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NUTRIENTS AND PHYTOPLANKTON DISTRIBUTION IN THE COASTAL WATERS OF AQABA GULF, RED SEA, EGYPT

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ABSTRACT

Phytoplankton distribution and species diversity were estimated and discussed in the coastal waters of the Aqaba Gulf during winter, spring and summer, 2006. The phytoplankton community included 127 taxa belonging to diatoms (75 spp), dinoflagellates (27 spp), blue-green algae (16 spp), green algae (8 spp) and one species of silicoflagellates. The winter showed a high-pronounced peak of phytoplankton (average of 35,110 unit/L), and then followed by spring (average of 21,374 unit/L). While, severe drop of phytoplankton populations was observed in summer (average of 6,005 unit/L). Also, the numbers of phytoplankton species were higher in winter and spring seasons (86 and 82 species, respectively) than summer (51 species). These results may be due to the effect of winter monsoon, which increase the productivity of the Red Sea. Generally, the highest abundance of phytoplankton was observed at Nuweiba (average of 27,758 unit/L) then followed by Dahab (19,886 unit/L), Sharm El-Sheikh (18,452 unit/L) and Taba (17,221 unit/L). Relative high values of phytoplankton diversity (2.58-3.64 nats) as well as the low concentrations of nutrients indicated that the Aqaba Gulf is still fairly unpolluted and has an oligotrophic nature. This is confirmed with the significant inverse relation between diversity values and the total counts of phytoplankton ($r = -0.61$ at $p < 0.05$ and $N = 12$). Statistically, the correlation matrices indicated that the total counts of phytoplankton were positively correlated with nitrate content ($r = 0.68$), dissolved oxygen ($r = 0.64$) and dissolved inorganic phosphate ($r = 0.63$). Whereas, they were inversely correlated with water temperature ($r = -0.69$) and pH value ($r = -0.58$) at confidence level 95% and $N = 12$. Also, the stepwise multiple regressions showed the high dependence of phytoplankton standing crop on the dissolved phosphate, nitrate and pH values then followed by ammonia concentrations, dissolved oxygen and water temperature. Thus, a regression model is obtained and could be applied to calculate the total counts of phytoplankton in the coastal waters of Aqaba Gulf in these periods.

1. INTRODUCTION

Gulf of Aqaba is the eastern of the two northerly extensions of the Red Sea. In contrast to the Gulf of Suez on the west side, it is a deep, narrow trench, 177 Km long, 14-25 Km wide and descending to over 1,800 m in its deepest regions. It is a desert-surrounded marine environment, separated at its southern end from the Red Sea itself by a shallow sill, 250 m deep at Tiran. These features contribute to the relative isolation of the gulf waters and affect the circulation pattern over the straits. There is very little precipitation and a high rate of evaporation, which is compensated for, by an inflow of less saline water from the main body of the Red Sea, over the sill. High evaporation rates drive a thermohaline circulation with a continuous advection of nutrient-poor surface waters from the Red Sea into the gulf, counter-balanced by an efflux of more dense deep waters (Murray *et al.* 1984 and Wolf-Vecht *et al*., 1992). These characters are probably responsible for the intermingling of neritic and oceanic species in regard to the number of taxonomic categories of plankton (Kimor, 1983 and Reiss and Hottinger, 1984).

Some studies of phytoplankton distribution in the Aqaba Gulf have been limited in scope with a focus on symbiotic associations of nitrogen-fixing Cyanobacteria with diatoms and dinoflagellates (Reiss and Hottinger, 1984; Kimor *et al*., 1992 and Gordon *et al*., 1994). On the other hand, Kimor (1983) studied the vertical distribution of phytoplankton in the Gulf of Aqaba. El-Sherif and Abo-El-Ezz (2000) evaluated the phytoplankton distribution at different locations in the northern Red Sea, including Sharm El-Sheikh and Taba regions of Aqaba Gulf. Post *et al*. (2002) studied the phytoplankton abundance in the open waters of the Gulf of Aqaba during summer.

The purpose of this study is to establish the seasonal distribution, abundance and diversity of phytoplankton species in the coastal waters of Aqaba Gulf according to the levels of nutrients and some water characteristics, with a check list of the recorded species and comparing the results with other studies and surrounding habitats.

2. MATERIAL AND METHODS

Four different stations were selected along the western coast of the Aqaba Gulf, namely Sharm El-Sheikh, Dahab, Nuweiba and Taba (Fig.1). Surface water and phytoplankton samples (50 cm below surface) were collected during winter, spring and summer, 2006. Water temperature was measured by using a simple pocket thermometer graduated to 0.1°C. The pH value of water samples was measured in situ using a pocket pH meter model Orion 210. Dissolved oxygen determination was carried out according to Winkler method (APHA, 1995). Nutrient salts (NO_3, NO_2, NH_4 and PO_4) were determined according to the methods described by Strickland and Parsons (1968) and expressed as µmol/L. Estimation of phytoplankton counts crop was carried out by using the sedimentation method (Ütermohl, 1936) and calculated as units per liter. The main keys used for identification of algal taxa included these; Cupp (1943), 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 correlations were carried out between the different ecological factors and the total counts of phytoplankton at confidence limit 95% ($p < 0.05$ and N=12). The stepwise multiple regression equations are also calculated to estimate the most effective environmental factors on the counts of phytoplankton.

