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SPECIES COMPOSITION AND DISTRIBUTION OF PHYTOPLANKTON IN THE WESTERN COAST OF SUEZ GULF, EGYPT

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ABSTRACT

Phytoplankton counts and species composition were evaluated and discussed in the coastal waters of Suez Gulf in relation to some environmental parameters during 2006. The results indicated 144 species of phytoplankton, distributed as 89 species of diatoms (forming about 70.3% by total phytoplankton numbers), 30 species of dinoflagellates (6.13%), 12 of green algae (18.4%), 12 species of blue-green algae (5.14%) and one species of euglenophytes. The mean counts of phytoplankton in the present study (average of 15,591 unit/L) sustained more two folds than recorded in 1995 (average of 5,862 unit/L). Also, the number of species is approximately duplicated from 70 species in the previous study to 144 species in this investigation. The identified 12 green species were completely absent in the former study. This finding is may be due to continuous discharge of freshwaters into the gulf from different factories and companies, which have been originated after 1995. The highest counts of phytoplankton was recorded in winter (average of 22,484 unit/L), and then followed by autumn (average of 15,233 unit/L). Ain-Sukhna was the most productive station (average of 24,001 unit/L), and then followed by Ghardaqa (average of 20,797 unit/L) and Zafarana (average of 18,494 unit/L). Whereas, relative low counts were found at Ras Gharib (average of 8,951 unit/L) and Adabyia (average of 3,652 unit/L). This is due to the high amounts of untreated sewage and industrial effluents discharged into the latter two stations. The diversity of species sustained the annual mean of 2.8 nats as compared with the value of 3.17 nats, which is recorded in 1995. However, the dissolved phosphate (0.17-0.62 µmol/L), nitrate content (0.65-2.42 µmol/L), pH values (7.9-8.4), water temperature (17-30^{o}C) and concentrations of ammonia (1.33-7.22 µmol/L) were the most effective factors controlling the phytoplankton abundance during the period of study. A general regression equation is achieved and could be applied in the future to predict the phytoplankton counts in the coastal waters of Suez Gulf. The study recommends that different sewage and industrial effluents must be treated as far as possible before discharging into the Suez Gulf, specially at the extremely polluted areas, Ras Gharib and Adabyia.

1. INTRODUCTION

The Gulf of Suez is relatively shallow and extends about 314 km south-southeast from Port Suez in the North (Lat. 29° 56` N) to Shadwan Island in the South (Lat. 27° 36` N) as shown in Fig.1. Its width varies between 20 and 40 km and its depth throughout its axis is fairly constant with a mean depth of 45 m (Pearse, 1983). The gulf is bordered by high land, reaching close to the coast at many points. Pollution potential in the Gulf of Suez is considerably increased in the last decades through the oil tankers, the removal of the industrial and domestic drainage waters at its northern part and the exploitation of the oil fields at its southern part. The prevailing northwesterly winds drive the surface water into the Red Sea (Morcos, 1970) and give the gulf a decidedly temperate character with seasonal temperature changes strongly influenced by the surrounding land.

The Red Sea phytoplankton studies are mainly reviewed by Halim (1969). He reported about 84 diatoms and 125 dinoflagellates in different regions of the Red Sea. Dowidar *et al*. (1978) identified 220 phytoplankton species in the neritic waters of Jeddah. Khalil *et al*. (1984) observed 100 species including 73 diatoms and 27 of dinoflagellates in the South region of Jeddah. Khalil and Ibrahim (1988) listed 124 species of phytoplankton (73 diatoms and 51 dinoflagellates) near Jeddah. Ibrahim (1988) reported 111 species, which classified as 63 diatoms, 42 dinoflagellates and six species of cyanophytes in Foul Bay of the Red Sea. Nassar (1994) recorded 76 species including 49 diatoms, 18 dinoflagellates, five blue-green algae, three species of green algae and one species of silicoflagellates in the northern part of Suez Gulf. El-Sherif and Abo El-Ezz (2000) reported 106 species of phytoplankton (41 diatoms, 53 dinoflagellates, 10 blue-green algae and two green algae) at different regions of the Red Sea. Nassar (2000) identified 70 phytoplankton species, which distributed as 47 diatoms, 18 species of dinoflagellates, four blue-green algae and one species of silicoflagellates in the Gulf of Suez. Shams El-Din *et al*. (2005) recorded 110 species of phytoplankton (57 diatoms, 23 dinoflagellates, 14 species of cyanophytes, 8 species of chlorophytes, six species of euglenophytes and one species of silicoflagellates) in the northern part of the Red Sea.

1.1. Aim of work

The aim of the present study is to evaluate the species composition and distribution of phytoplankton in the coastal waters of Suez Gulf as a result of initiation of many new factories and companies on the western side of the gulf during the period from 1995 up till now (e.g., new Harbour of Ain-Sukhna, Sewage Treatment Station (ABB company), Trust Textile factory, Suez Steel Company, Industrial Treatment Station as well as many oil factories) and comparing the results with the previous studies.

2. MATERIALS AND METHODS

Water and phytoplankton samples were seasonally collected during 2006. Seven stations were chosen covering the different ecological habitats along the western coast of Suez Gulf, namely Adabyia (I), Ain-Sukhna (II), Zafarana (III), Ras Gharib (IV), Ras Shukeir (V), Gemsha (VI) and Ghardaqa (VII) as shown in Fig. 1.

Adabyia marine region is subjected to different sources of pollution as; sewage effluents of Suez City (partially treated by ABB Company from 1994 up till now); oil refineries (El-Nasr and Suez Petroleum Companies) as well as the industrial effluents of many factories and companies. Finally, the outflow from the Industrial Treatment Station, where partial treatment processes are going on to remove some of the dangerous components from the drainage water to the gulf.

