopyxis nipponica Gran & Yendo	+	+	-	-	-	+
Striatella unipunctata Lyngb.	+	-	+	-	-	-
Surirella ovata Kütz	+	+	+	+	++	+
Surirella robusta Ehr.	+	+	-	+	+	-
Synedra crystallina Lyngb.	+	+	-	-	+	++
Synedra ulna (Nitzsch)	+	+	++	+	+	-
Thalassionema nitzschioides Grun	+	+	-	++	-	++
Thalassiothrix longissima Cleve & Grun.	+	+	+	-	-	+
Thalassiothrix frauenfeldii Grun.	+	+	-	-	+	++
Dinophyceae						
Ceratium furca Ehr.	++	+	++	++	++	++
Ceratium fusus Ehr.	+	+	+	+	++	+
Ceratium trichoceros (Ehr.) Kofoid	+	+	-	+	+	+
Ceratium tripos (O.M. Muller) Nitzsch.	+	-	-	-	+	-
Ceratium egyptiacum Halim	+	+	-	-	+	+
Dinophysis caudata Savielle-Kent	+	+	-	-	+	+
Diplopsalis rotunda Lebour (wood)	+	+	+	+	+	++
Gonyaulax minuta Kofoid and Michener	-	+	+	-	-	-
Oxytoxum scolopax Stein	+	+	-	-	-	+
Phalacroma rapa Stein	+	-	-	-	+	-
Prorocentrum marina Otenfeld	+	+	+	+	+	+
Prorocentrum micans Ehr.	+	+	+	+	+	+
Protoperidinium cerasus Paulsen	+++	+	+	+	+	+++
Protoperidinium depressum Bailey	++	+	+	+	+	++
Protoperidinium divergens Her.	+	+	+	+	+	+
Pyrophacus horologicum Stein	+	+	-	+	-	-
Chlorophyceae						
Actinastrum hantzschii Lagerh	+	++	++	+	+	+
Chlamydomonas sp.	+	++	-	++	-	-
Chlorella vulgaris Beij.	+	++	-	+++	-	-
Closterium sp.	+	+	+	+	+	+
Oocystis borgei Snow	-	+	-	+	-	-
Pediastrum clathratum Lemm.	+	+	+	+	+	+
Pediastrum boryanum Menegh	-	+	+	+	+	-
Pediastrum tetras Ralfs	-	+	-	-	-	+

Table (5) Continued

Scenedesmus quadricauda Breb.	+	+	-	+	+	+
Scenedesmus bijuga Turp.	+	+	+	+	-	+
Scenedesmus dimorphus Tarp.	+	+	-	+	+	+
Scenedesmus obliquus Turp.	+	+	-	-	-	+
Staurastrum gracile Ralfs	+	+	+	-	+	+
Stigoclonium sp.	+	+	+	-	+	-
Cyanophyceae						
Chroococcus turgidus (Kütz) Naeg.	+	++	-	++	-	-
Gomphospheria aponina Kütz	+	+	+	+	+	-
Lyngbya sp.	++	+	-	-	-	++
Merismopedia punctata Meyen	+	+	+	-	+	-
Oscillatoria erythraeum Drouet	+	+	-	-	+	+
Oscillatoria tenuis Agardh	+	+	-	+	+	+
Oscillatoria constricta	+	++	+	++	+	+
Oscillatoria limnetica Lemm.	+	+	+	-	+	-
Phormidium sp.	+	+	+	++	-	-
Spirulina major KG.	+	+	-	-	-	+
Spirulina platensis Nordst.	+	+	-	+	-	+
Euglenophyceae						
Euglena sp.	+	+	-	++	-	-
Phacus sp.	+	+	+	+	-	-
Silicoflagellates						
Dictyocha fibula Ehr.	+	+	-	+	+	+

Note: +++ =Abundant, ++ =Common, + =Frequent and - =absent

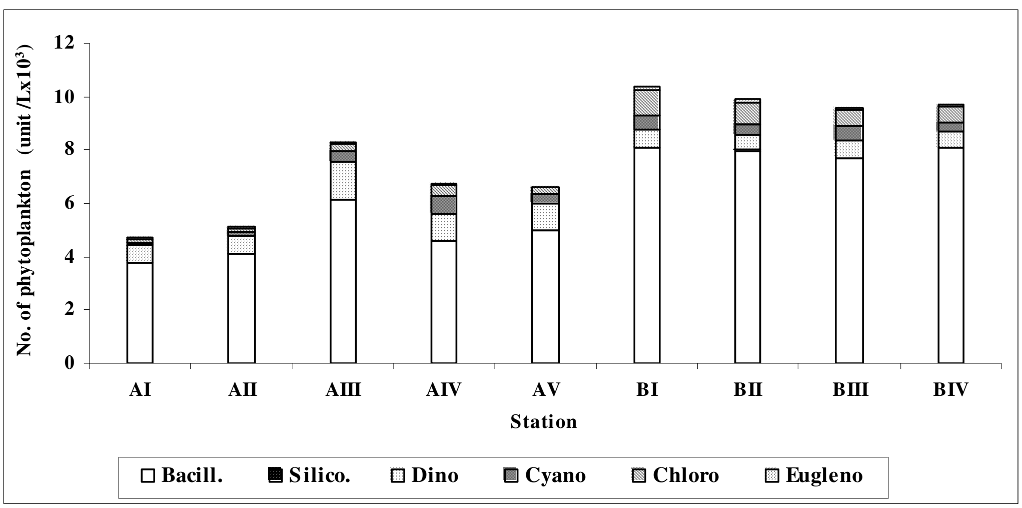

Fig. (3): Annual average counts of phytoplankton in Bitter Lake and Temsah Lake (unit/Lx10^3)