3. RESULTS AND DISCUSSION

3.1. Physico-chemical conditions

3.1.1 Water temperature

The results in Table 1 indicate that water temperature ranged between a minimum of 17 °C during winter at Taba and a maximum of 30 °C in summer at Sharm El-Sheikh. The high values of temperature in summer (28.5-30°C) were generally associated with severe drop of total phytoplankton counts (average of 6,005 unit/L). Whereas, some species showed their highest occurrence in summer namely, *Rhizosolenia alata* form *gracillima* and *Climacodium biconcavum* of diatoms. These results are achieved in the Gulf of Suez and Red Sea for the first species (Nassar 1994 and 2007) and eastern Mediterranean (El-Sherif *et al*., 2007). On the other hand, low values of temperature in winter (17-19°C) coordinated with the highest blooming of phytoplankton (average of 35,110 unit/L). The results revealed a significant inverse correlation between temperature and the total counts of phytoplankton ($r = -0.68$ at $p<0.05$ & N=12).

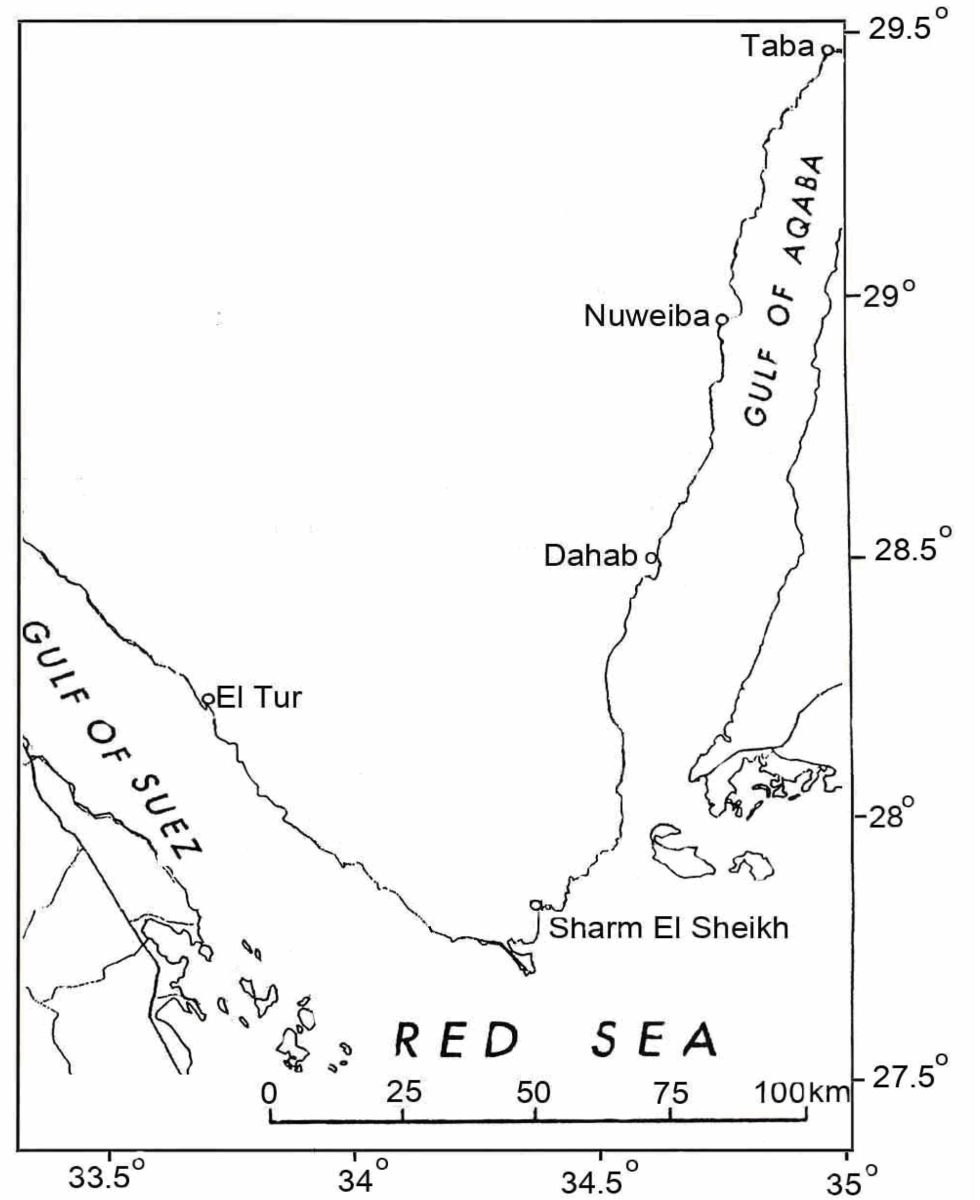

Fig. (1): Positions of the sampling stations.

Table (1): Seasonal fluctuations of temperature (°C), pH values, dissolved oxygen (mg/L) and nutrients; NH_4, NO_3, NO_2 & PO_4, (µmol/L) in the Aqaba Gulf during 2006.