Ras Gharib is also subjected to untreated sewage of Gharib City and the oil effluents of the Oil Pipeline Company Terminals of Ras Gharib. The stations III & V are close to the oil companies of Ras Shukeir and Zafarana. On the other hand, the stations II & VII are relatively far from pollution sources, although the first is situated few kilometers from both, SUMED Pipeline Company Terminals and the new Harbour of Ain-Sukhna, while the latter is located in front of National Institute of Oceanography & Fisheries, at 6 Km north of Ghardaqa.

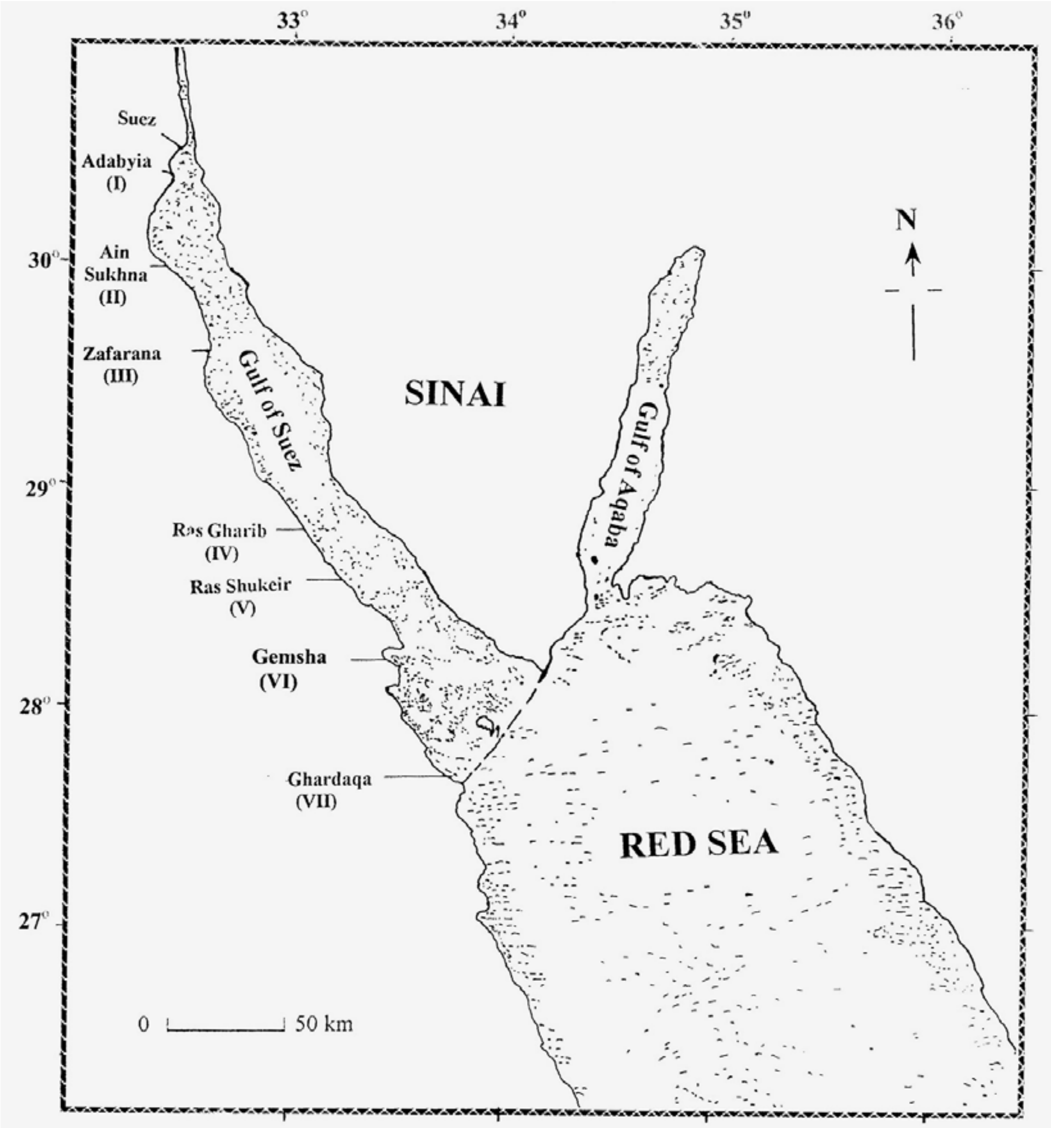

Fig. (1): Positions of the sampling stations.

Water temperature was measured using a simple pocket thermometer with a precision of 0.1°C. The pH value was measured in Situ using a pocket pH meter model Orion 210. Dissolved oxygen determination was carried out according to Winkler's method as described in APHA (1995). Nutrient salts (NO_3, NH_4 and PO_4) were determined applying the methods of Strickland and Parsons (1968).

Estimation of phytoplankton standing crop was carried out using the sedimentation method (Ütermohl, 1936) and the different species were calculated as their total numbers per liter (units/L). The main keys used for identification of algal taxa included these of Cupp (1943), Ferguson Wood (1968), Sourina (1986) and Mizuno (1990). Diversity of phytoplankton species was calculated on the computer according to the equation of Shannon and Weaver (1963) and expressed as nats.

The correlation matrices were estimated on the computer using the program of STATISTICA. The stepwise multiple regression equation is calculated at the confidence limit 95% ($p \leq 0.05$ and N=24) to estimate the most effective environmental factors on the abundance of the phytoplankton.