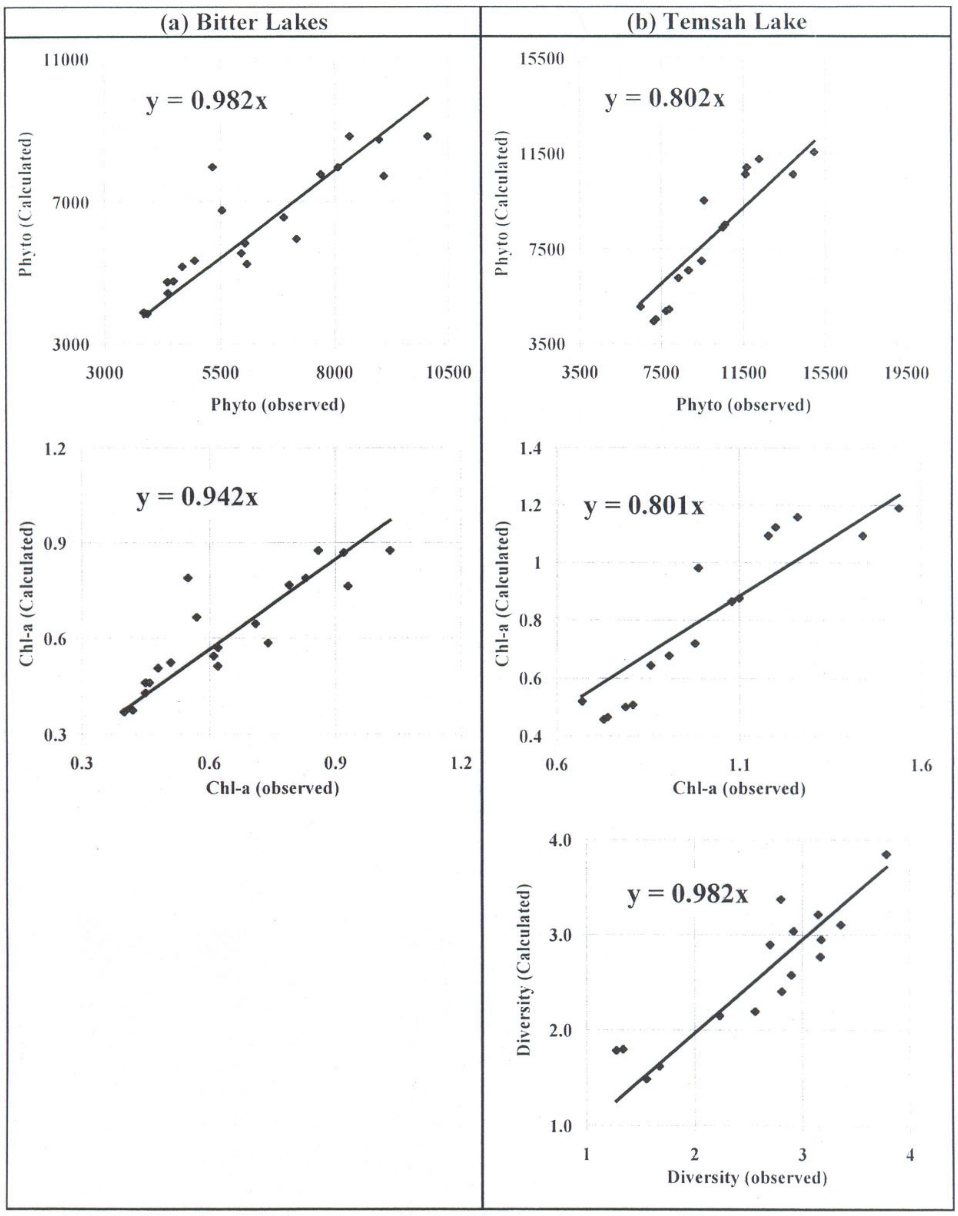

Fig. (4): The difference between the calculated and observed values for total phytoplankton abundance, chlorophyll-*a* and diversity in Bitter Lakes and Temsah Lake

CONCLUSION AND RECOMMENDATION

The present study indicates that the phytoplankton in the two lakes of Suez Canal was slightly more diversified than other adjacent areas like Suez and Aqaba Gulfs of the Red Sea as well as the Egyptian waters of eastern Mediterranean. Contrarily pronounced drop in phytoplankton abundance was observed in the present study as compared with the previous works. On the other hand the high nutrient concentrations in Bitter Lakes and Temsah Lake indicates the pollution of the two lakes. These results could be explained by the prevailing ecological conditions such as continuous passage of ships and oil tankers at Bitter Lakes and the discharge of agricultural ands sewage wastes as well as the human activities at Temsah Lake.

Our recommendation is to avoid as far as possible the discharge of oil spills, sewage and agriculture wastes into the waters of Suez Canal, specially at Temsah Lake, which is considered a good source of fishes and tourist area for the people of canal cities.

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