	Winter				
	Taba	**Nuweiba**	**Dahab**	**Sharm El-Sheikh**	**Average**
Temp	17	17.5	18	19	17.87
pH	8.11	8.11	8.16	8.10	-
DO	7.60	8.19	8.00	7.74	7.88
NH_4	1.00	0.48	0.60	0.78	0.715
NO_3	0.56	0.84	0.75	0.66	0.702
NO_2	0.14	0.06	0.08	0.12	0.100
PO_4	0.14	0.21	0.19	0.17	0.177
	Spring				
Temp	22	22.5	23	23.5	22.75
pH	8.13	8.14	8.20	8.23	-
DO	7.00	8.00	7.90	7.40	7.575
NH_4	1.14	0.71	0.83	0.91	0.897
NO_3	0.42	0.75	0.66	0.56	0.597
NO_2	0.18	0.12	0.14	0.16	0.15
PO_4	0.09	0.18	0.16	0.13	0.14
	Summer				
Temp	28.5	29	29.5	30	29.25
pH	8.23	8.21	8.28	8.22	-
DO	5.11	6.50	6.00	5.40	5.75
NH_4	1.17	0.74	1.00	1.15	1.015
NO_3	0.21	0.42	0.37	0.30	0.325
NO_2	0.23	0.17	0.19	0.22	0.202
PO_4	0.04	0.13	0.09	0.06	0.08

3.1.2. pH value

The pH value in marine system has a little ecological role because seawater is highly buffered and pH value remains relatively constant (Michael, 1984). It oscillated in the coastal waters of the Aqaba Gulf within a narrow limit (8.1-8.28) and it lies in the alkaline side. A strong positive correlation was observed between pH values and temperature at confidence limit 95% (r = 0.85). This agrees with the results of El-Naggar *et al*. (2002) and Nassar and Shams El-Din (2006) in Suez Gulf and Bitter Lakes & Temsah Lake of Suez Canal. Generally, the total counts of phytoplankton were inversely correlated with the values of pH (r = –0.58 at $p < 0.05$ & N=12).

3.1.3. Dissolved Oxygen (DO)

Dissolved oxygen is considered as one of the most important and useful parameters for identification of different water masses and in assessing the degree of pollution in the marine environment. The annual mean value of DO in the present study (7.10 mg/L) was higher than the well-oxygenated level (< 4 mg/L) proposed by Huet (1973). Such result was found by Fahmy (2001), who indicated that the coastal waters of Aqaba Gulf is well oxygenated (average of 7.43 mg/L) and the relative load of organic matter and nutrients reached to the gulf is below the level which bring about oxygen deficiency (8.72 mg/L, Hottinger, 1984). However, the results in Table 1 show that dissolved oxygen ranged from 8.19 mg/L during winter at Nuweiba, which sustained the highest abundance of phytoplankton and 5.11 mg/L during summer at the region of Taba. This is due to the high solubility of gases involved in the metabolic activities as carbon dioxide and oxygen in winter (El-Gohary, 1984) as well as good upwelling and agitation of water column by the winter monsoon (Halim, 1969 and Nassar, 1994). Generally, the high DO values in winter (7.6-8.19 mg/L) were correlated with the high peak of phytoplankton populations (24,400 & 69,695 unit/L respetively) as compared with other seasons. A significant correlation was found between DO and total phytoplankton counts (r= 0.64 at $p < 0.05$ and N = 12). This agrees with those obtained by Nassar (2000) and Nassar and Shams El-Din (2006) for the northern Red Sea.

3.1.4. Dissolved Ammonia

As presented in Table 1, relative high values of ammonia were observed during summer at Taba and Sharm El-Sheikh with 1.17 and 1.15 µmol/L, respectively. This is may be due to the human activities and increasing numbers of ship feces at the beach of these stations as reported by EIMP (1999 and 2000). They also reported that the levels of ammonia were generally low in the Red Sea proper and the Gulf of Aqaba as compared with the Gulf of Suez (average of 3.35 µmol/L, Nassar, 2007). On the other hand, the lowest concentration of ammonia in the present study was 0.48 µmol/L during winter in the coastal waters of Nuweiba, at which the highest occurrence of phytoplankton was recorded (69,695 unit/L). However, the dissolved ammonia was recorded with the averages of 0.715, 0.897 and 1.02 µmol/L during winter, spring and summer, respectively. Fahmy (2001) reported that the human impact at few locations, excretion from the pelagic food web as well as the microbiological and mixing processes are considered the main factors affecting the distribution pattern of ammonia in Aqaba Gulf coastal waters.