3. RESULTS AND DISCUSSION

3.1. Physico-chemical factors

3.1.1. Temperature

Temperature plays an important role in the aquatic environment in that certain organisms including fish are sensitive to water temperature. It affects the metabolic activities of plankton by changing the viscosity of water, which in turn affects the rate of sinking of suspended particles as planktonic organisms and clay (Shakweer, 2003). The coastal water temperature in this investigation varied between a minimum of 17°C during winter at Adabyia (St. I) and a maximum of 30°C at Ghardaqa (St. VII) as shown in Table 1. The high temperature in summer (28-30°C) was generally associated with high abundance of blue-green algae, specially *Oscillatoria simplicissima* (average of 740 filament/L) and *Lyngbya limnetica* (average of 308 filament/L). Such approach agrees with the results obtained by Ibrahim (1988) and Nassar (2000). They observed the highest occurrence of blue-green algae in summer. Halim (1969) reported that the dinoflagellates of the Red Sea seem to thrive at high temperature.

3.1.2. pH

The hydrogen ion plays an important role in many of the life processes, and living organisms are dependant and sensitive to pH (Welch, 1952). Relative high pH values were observed during summer at St. IV with 8.4, due to the untreated sewage and industrial effluents discharged into the waters of this area (EIMP, 1999). The lowest pH value was 7.9 in winter at St. VII, which is relatively far from the pollution sources. Generally, the high tendency in pH values was mostly related to the rise in temperature, where a positive correlation was observed between the two factors ($r = 0.55$ at $p < 0.05$ & N=24). Lathrop (1988) stated that in natural habitats, the increase in pH value represents a stress factor giving the chance of blue-green algal dominance, which coincided with the results of the present study.

Table (1): Some physico-chemical characteristics in Suez Gulf during 2006.

	Winter							
	I	II	III	IV	V	VI	VII	Average
Temp	17.0	18.10	19.0	18.0	17.50	17.5	17.50	17.73
pH	8.25	8.14	8.18	8.21	8.16	8.10	7.90	8.13
DO	7.20	7.50	7.90	7.42	7.72	7.71	8.11	7.65
PO_4	0.68	0.47	0.50	0.62	0.56	0.53	0.47	0.55
NO_3	1.50	2.42	1.95	1.54	1.71	1.88	2.05	1.85
NH_4	5.00	1.50	1.60	3.50	2.30	2.00	1.83	2.53
	Spring							
Temp	--	22.20	23.50	23.70	24.00	24.0	25.0	23.73
pH	--	8.20	8.21	8.30	8.27	8.22	8.19	8.23
DO	--	6.00	6.11	6.60	6.64	6.90	7.33	6.60
PO_4	--	0.28	0.36	0.55	0.41	0.37	0.34	0.385
NO_3	--	2.00	1.72	1.00	1.42	1.62	1.90	1.61
NH_4	--	2.11	4.00	5.50	4.70	3.62	2.50	3.73
	Summer							
Temp	28.0	28.70	29.0	28.5	28.50	27.80	30.0	28.64
pH	8.31	8.20	8.25	8.40	8.34	8.27	8.18	8.28
DO	5.11	5.50	6.00	5.00	5.55	5.70	6.40	5.60
PO_4	0.36	0.17	0.25	0.40	0.32	0.28	0.20	0.28
NO_3	0.65	1.90	1.60	0.78	1.35	1.55	1.78	1.37
NH_4	6.81	3.44	5.11	7.22	5.15	4.18	2.92	4.97
	Autumn							
Temp	--	21.30	20.50	20.30	20.50	20.0	19.70	20.40
pH	--	8.16	8.20	8.30	8.27	8.20	7.95	8.18
DO	--	7.00	7.12	6.80	7.16	7.05	7.44	7.09
PO_4	--	0.39	0.43	0.53	0.50	0.45	0.43	0.455
NO_3	--	2.20	1.83	1.33	1.58	1.68	1.75	1.728
NH_4	--	1.33	1.80	3.84	2.62	1.80	1.65	2.17

-- Samples not collected

3.1.3. Dissolved Oxygen (DO)

The dissolved oxygen in water depends on its temperature and salinity. It also depends, to a considerable degree on the quantity of organic matter present in the aquatic environment. If the decomposing of organic matter is in great proportion, it will absorb too much of the dissolved oxygen in water (Huet, 1973 and Shakweer, 2003). The results in Table 1, indicate that DO varied between a maximum of 8.11 mg/L during winter at St.VII and a minimum of 5.0 mg/L in summer at St.IV. Generally, the high oxygen content was observed during winter and autumn (averages of 7.65 and 7.10 mg/L, respectively). This indicates a good mixing in the water column (Gergis, 1983), and mostly correlated with high abundance of phytoplankton during the two seasons (averages of 22,484 & 15,233 unit/L, respectively). On the other hand, the relative low amounts of dissolved oxygen were observed during summer specially at the polluted stations, Ras Gharib and Adabyia. This may be due to the low occurrence of phytoplankton as well as oxygen consumption in the biological and nonbiological oxidation of the high organic matters at the polluted regions (Abdallah *et al*., 1995 and Nassar, 2000). Also, the solubility of gases involved in the metabolic activity as carbon dioxide and oxygen will also decrease by increasing temperature (El-Gohary, 1984). This support the high negative correlation between DO and water temperature in this investigation ($r = -0.85$ at $p < 0.05$ & N=24) as shown in Table 3.

3.1.4. Dissolved phosphate

The environmental significance of phosphorus arises from its role as a major nutrient for both plants and microorganisms. It can be considered as the most limiting factor for eutrophication (Vanloon and Duffy, 2000). The dissolved phosphate fluctuated between the highest value of 0.62 µmol/L during winter at St. IV and the lowest of 0.17 µmol/L in summer at St. II, due to the discharge of untreated sewage and industrial effluents into the gulf water near St.IV (EIMP, 1999). Stirn (1988) concluded that the eutrophic areas contaminated with sewage water, are fairly receiving total phosphorus supplies at levels approaching the optimum needed for the growth of mixed phytoplankton populations at an eutrophic level of 0.3-0.5 µmol/L. Also, Mahmoud (1995) reported that the typical concentrations of inorganic phosphate for eutrophic waters are > 0.15 µmol/L and for highly eutrophic systems > 0.3 µmol/L. In the present study, the annual mean value of dissolved phosphate was 0.412 µmol/L. Accordingly, the coastal waters of the Gulf of Suez could be considered as eutrophic area as previously reported by EIMP (2000) for the northern part of Suez Gulf.