3.1.5. Nitrate

The dominating inorganic nitrogen species in seawater is the nitrate ion, the concentration of which may vary within a wide range. Under aerobic conditions, nitrate is the most stable inorganic nitrogen in seawater (Vanloon and Duffy, 2000). In oligotrophic areas, both nitrate and ammonia originate from marine regeneration and from the atmosphere (Stirn, 1988). The results indicated that dissolved nitrate was generally low in the coastal waters of the Aqaba Gulf with an average of 0.54 µmol/L. It varied between a maximum of 0.84 µmol/L during winter at Nuweiba and a minimum of 0.21 µmol/L during summer at Taba. This agrees with EIMP (1999), except the highest value of 9.63 µmol/L that they found in the coastal waters near Taba City. Generally, the increase of nitrate at the region of Nuweiba (average of 0.67 µmol/L) was associated with high abundance of phytoplankton (average of 27,758 unit/L). These results are in accordance with the data reported by Nassar and Hamed (2003) in the northern part of Suez Gulf. However, Vucak & Stirn (1982) and Franco (1983) stated that concentrations of nitrate in eutrophic water are usually 2.0 µmol/L. While in oligotrophic water, the nitrate values are about 0.50 µmol/L. According to these nitrate levels, the coastal waters of Aqaba Gulf can be classified as oligotrophic state (Klinker *et al*., 1978 and Fahmy, 2001). The results recorded a significant correlation between total counts of phytoplankton and nitrate values ($r = 0.68$ at $p < 0.05$).

3.1.6. Nitrite

Nitrite is an intermediate oxidation state between the low oxidant state (ammonia) and the higher oxidant state (nitrate). Nitrite appears in the water mainly as a result of biochemical oxidation of ammonia; nitrification or the reduction of nitrate; denitrification (Abel-Moneim, 1977). In this study, it was very low at most stations and oscillated between 0.23 µmol/L during summer at Taba and 0.06 µmol/L in winter at Nuweiba (Table 1). Nitrite exhibited a significant inverse correlation with phytoplankton abundance ($r= -0.71$ at $p<0.05$ and $N = 12$), which is agreeing with El-Naggar *et al*. (2002) and El-Sherif *et al*. (2007) in the Gulf of Suez and eastern Mediterranean, respectively.

3.1.7. Dissolved phosphate

Phosphorus is the nutrient that may limit primary productivity in the oceans and seas (FAO, 1989). It is adding to the oceans primarily by runoff and is removal by sedimentation. Remobilization of the sedimentary phosphate depends on its association with different sediment fractions and on the environmental conditions of the sediment (De Lange, 1986). The coastal waters of the Aqaba Gulf were generally poor in dissolved phosphate with an average of 0.132 µmol/L. It ranged from 0.21 µmol/L during winter at Nuweiba and 0.04 µmol/L in summer at Taba (Table 1). According to the eutrophication levels for phosphate in seawater (0.15-0.5 µmol/L) that proposed by Franco (1983) and Stirn (1988); the coastal waters of Aqaba Gulf are in the oligotrophic state in the present study. This also agrees with the results of EIMP (1999) and Post *et al*. (2002). Generally, (EIMP, 2000) indicated that the phosphorus concentrations were near depletion or below the detection limit at most locations in Aqaba Gulf. These low phosphate contents could be related mostly to their sorption and deposition on iron born dust conveyed to the basins from the great areas of surrounding deserts (Fahmy, 2001). The present study indicated a positive correlation between phosphate and total counts of phytoplankton at confidence level 95% ($r = 0.63$ & $N = 12$).

3.2. Phytoplankton

3.2.1. Community composition and distribution

Phytoplankton counts are good estimate of the current degree of productivity. The occurrence of algal blooms may indicate possible impacts of anthropogenic inputs on the ecosystem (Zagloul and Hussein, 2000). The phytoplankton community in the Gulf of Aqaba included 127 taxa belonging to diatoms (75 spp.), dinoflagellates (27 spp.), blue-green algae (16 spp.), green algae (8 spp.) and one species of silicoflagellates (Table 2). Some species are responsible for the high peak of phytoplankton, particularly the green one, *Pleurotaenium trabecula* (16.2% of total phytoplankton counts) then followed by the diatoms, *Melosira* spp. (9.42%), *Nitzschia* spp. (7.7%), *Rhizosolenia* spp. (7.58%) and *Guinardia flaccida* (5.42%)

as well as *Oscillatoria simplicissima* (4.78%) of cyanophytes.

The results (Table 3 and Fig. 2) show that diatoms dominated the other phytoplankton classes, formed about 66.3% by number to the total phytoplankton. Green algae contributed 18%, blue-green algae constituted 9.3%, dinoflagellates shared with 6.32% and silicoflagellates were rarely observed. The highest abundance of phytoplankton was observed at Nuweiba (average of 27,758 unit/L) then followed by Dahab (19,886 unit/L), Sharm El-Sheikh (18,452 unit/L) and Taba (17,221 unit/L). This is mostly correlated at Nuweiba with relative high values of dissolved oxygen (6.5-8.19 mg/L), dissolved nitrate (0.42-0.84 µmol/L) and relatively low levels of ammonia (0.48-0.74 µmol/L) than other investigated stations (Table 1). However, some species are responsible for the flourishing of phytoplankton at Nuweiba namely, *Licmophora flabellata*, *L. gracilis*, *Climacosphenia moniligera*, *Rhizosolenia stolterfothii* and *Melosira italica* of diatoms as well as the leading green species, *Pleurotaenium trabecula*.

El-Sherif and Abo El-Ezz (2000) reported that Sharm El-Sheikh sustained the highest numbers of species (46 spp.) and was dominated by *Oscillatoria, Spirulina* and *Phormidium* of Cyanophyceae. While, Taba region represented with low number of species (30 spp.) and dominated by *Chaetoceros curvisetus, Hemiaulus hauckii, Synedra ulna, Rhizosolenia delicatula, Cyclotella* sp., and *Licmophora gracilis*. Generally, they identified about 68 species classified as 33 dinoflagellates, 27 diatoms, six species of cyanophytes and two species of green algae. Post *et al*. (2002) indicated that diatoms was the most abundant group in the Gulf of Aqaba and consisted mostly of *Chaetoceros, Leptocylindrus, Rhizosolenia* and *Hemiaulus*. While, *Trichodesmium* spp., (*Oscillatoria* spp.) of Cyanobacteria became more prominent as the stratification period progressed. They also pointed to the oligotrophic conditions in the Aqaba Gulf as previously mentioned by many workers (Genin *et al*., 1995 and Yahel *et al*., 1998), which is coincided with the striking feature in the present study.

Table (2): Number of genera and species of the different phytoplankton classes at the different seasons and the annual counts-percentage of each group in Aqaba Gulf.

Season / Group	Winter		Spring		Summer		Total		Aver. counts	%
	G.	sp.	G.	sp.	G.	sp.	G.	sp.		
Diatoms	31	53	27	48	16	27	34	75	13,807	66.29
Dinoflagellates	7	18	6	15	8	16	12	27	1,317	6.32
Green algae	5	5	6	6	3	3	7	8	3,748	18.0
Cyanophytes	6	9	6	13	3	5	8	16	1,938	9.30
Silicoflagellates	1	1	--	--	--	--	1	1	19	0.09
Total	50	86	45	82	30	51	62	127	20,829	100

Table (3): Abundance of the different phytoplankton classes (unit/L), their frequency percentage and diversity (nats) in Aqaba Gulf during 2006.

Station / Group	Winter					
	Taba	**Nuweiba**	**Dahab**	**Sharm El-Sheikh**	**Average**	**%**
Diatoms	21,590	53,589	13,922	15,886	26,247	74.75
Dinoflagellates	1,410	2,473	3,123	1,929	2,234	6.36
Green algae	500	12,450	1,200	5,211	4,840	13.78
Cyanophytes	900	1,033	1,966	3,028	1,732	4.93
Silicoflagellates	--	150	78	--	57	0.16
Total	24,400	69,695	20,289	26,054	35,110	100
Diversity	2.80	2.58	3.11	3.08	2.89	
	Spring					
Diatoms	14,529	4,428	12,867	12,470	11,074	51.81
Dinoflagellates	984	534	645	629	698	3.26
Green algae	3,467	3,417	12,350	4,806	6,010	28.11
Cyanophytes	5,417	1,700	5,622	1,634	3,593	16.81
Silicoflagellates	--	--	--	--	--	--
Total	24,397	10,079	31,484	19,539	21,374	100
Diversity	2.69	3.13	2.35	3.10	2.81	
	Summer					
Diatoms	1,513	1,853	5,519	7,518	4,101	68.29
Dinoflagellates	939	1,115	1,068	962	1,021	17.00
Green algae	357	167	450	600	394	6.54
Cyanophytes	57	367	850	684	489	8.16
Silicoflagellates	--	--	--	--	--	--
Total	2,866	3,502	7,887	9,764	6,005	100
Diversity	3.64	3.35	2.85	2.72	3.14	