3.1.5. Nitrate

Nitrate is the most stable form of inorganic nitrogen in oxygenated water. It is the end product of nitrification process in natural water. In many cases, nitrate is considered to be the micronutrient controlling primary production in the water (EIMP, 2000). If the oxygen content of the water is depleted as a result of microbial remineralization process, nitrate may be used as alternative electron acceptor instead of oxygen. This process is called denitrification, which leads to reduction of a portion of nitrate molecular nitrogen (Grasshoff, 1976). In the present study, the maximum value of nitrate was 2.42 µmol/L during winter at St.II, which sustained the highest abundance of phytoplankton (average of 24,001 unit/L). The minimum value was 0.65 µmol/L in summer at St.I. Hamed (1992) and Nassar & Hamed (2003) indicated that nitrate concentrations varied between 0.21 and 18.0 µmol/L in the Suez Bay. Generally, the low nitrate content was observed at the stations IV and I, at which relative low counts of phytoplankton were found (Table 1 and Fig.2). The results indicated that a strong negative correlation was found between dissolved nitrate and ammonia (r = -87, n = 24)

3.1.6. Ammonia

Ammonia is the nitrogenous end product of the bacterial decomposition of natural organic matter containing nitrogen, and is considered as important excretory product of animals in the aquatic system (Mahmoud, 1995). It also discharges into water bodies by industrial processes and as product of municipal or community wastes as well as the use of ammonia fertilizers such as ammonium sulphate, ammonium nitrate, urea and ammonia itself (Shakweer, 2003). On the other hand, the dissolved ammonia could be utilized as nutrients by several algal species and when NH_4 concentrations are depleted to < 0.15 µmol/L; NO_3 and NO_2 will be utilized (UNESCO, FAO, UNEP, 1988). The maximum values of ammonia were 7.22 and 6.81 µmol/L during summer at the stations IV and I, respectively. These high values of ammonia at the polluted regions are due to the breakdown of amino acids or protein by bacteria with urea as one of the by-products (Wafer *et al*., 1986). The lowest value was 1.33 µmol/L during autumn at St. II, which is relatively far from the pollution sources and sustained the high abundance of phytoplankton. The obtained results are in agreement with EIMP (2000) that observed relative high levels of ammonia at the polluted stations, Ras Gharib and Ras Shukeir, with an annual mean of 12.9 µmol/L and has a range of 0.76-37.24 µmol/L.

El-Gohary (1983) reported that pollution from industrial and domestic wastes generally disappears at few kilometers downstream far from their outfalls. This supports the high self-purification capacity at St. II (Ain-Sukhna), which is located few kilometers from both SUMED Company and the new Harbour of Ain-Sukhna (partial oxidation of organic matter occurs by the activity of algae and bacteria).

3.2. Phytoplankton

3.2.1. Community composition

The mean abundance of phytoplankton in the present study (average of 15,591 unit/L) sustained more two folds than recorded in 1995 by Nassar, 2000 (average of 5,862 unit/L) as shown in Table 2. Also, the number of species is approximately duplicated from 70 species in the previous study to 144 species in the present study. Diatoms were the most dominant group forming about 70.3% of total phytoplankton abundance. Green algae were recorded with moderate counts constituting about 18.4% of total counts, while they were completely absent in the previous study. This finding is may be due to continuous discharge of freshwaters into the gulf from the different factories and companies, which have been originated after 1995. On the other hand, the dinoflagellates and blue-green algae were observed with relatively low counts forming together about 5.63% of total abundance and the euglenophytes were rarely and it represented by one species.

The highest outstanding peak of phytoplankton was recorded at Ain-Sukhna with average of 24,001 unit/L, and then followed by Ghardaqa (average of 20,797 unit/L), Zafarana (average of 18,494 unit/L), Gemsha (St. VI, average of 16,130 unit/L) and Ras Shukeir (St. V, average of 12,124 unit/L) as shown in Fig.2. However, several workers reported that the low concentrations of petroleum hydrocarbons could be stimulating the abundance and biomass of phytoplankton (Rinckevich and Loya, 1983; Nassar, 1994 and Hamed *et al*., 2003). This is clearly achieved at St. II, where low fractions of petroleum hydrocarbons are discharged from SUMED Company. Generally, some diatoms are responsible for phytoplankton flourishing at the most productive stations II and VII, namely *Rhizosolenia alata* f.

gracillima, *R. calcar avis*, *Nitzschia pungens*, *Chaetoceros tortissimus*, *C. curvisetus*, *Hemiaulus heibergii*, *Guinardia flaccida* and *Climacosphenia moniligera* as well as *Pleurotaenium trabecula* of green alga. It was obvious that, the high abundance of phytoplankton at these stations is associated with high dissolved oxygen (5.5–8.11 mg/L), high nitrate (1.9-2.42 µmol/L) and low concentrations of dissolved ammonia (1.33–2.92 µmol/L) than other investigated stations. On the other hand, the relative low occurrence of phytoplankton was found at Ras Gharib (average of 8,951 unit/L) and Adabyia (average of 3,652 unit/L), due to the heavy industrial effluents and untreated sewage that discharged into these stations (Nassar, 2000).

Table (2): Phytoplankton production in Suez Gulf in 1995 and 2006.