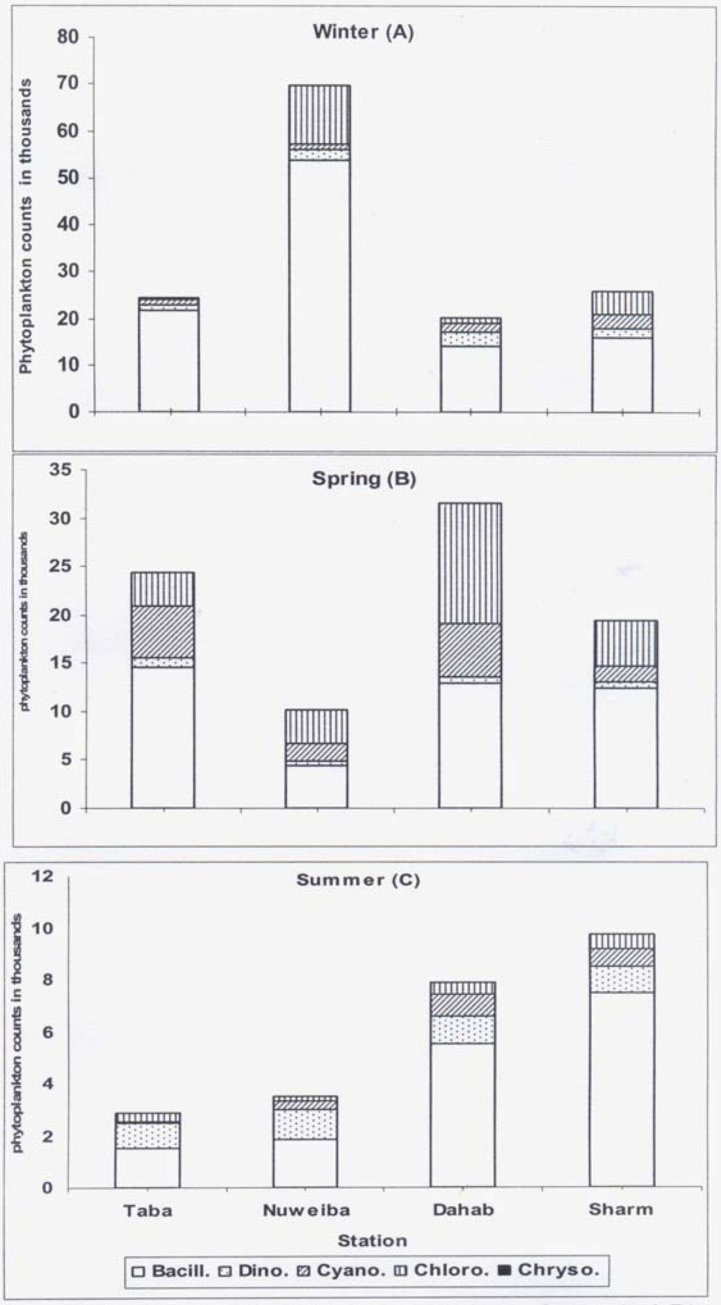

Fig. (2): Seasonal variations of phytoplankton classes (unit/L) during winter (A), Spring (B) and Summer (C) at the different stations.

3.2.2. Seasonal distribution

The phytoplankton standing crop showed a high-pronounced peak in winter (average of 35,110 unit/L), and then followed by spring (average of 21,374 unit/L). While, a severe drop of phytoplankton populations was observed in summer (average of 6,005 unit/L). Also, the numbers of phytoplankton species were higher in winter and spring seasons (86 and 82 species) than summer (51 species). This high flourishing of phytoplankton in winter was mostly associated with high values of dissolved oxygen (7.6-8.19 mg/L), relative high values of nitrate (0.56-0.84 µmol/L) and low levels of ammonia (0.48-1.0 µmol/L) than other seasons. These findings may be due to the effect of the winter monsoon, which increase the productivity of the Red Sea (Halim, 1969). Generally, the high abundance of phytoplankton during winter was previously recorded in the northern Red Sea, Suez Gulf and Suez Canal by El-Sherif and Ibrahim (1993); Nassar (1994); Shams El-Din *et al*. (2005) and Nassar (2007).

However, the diatoms were the predominant group in winter forming about 74.75% of the total phytoplankton counts. The leading species were *Guinardia flaccida* (average of 3,325 cell/L), *Asterionella japonica* (2,625 cell/L) and *Climacosphenia moniligera* (1,975 cell/L).

Green algae showed their highest occurrence in spring representing about 28.11% of total phytoplankton crop. This is due to the highest blooming of the leading green alga, *Pleurotaenium trabecula* forming about 91.5% of total green algae and 27.3% of the total phytoplankton crop in spring.

On the other hand, some phytoplankton species showed their maximum abundance during summer, which sustained the lowest abundance of phytoplankton. These namely, Rhizosolenia *alata* form *gracillima* (43.6% of total diatoms in summer), *Climacodium biconcavum* (about 11% of total diatoms) and *Oscillatoria simplicissima* (63.8% of total cyanophytes). These species may prefer the warm waters for the high growth and flourishment (Carr and Whitton, 1982). However, *Oscillatoria* spp., formed about 6.31% of the total phytoplankton in summer in this study, while it contributed 13-35% of the surface production by other phytoplankton in early summer as reported by Post *et al*. (2002). Moreover, the general oligotrophic status in the coastal waters of Aqaba Gulf as well as the low nutrient concentrations are the important factors responsible for the low abundance of phytoplankton in summer (Dowidar *et al*., 1978).

3.2.3. Species diversity

Results of diversity revealed that the coastal waters of Aqaba Gulf sustained good variations of species as indicated by the averages of 2.89, 2.81 and 3.14 nats during winter, spring and summer, respectively as shown in Table 3. It ranged from a maximum value of 3.64 nats during summer at Taba region and a minimum of 2.35 nats in spring at Dahab. Such high diversity values in summer means the absence of distinct dominance of any particular species or more and the community was shared by several taxa. While in spring, the leading green alga, *Pleurotaenium trabecula* formed 38.1% of the total phytoplankton in the coastal waters of Dahab station, while other species are fairly distributed. Generally, these diversity values (average of 2.94 nats) are relatively high as compared with the surrounding habitats; Suez Canal (average of 1.8 nats, El-Sherif and Ibrahim, 1993); Bitter Lakes and Temsah Lake (2.6 nats, Nassar and Shams El-Din, 2006) and the southeastern Mediterranean (2.55 nats, El-Sherif *et al*., 2007). These findings indicate that the Gulf of Aqaba is still fairly unpolluted and has the oligotrophic nature. This is also confirmed with the significant inverse relation between diversity values and the total counts of phytoplankton (r= - 0.61at $p < 0.05$ and N=12).

4. STATISTICAL ANALYSIS

The correlation matrices indicated that the total counts of phytoplankton were positively correlated with nitrate content (r= 0.68), dissolved oxygen (r = 0.64) and dissolved inorganic phosphate (r= 0.63). Whereas, they were inversely correlated with water temperature (r= - 0.69) and pH value (r= - 0.58) at confidence level 95% and N=12 as shown in Table 4.