Class	Suez Gulf, 1995 (Nassar, 2000)				Suez Gulf (Present study)			
	Genus	species	Total counts (unit/L)	%	Genus	species	Total counts (unit/L)	%
Bacillariophyceae	28	47	4,252	72.53	40	89	10,958	70.3
Dinophyceae	9	18	1,278	21.8	11	30	957	6.13
Cyanobacteria	3	4	314	5.35	7	12	802	5.14
Chlorophyceae	0.0	0.0	0.0	0.0	10	12	2,869	18.4
Euglenophyceae	0.0	0.0	0.0	0.0	1	1	5.0	0.03
Chrysophyceae	1	1	17	0.29	0.0	0.0	0.0	0.0
Total	41	70	5,862	100	69	144	15,591	100

Table 3. The correlations between some physico-chemical factors and the total counts of phytoplankton in Suez Gulf, 2006.

	Phyto.	Temp	pH	DO	PO_4	NO_3	NH_4	Diversity
Phyto.	1.00							
Temp	0.28	1.00						
pH	- 0.3	**0.55**	1.00					
DO	0.39	**- 0.85**	**- 0.68**	1.00				
PO_4	0.04	**- 0.81**	-0.13	**0.67**	1.00			
NO_3	**0.57**	**- 0.41**	**- 0.67**	**0.51**	- 0.13	1.00		
NH_4	**- 0.51**	**0.67**	**0.72**	**- 0.74**	-0.19	**- 0.87**	1.00	
Diversity	**- 0.43**	0.32	-0.12	-0.16	-0.29	-0.10	0.26	1.00

Bold correlations are significant at $p < 0.05$ and N=24.

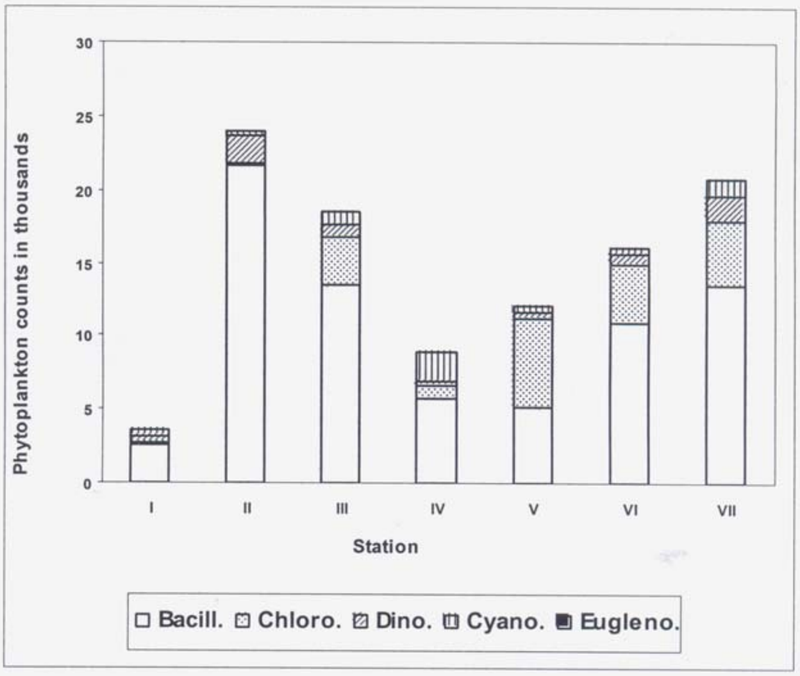

Fig. (2): Average annual counts of phytoplankton classes (unit/L) at the different stations.

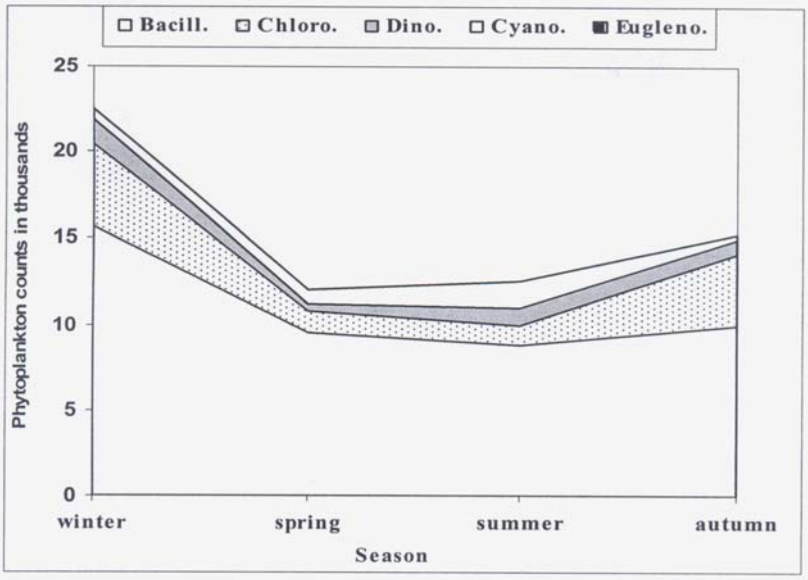

Fig. (3): Seasonal distribution of phytoplankton classes (unit/L) at all stations.

3.2.2. Seasonal distribution

The phytoplankton in the coastal waters of Suez Gulf showed the highest flourishing in winter (average of 22,484 unit/L), then followed by autumn (average of 15,233 unit/L) as shown in Fig.3. In summer and spring, frequent counts (averages of 12,585 and 12,063 unit/L, respectively) were recorded. High population density during winter is due to, *Pleurotaenium trabecula* (average of 4,457 cell/L) as well as *Nitzschia longissima* (average 2,065 cell/L), *Nitzschia pungens* (average of 1,781 cell/L) and *Guinardia flaccida* (average of 1,079 cell/L). These results are in accordance with Nassar (1994) in Suez Bay. Also, the winter formed more than six times of total phytoplankton counts of summer in the northern part of the Red Sea as reported by Shams El-Din *et al*. (2005). In the present study, total of 114 species were observed in winter as compared with 94, 90 and 85 species in spring, summer and autumn, respectively. On the other hand, Levanon-Spanier *et al*. (1979); Khalil *et al*. (1984); Khalil and Ibrahim (1988); Nassar (2000) and Nassar and Shams El-Din (2006) reported that the Red Sea exhibited a characteristic trend in which autumn represented the most productive season.

The results indicated that blue-green algae (Cyanobacteria) and some dominant diatoms showed their frequent abundance at the polluted station (IV). Among these species, *Oscillatoria simplicissima*, formed about 22% of total phytoplankton at St. IV in summer; *Hemiaulus heibergii* constituted about 56% of total phytoplankton at St. IV during autumn, while it was completely missed at other stations (Table 4). *Nitzschia longissima* and *Plagiogramma vanheurchii* of diatoms formed togher the annual mean of 49% by total phytoplankton counts at St.IV. Also, *Rhizosolenia alata* f. *gracillima* observed with high counts during summer, which associated with the results of Ibrahim (1988) in Foul Bay of the Red Sea.

In this connection, Mihnea (1985) reported that the dominance of any species in polluted water for one season or more constituting about 10% of the total community might be considered as indicator species. Accordingly, the previous four species (*Oscillatoria simplicissima, Nitzschia longissima, Plagiogramma vanheurchii* and *Hemiaulus heibergii)* could be considered as pollution tolerant species in Suez Gulf. However, Humm and Wicks (1982) stated that blue-green algae are renowned for their ability to tolerate a wide range of environmental conditions and they prefer warm waters and sewage pollution (James, 1975). This agrees with the present study for the coastal waters of Suez Gulf.

As a general trend, the phytoplankton abundance is always depending on the level of nutrients in marine ecosystem (Raymont, 1980) as well as the interaction between ecological, biological and evolutionary processes in the surrounding habitats (Hallegraeff and Reid, 1986). Thus, the relative high values of nitrate and phosphate during winter may be due to the compensation of nutrients as a result of water upwelling as recorded by Levasseur *et al*. (1992) for coastal waters. These high nutrients could be stimulating the growth and flourishment of phytoplankton in winter and autumn in the present study.

Table (4): List of the recorded species of phytoplankton in Suez Gulf and their seasonal distribution (average of the seven stations, unit/L) during 2006.

Season / Class	Winter	Spring	Summer	Autumn	Average
Bacillariophyceae (cell/L)					
Amphiprora alata Kütz	0.0	28	7.0	0.0	9.0
Amphiprora paludosa W. Smith	0.0	0.0	143	20	41
Amphora grevilleana Cleve	10	33	0.0	20	16
* Amphora lineolata Ehr.	7.0	36	64	30	34
Amphora marina Smith	97	238	109	96	135
Asterionella japonica Cleve	0.0	0.0	0.0	33	8.0
* Asterionella kariana Grun	0.0	42	0.0	31	18
Bacillaria paradoxa (Gmel.) Grun	386	64	0.0	45	124
* Bacteriastrum hyalinum Lauder	21	17	0.0	0.0	10
* Bellarochea sp.	476	0.0	0.0	0.0	119
* Biddulphia aurita (Lyng.) Breb.	14	76	0.0	34	31
Biddulphia obtusa Kütz	60	8.0	133	0.0	50
Campylodisus noricus var. hibernica (Ehr) Grun	10	283	169	35	124
* Cerataulina bergonii H. Peragallo	0.0	0.0	21	0.0	14
* Chaetoceros affinis Lauder	40	0.0	0.0	0.0	10
Chaetoceros coarctatus Lauder	64	17	0.0	0.0	20
Chaetoceros curvisetus Cleve	805	1,333	0.0	365	626
Chaetoceros decipiens Cleve	107	100	143	467	204
* Chaetoceros densum Cleve	25	0.0	0.0	0.0	6.0
* Chaetoceros lauderi Ralfs	71	46	0.0	0.0	29
Chaetoceros peruvianus Brightw.	71	0.0	14	36	30
* Chaetoceros radicans Schütt	0.0	33	0.0	0.0	8.0
* Chaetoceros tetrastichon Cleve	54	31	0.0	0.0	21
* Chaetoceros tortissimus Gran	0.0	0.0	1,643	0.0	411
Climacodium biconcavum Cleve	10	0.0	0.0	0.0	3.0
* Climacodium frauenfeldianum Grun	0.0	0.0	0.0	17	4.0
Climacosphenia moniligera Ehr.	719	753	283	239	499
Cocconeis placentula Ehr.	114	149	111	45	105

Table 4. (Continued)