Stepwise multiple regressions showed the high dependence of phytoplankton standing crop on the dissolved phosphate, nitrate and pH values then followed by ammonia concentrations, dissolved oxygen and water temperature and the calculated regression model is:

Total phytoplankton counts = 702506 – 843769 PO_4 + 73498 NO_3 – 70374 pH – 15293 NH_4 + 7426 DO + 1116 Temperature (M.R.= 0.798, N = 12 & $p < 0.54$).

This model could be applied to calculate the total counts of phytoplankton in the coastal waters of Aqaba Gulf in these periods.

Table (4): The correlations between physico-chemical factors and the total counts of phytoplankton and diversity in Aqaba Gulf.

	Phyto.	**Temp**	**pH**	**DO**	**PO_4**	**NO_3**	**NO_2**	**NH_4**	**Diver.**
Phyto.	1.00								
Temp.	**-0.69**	1.00							
pH	**-0.58**	**0.85**	1.00						
DO	**0.64**	**-0.86**	**-0.68**	1.00					
PO_4	**0.63**	**-0.76**	**-0.61**	**0.94**	1.00				
NO_3	**0.68**	**-0.80**	**-0.63**	**0.96**	**0.98**	1.00			
NO_2	**-0.71**	**0.83**	**0.66**	**-0.91**	**-0.97**	**-0.97**	1.00		
NH_4	-0.55	0.54	0.41	**-0.75**	**-0.93**	**-0.87**	**0.91**	1.00	
Diversity	**-0.61**	0.30	0.22	-0.39	-0.27	-0.35	0.28	0.04	1.00

Marked correlations are significant at $p < 0.05$ and N=12.

Table (5): List of the recorded species of phytoplankton and their seasonal counts (average of the four stations, unit/L) in Aqaba Gulf during 2006.

Season / Class	Winter	Spring	Summer	Average
Bacillariophyceae (cell/L)				
Amphiprora alata Kütz	62	32	--	31
Amphora grevilleana Cleve	--	25	--	8
Amphora lineolata Ehr.	25	45	--	23
Amphora marina Smith	333	595	76	335
Asterionella japonica Cleve	2,625	80	--	902
Asterionella kariana Grun	800	--	--	267
Bacillaria paradoxa (Gmel.) Grun	200	175	--	125
Bacteriastrum hyalinum Lauder	25	--	--	8
Biddulphia aurita (Lyng.) Breb.	50	32	--	27
Biddulphia obtusa Kütz	95	82	--	59
Campylodisus noricus var. hibernica (Ehr) Grun	--	375	--	125
Cerataulina bergonii H. Peragallo	178	--	--	59
Chaetoceros coarctatus Lauder	--	17	--	6
Chaetoceros curvisetus Cleve	445	--	--	148
Chaetoceros decipiens Cleve	354	--	190	181
Chaetoceros sp.	--	25	--	8
Chaetoceros lauderi Ralfs	103	--	--	34
Chaetoceros peruvianus Brightw.	42	--	--	14
Chaetoceros radicans Schütt	--	--	46	15
Chaetoceros tetrastichon Cleve	--	--	117	39
Chaetoceros tortissimus Gran	158	--	--	53
Climacodium biconcavum Cleve	--	--	447	149
Climacosphenia moniligera Ehr.	1,975	213	102	763
Cocconeis placentula Ehr.	111	178	--	96
Coscinodiscus granii Gough	125	50	--	58
Coscinodiscus radiatus Ehr.	1,008	1,375	177	853
Coscinodiscus excentricus Ehr.	--	25	--	8

Table 5 (Continued)

Class \ Season	Winter	Spring	Summer	Average
Coscinodiscus centralis Ehr.	99	13	--	37
Cyclotella meneghiana Kütz	--	63	78	47
Cymbella ventricosa Kütz	78	20	--	33
Diploneis interrupta (Kütz) Cleve	34	63	--	32
Fragillaria capucina Desm.	229	220	--	150
Fragillaria construens (Ehr.) Grun.	37	--	--	12
Guinardia flaccida H. Peragallo	3,325	--	61	1,129
Gyrosigma attenuatum Ehr.	132	250	29	137
Hemiaulus heibergii Cleve	--	--	154	51
Hemidiscus cuniformis var. ventricosa (Castr.) Hust.	29	--	--	10
Lauderia borealis Gran	467	--	--	156
Leptocylindrus danicus Cleve	133	325	--	153
Licmophora abbreviata Ag.	328	96	--	141
Licmophora flabellata (Gran) Ag.	1,875	61	--	645
Licmophora gracilis (Ehr.) Grunow	1,086	137	--	408
Lithodesmium undulatum Ehr.	--	12	--	4
Melosira granulata var. angustissima Ehr.	1,008	650	50	569
Melosira italica (Ehr.) Kütz	2,088	2,092	--	1,394
Nitzschia closterium W. Smith	58	165	--	74
Nitzschia seriata Cleve	--	63	--	21
Nitzschia longissima Ehr.	1,387	1750	25	1,054
Nitzschia palea (Kütz) W. Smith	19	44	65	43
Nitzschia pungens var.atlantica Cleve	945	--	--	315
Nitzschia sigma Kütz	162	94	34	97
Navicula cancellata Donkin	--	32	--	11
Navicula distans (W. smith) Ralfs	--	25	--	8
Navicula gracilis Cleve	87	90	77	85
Navicula placentula Ehr.	111	82	36	76
Navicula membranaceae Cleve	37	--	--	12
Navicula sp.	--	50	--	17
Rhizosolenia bergonii H. Peragallo	--	--	36	12