	Win.	Spr.	Sum.	Aut.	Aver.
Coscinodiscus granii Gough	122	67	24	0.0	53
* Coscinodiscus radiatus Ehr.	217	314	170	138	210
* Coscinodiscus excentricus Ehr.	11	0.0	0.0	0.0	3.0
* Cyclotella meneghiana Kütz	24	0.0	0.0	17	10
* Cymbella ventricosa Kütz	25	0.0	25	0.0	13
Diploneis interrupta (Kütz) Cleve	0.0	38	17	0.0	14
* Fragillaria capucina Desm.	133	51	93	158	109
* Fragillaria construens (Ehr.) Grun.	0.0	661	150	0.0	203
* Gramatophora marina (Lyng.) Kütz	29	100	214	0.0	86
* Gramatophora oceanica Ehr.	29	158	0.0	0.0	47
Guinardia flaccida H. Peragallo	1,079	61	75	423	410
Gyrosigma attenuatum Ehr.	244	350	149	281	256
Gyrosigma balticum Ehr.	0.0	28	26	0.0	14
Hemiaulus heibergii Cleve	21	155	17	3,366	890
* Hemiaulus sp.	33	0.0	0.0	0.0	8.0
Lauderia borealis Gran	54	0.0	0.0	0.0	14
Leptocylindrus danicus Cleve	174	192	73	636	269
* Licmophora abbreviata Ag.	14	21	0.0	30	16
* Licmophora flabellata (Gran) Ag.	904	83	57	495	385
Licmophora gracilis (Ehr.) Grunow	44	85	49	69	62
* Melosira granulata var. angustissima Ehr.	300	180	290	92	216
* Melosira italica (Ehr.) Kütz	0.0	412	175	183	193
* Melosira sulcata (Ehr.) Kütz	0.0	34	10	0.0	11
Nitzschia closterium W. Smith	44	87	164	42	84
* Nitzschia Kützingiana Hilse	54	0.0	0.0	76	33
Nitzschia longissima Ehr.	2,065	315	368	170	730
* Nitzschia obtusa W. Smith	0.0	0.0	35	0.0	9.0
* Nitzschia palea (Kütz) W. Smith	136	13	0.0	22	43
Nitzschia pungens var.atlantica Cleve	1,781	100	179	17	519
Nitzschia sigma Kütz	443	172	86	148	212
* Navicula cancellata Donkin	7.0	30	43	8.0	22

Table 4. (Continued)

	Win.	Spr.	Sum.	Aut.	Aver.
* Navicula dicephala Ehr.	21	0.0	26	0.0	12
* Navicula distans (W. smith) Ralfs	14	80	14	0.0	27
Navicula gracilis Cleve	127	102	93	71	98
Navicula lyra var. atlantica (Schum) Cleve	0.0	38	48	17	26
* Navicula placentula Ehr.	65	113	111	63	88
* Plagiogramma vanheurchii Grun	57	0.0	445	124	157
Pleurosigma angulatum (Quekett) W.Smith	0.0	13	33	0.0	12
* Rhabdonema adriaticum Kütz	0.0	25	0.0	0.0	6.0
Rhizosolenia imbricata var. shrubsolei (Cleve) Schröder	262	58	54	81	114
* Rhizosolenia styliformis Brightwell	457	8.0	25	71	140
* Rhizosolenia alata Brightwell	0.0	500	0.0	0.0	125
Rhizosolenia alata f. indica H. Peragallo	50	13	0.0	0.0	16
Rhizosolenia calcar avis M. Schultze	1,126	30	18	75	312
Rhizosolenia stolterfothii H. Peragallo	73	21	83	186	91
Rhizosolenia alata f. gracillima Cleve	1,383	133	1,636	75	807
Skeletonema costatum (Grev.) Cleve	0.0	100	0.0	166	67
* Striatella delicatula (Kütz) Grun	0.0	0.0	11	0.0	3.0
Striatella unipunctata Lyngb.	286	181	128	193	197
Surirella baldjickii Norman	0.0	13	21	0.0	9.0
Surirella ovata Kütz	52	224	140	39	114
Surirella robusta Ehr.	0.0	69	0.0	0.0	17
* Surirella sp.	7.0	24	0.0	0.0	8.0
* Synedra ulna Nitzsch.	58	109	83	71	80
* Synedra undulata Bail.	190	104	157	171	156
* Tabellaria fenestrata (Lyng.) Kütz	0.0	0.0	0.0	58	15
* Thalassionema nitzscioides Grun	0.0	0.0	29	46	19
* Thalassiothrix mediterranea Pavill.	61	0.0	0.0	0.0	15
* Thalassiothrix frauenfeldii Grun	64	64	62	41	58
* Thalassiothrix longissima Cleve & Grun	87	344	167	375	243
* Tropidoneis antarctia var. polyasta Gran and Angst	0.0	63	7.0	0.0	18
Tropidoneis lepidoptera (Greg.) Cleve	45	75	62	64	62

Table 4. (Continued)

	Win.	Spr.	Sum.	Aut.	Aver.
Dinophyceae (cell/L)					
* Centrodinium intermedium Pavill.	21	0.0	0.0	0.0	5.0
* Ceratium setaceum Jörgensen	26	28	24	0.0	20
* Ceratium candelabrum (Ehr) Stein	10	0.0	0.0	0.0	3.0
Ceratium furca (Ehr)	62	83	103	163	103
Ceratium fusus (Ehr) Dujardin	14	17	25	25	20
* Ceratium kofoidi Jörgensen	183	0.0	0.0	21	51
*Ceratium macroceros var. gallicum Kofoid	349	0.0	0.0	21	93
Ceratium massiliense (Gourret) Jörgensen	57	13	49	33	38
* Ceratium puchellum Schröder	29	8.0	0.0	0.0	9.0
Ceratium trichoceros (Ehr) Kofoid	66	8.0	11	8.0	23
Ceratium tripos (O.F.Müller) Nitzsch	32	0.0	40	36	27
Dinophysis caudata Saville-Kent	25	0.0	0.0	25	13
* Dinophysis sp.	7.0	0.0	10	0.0	4.0
Diplopsalis rotunda (Lebour) Wood	30	17	68	21	34
Exuviaella compressa Ostenfeld	76	0.0	298	0.0	94
* Exuviaella baltica Lohmann	11	50	0.0	87	37
Goniaulax minuta Kofoid & Mich.	0.0	17	10	20	12
* Protoperidinium steini Jorgensen	7.0	0.0	0.0	0.0	2.0
Protoperidinium cerasus Paulsen	174	70	167	96	127
Protoperidinium depressum Bailey	21	8.0	81	20	32
Protoperidinium divergens Ehr.	11	0.0	0.0	0.0	3.0
* Protoperidinium globules Stein	198	80	101	134	128
* Protoperidinium trochoideum Stein	11	0.0	0.0	0.0	3.0
Phalacroma rapa Stein	36	0.0	0.0	21	14
* Prorocentrum gracile Schütt	19	0.0	30	21	17
Prorocentrum micans Ehr.	11	8.0	9.0	20	12
* Prorocentrum schilleri Bohm	29	0.0	0.0	0.0	7.0
* Pyrocystis fusiformis (W.Thom.) Murray	0.0	26	36	0.0	15
* Pyrocystis hnula Schütt	0.0	8.0	0.0	0.0	2.0
Pyrophacus horologicum Stein	0.0	8.0	29	0.0	9.0