Table 5 (Continued)

Season / Class	Winter	Spring	Summer	Average
Rhizosolenia styliformis Brightwell	545	--	36	194
Rhizosolenia alata Brightwell	--	--	225	75
Rhizosolenia calcar avis M. Schultze	--	--	36	12
Rhizosolenia stolterfothii H. Peragallo	1,958	--	58	672
Rhizosolenia alata f. gracillima Cleve	--	--	1,788	596
Rhizosolenia delicatula *Cleve*	50	--	--	17
Striatella unipunctata Lyngb.	113	261	--	125
Surirella ovata Kütz	57	162	20	80
Surirella sp.	--	37	--	12
Synedra ulna Nitzsch.	308	95	--	134
Synedra undulata Bail.	271	208	--	160
Tabellaria fenestrata (Lyng.) Kütz	--	62	--	21
Thalassionema nitzscioides Grun	50	--	--	17
Thalassiothrix frauenfeldii Grun	63	--	64	42
Thalassiothrix longissima Cleve & Grun	278	391	36	235
Tropidoneis antarctia var. polyasta Gran and Angst	--	29	--	10
Tropidoneis lepidoptera (Greg.) Cleve	86	108	38	77
Dinophyceae (cell/L)				
Centrodinium intermedium Pavill.	--	--	66	22
Ceratium karasteni Pavillard	17	17	67	34
Ceratium candelabrum (Ehr) Stein	67	75	--	47
Ceratium furca (Ehr)	114	82	87	94
Ceratium fusus (Ehr) Dujardin	29	89	70	63
Ceratium kofoidi Jörgensen	19	--	--	6
Ceratium macroceros var. gallicum Kofoid	196	--	--	65
Ceratium massiliense (Gourret) Jörgensen	36	--	--	12
Ceratium trichoceros (Ehr) Kofoid	--	12	65	26
Ceratium tripos var. atlanticum Ostenfeld	117	25	--	47

Table 5 (Continued)

Season / Class	Winter	Spring	Summer	Average
Ceratium pentagonum Gourret	171	29	--	67
Ceratium setaccum Jörgensen	--	--	136	45
Diplopsalis rotunda (Lebour) Wood	--	82	84	55
Exuviaella baltica Lohmann	--	44	115	53
Exuviaella compressa Ostenfeld	44	--	64	36
Goniaulax minuta Kofoid & Mich.	--	57	--	19
Noctiluca sp.	--	--	31	10
Oxytoxum sceptrum (Stein) Schröder	--	--	43	14
Oxytoxum sphaeroideum Stein	--	--	14	5
Phalacroma rapa Stein	54	--	--	18
Pronoctiluca spinifera (Loham.) Schill.	17	--	--	6
Prorocentrum schilleri Bohm	20	13	29	21
Protoperidinium cerasus Paulsen	171	36	79	95
Protoperidinium depressum Bailey	29	57	46	44
Protoperidinium globules Stein	183	67	25	92
Protoperidinium steini Jörgensen	25	13	--	13
Pyrocystis fusiformis (W.Thom.) Murray	925	--	--	308
Chlorophyceae (cell or colony/L)				
Actinastrum hantzschii Lagerheim	50	--	--	17
Chlorella vulgaris Beyerinck	--	232	--	77
Closterium gracile Brebisson	271	44	--	105
Oocystis borgei Snow	--	125	125	83
Pediastrum clathratum Lemm.	--	67	119	62
Pediastrum duplex Meyen	25	--	--	8
Pleurotaenium trabecula (Ehr) Naeg.	4,450	5,500	150	3,367
Treubaria crassipina Smith	44	42	--	29

Table 5 (Continued)

Class \ Season	Winter	Spring	Summer	Average
Cyanophyceae (filament or colony/L)				
Anabaena sp.	--	19	--	6
Aphanocapsa nidulus Smith	120	--	--	40
Chroococcus turgidus (Kütz) Naeg.	50	82	36	56
Lyngbya limnetica Lemm.	225	212	38	158
Lyngbya major Menegh.	175	796	36	336
Lyngbya majuscula Harvey	--	19	--	6
Merismopedia punctata Smith	--	38	--	13
Oscillatoria agardhii Gomont	--	138	--	46
Oscillatoria erythraeum Drouet	--	187	--	62
Oscillatoria formosa Bory.	--	13	--	4
Oscillatoria simplicissima Gom.	750	1,925	312	996
Oscillatoria curviseps Agardh	--	36	--	12
Oscillatoria tenuis Agardh.	200	33	67	100
Oscillatoria sp.	50	--	--	17
Phormidium sp.	125	95	--	73
Spirulina major KG.	37	--	--	12
Silicoflagellates (cell/L)				
Dictyocha fibula Ehr.	57	--	--	19

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