Table 4. (Continued)

	Win.	Spr.	Sum.	Aut.	Aver.
Chlorophyceae (cell/L)					
* Actinastrum hantzschii Lagerheim	7.0	11	0.0	0.0	5.0
*Chlorella vulgaris Beyerinck	126	0.0	0.0	70	49
* Closterium gracile Brebisson	11	31	0.0	16	15
* Coelastrum sp.	14	0.0	0.0	0.0	3.0
* Oocystis borgei Snow	61	0.0	0.0	46	27
* Pediastrum biwae Negoro	26	0.0	0.0	0.0	6.0
* Pediastrum simplex (Meyen) Lemm.	38	0.0	0.0	17	14
*Pleurotaenium trabecula (Ehr) Naeg.	4,457	1,233	1,143	4,000	2,708
* Scenedesmus bijuga (Turpin) Lagerheim	0.0	0.0	0.0	13	3.0
* Scenedesmus quadricauda (Turpin) Breb.	0.0	0.0	11	0.0	3.0
* Staurastrum gracile Ralfs	29	0.0	0.0	25	13
* Treubaria crassipina G. M. Smith	7.0	33	0.0	51	23
Cyanophyceae (unit/L)					
* Aphanocapsa nidulus Smith	0.0	0.0	0.0	17	4.0
* Chroococcus turgidus (Kütz) Naeg.	54	0.0	22	22	25
Lyngbya limnetica Lemm.	145	141	308	0.0	148
* Merismpodia punctata Meyen	0.0	11	0.0	0.0	3.0
* Oscillatoria agardhii Gomont	76	17	25	0.0	30
Oscillatoria erythraeum Drouet	68	42	75	0.0	46
* Oscillatoria Formosa Bory.	10	0.0	40	31	20
* Oscillatoria simplicissima Gom.	106	472	740	71	347
* Oscillatoria sp.	0.0	117	158	0.0	69
* Oscillatoria tenuis Agardh.	47	8.0	67	77	50
* Phormidium sp.	54	0.0	83	71	52
Spirulina major KG.	0.0	0.0	19	13	8.0
Euglenophyceae (cell/L)					
* Euglena sp.	0.0	0.0	21	0.0	5.0

Note. Signaled species (*) are new records in the coastal waters of Suez Gulf.

In conclusion, comparing the results of this investigation with the previous study (in 1995 by Nassar, 2000); about 60 species in the present study were formerly detected in the Gulf of Suez, while the other 84 species could be considered as new records in this area (these species are signaled with * in Table 4). It is worth mention the recorded species of green algae (12 species) in this study were completely absent in the previous study. This may be due to the continuous discharge of freshwaters from sewage and industrial effluents into the gulf as mentioned before. However, some of these records were previously observed in Suez Bay, Suez Canal, Red Sea and South-eastern Mediterranean as reported by Halim, 1969; Dowidar, 1974; Nassar, 1994; Nassar and Hamed, 2003; Ibrahim, 1988; El-Sherif and Ibrahim, 1993; El-Sherif and Abo El-Ezz, 2000 and Nassar and Shams El-Din, 2006.

Consequently, this study recommends that different sewage and industrial effluents must be treated as far as possible before discharging into the Gulf of Suez, specially at the highly polluted areas, Ras Gharib and Adabyia.

3.2.3. Species diversity

The diversity of phytoplankton species in Suez Gulf sustained the highest value of 3.43 nats during winter at Ghardaqa, due to the increased number of species (68 spp.), which were fairly distributed, i.e. the dominancy was shared by several algal species. While, the lowest diversity value of 1.53 nats was found in autumn at the polluted station, Ras Gharib, at which 49 species were observed and the dominant diatom *Hemiaulus heibergii* formed about 56% of the total phytoplankton counts. Generally, the diversity values of 2.8, 3.1, 2.95 and 2.3 nats were observed during winter, spring, summer and autumn, respectively, giving an average of 2.8 nats. This annual value is relatively low as compared with the value of 3.17 nats, which is recorded in 1995 in Suez Gulf (Nassar, 2000). This means the increased levels of pollution during the last ten years, which are mostly attributed to the huge amounts of untreated sewage and industrial effluents discharged into the gulf. These results are also confirmed by the inverse correlation between the total counts of phytoplankton and diversity of species ($r = - 0.43$ at $P< 0.05$ and $N=24$) as shown in Table 3.

4. STATISTICAL ANALYSIS

The correlation matrices pointed to the total counts of phytoplankton in this investigation are positively correlated with nitrate content ($r = 0.57$ at $p < 0.05$ & $N=24$) but negatively correlated with the concentrations of ammonia ($r = –0.51$) as shown in Table 3.

The multiple regression analysis is calculated to show the relationship between phytoplankton abundance and the most effective environmental factors. The results indicated that: total phytoplankton = –261022 + 60309 $\mathbf{PO_4}$ + 29371 $\mathbf{NO_3}$ + 18071 **pH** + 2156 **DO** + 1854 **Temperature –** 434 $\mathbf{NH_4}$ (M.R. = 0.97, N=24 and $p < 0.05$).

This regression equation could be applied in the future to predict the total phytoplankton counts in the coastal waters of Suez Gulf

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