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Phytoplankton population along certain Egyptian coastal regions of the Red Sea

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ABSTRACT

Surface phytoplankton samples were collected at eight sites along certain Egyptian coasts of the Red Sea located at the southern of Sinai Peninsula and the two gulfs (Gulf of Suez and Gulf of Aqaba). Qualitative and quantitative estimation of phytoplankton species were conducted seasonally during the period from autumn 2007 to summer 2008. The phytoplankton population was fairly diversified (181 species) comprised mainly two groups; dinoflagellates (116 species) and diatoms (60 species). The dominant genera, in terms of the number of species, were *Ceratium*, *Protoperidinium*, *Dinophysis* and *Gonyaulax* for dinoflagellates, while *Chaetoceros*, *Rhizosolenia* and *Nitzschia* for diatoms. The phytoplankton standing crop was relatively low with and average seasonal density of $1.4\text{-}7.7\times10^3$ individual/l, reflecting the oligotrophic conditions of this area. The phytoplankton abundance showed one peak in summer when *Hemiaulus hauckii* (9×10^3 individual/l) from diatoms and *Trichodesmium* spp. (3×10^3 individual/l) from blue-green algae comprised the main bulk of the phytoplankton standing crop. Relatively high production of different species appeared at different sites during specific season, such as *Nitzschia closterium*, *Pseudo-nitzschia delicatissima*, *Rhizosolenia alata* and *R. calcar-avis*. On the other hand, there were relatively low variations in phytoplankton composition the along study area. Spatial distribution of phytoplankton showed that Gulf of Suez differes in the dominant species and timing of abundance from both Gulf of Aqaba and the southern sites of Sinai Peninsula.

Key words: Phytoplankton, species composition, Gulf of Suez, Gulf of Aqaba, Red Sea.

INTRODUCTION

The Red Sea is a long narrow basin which extends over 1900 km north of the narrow straits of Bab-el-Mandab between 30° N to 12° 30´ N. The Sinai Peninsula divides the northern extremity into the shallow Gulf of Suez and the deep Gulf of Aqaba. There is almost no rainfall as any permanent rivers inflow into the Red Sea, and evaporation is high (Edwards, 1987). Salinity values increase from south to north with decreasing surface temperatures (Edwards, 1987). In the northern Red Sea, the average surface temperature fluctuates between 21.3°C and 27.9°C showing slightly greater amplitude in the Gulf of Suez (17.9°C to 26.5°C) (Morcos, 1970). Surface salinity reaches up to 40-41‰

in the northern Red Sea and the Gulf of Aqaba, and to more than 41‰ in the Gulf of Suez (Halim, 1969). The northern Red Sea is permanently stratified throughout the year, mixing depth is <100 m, a deep chlorophyll maximum is present year-round at about 80-100 m depth, and the euphotic depth is well beyond 100 m (Pätzold *et al.*, 2000).

Previous studies on the phytoplankton population of the Red Sea introduced some information about the phytoplankton species composition and community structure. In oceanic water of the central Red Sea, Halim (1969) reported 209 species (125 dinoflagellates and 84 diatoms) and Skaikh *et al.* (1986) recorded 283 species (of them, 110 dinoflagellates and 137 diatoms). At Saudi Arabia coasts, Dowidar *et al.,* (1978) recorded about 224 species in the region of Obhor, Jeddah (111 dinoflagellates and 112 diatoms). Recently, Touliabah *et al.* (2010) studied phytoplankton composition at Jeddah coast in relation to some ecological factors and recorded 73 species. Few studies have been carried out on the Gulf of Aqaba, some concerning seasonal dynamics of phytoplankton (Al-Najjar *et al*., 2007) or the primary production (Sournia, 1977; Levanon-Spanier *et al.,* 1979). In the Gulf of Suez, the phytoplankton composition and distribution in relation to environmental factors was studied by Deyab *et al*. (2004) and Ismail (2005).

Most of the previous studies reported that late winter-early spring is characterized by high phytoplankton production throughout the Red Sea, resulting from the winter monsoon (Halim, 1969; Levanon-Spanier *et al.,* 1979). Other studies observed bimodal pattern with a higher one in December-February and a smaller one in June-August (Skaikh *et al.*, 1986). The flourishing of *Trichodesmium* spp. is a known phenomenon along the Red Sea during summer as reported in Saudi coasts (Dowidar *et al.*, 1978) and in the Gulf of Aqaba (Kimor and Golandsky, 1977; Gordon *et al.*, 1994; Post *et al.,* 2002). Occurrence of some diatoms such as *Hemiaulus* and *Rhizosolenia* in adequate high numbers associating with *Trichodesmium* was reported from the Gulf of Aqaba (Post *et al.*, 2002). These species often associate cyanobacterial symbionts capable of nitrogen fixation (Gordon *et al.,* 1994). In the Gulf of Aqaba, phytoplankton is dominated by ultra- and picoplankton (Sommer, 2000; Sommer *et al.,* 2002).

Studies on the phytoplankton population of the Red Sea still remain inadequate when compared to the size and ecological importance of this area. The present paper aims to study the seasonal changes in phytoplankton composition and standing crop distribution in the neritic waters of the Egyptian Red Sea coasts, including the Gulf of Suez and the Gulf of Aqaba.

MATERIALS AND METHODS

In the present study, surface water samples were collected seasonally between autumn 2007 and summer 2008 at eight sites along the Egyptian Red Sea coasts (Fig. 1). Sites 1 and 2 represent the Gulf of Suez locating in front of

El-Tor and at the entrance of the gulf, respectively. Sites 3-6 are situated around the southern tip of Sinai Peninsula. Site 3 lies in front of Ras Mohamed; sites 4 and 5 are situated at a semi-enclosed coastal bay (Sharm El-Maya) and site 6 is located off Sharm El-Sheikh city. Sites 7 and 8 represent the Gulf of Aqaba, the former located at southern entrance of the gulf and the later lies in front of Dahab. At each site, water temperature and dissolved oxygen were measured *in situ* by an ordinary thermometer and oxygen meter (JENWAY, Model 9070), respectively. Nutrient salts (nitrate, nitrite, phosphate and silicate) were measured spectrophotometrically following the methods of Parsons *et al.* (1984). For chlorophyll *a* estimation, 5 liters of seawater were filtered using 0.45 µm membrane filters, extracted in 90% acetone and measured spectrophotometrically according to Parsons *et al.* (1984).

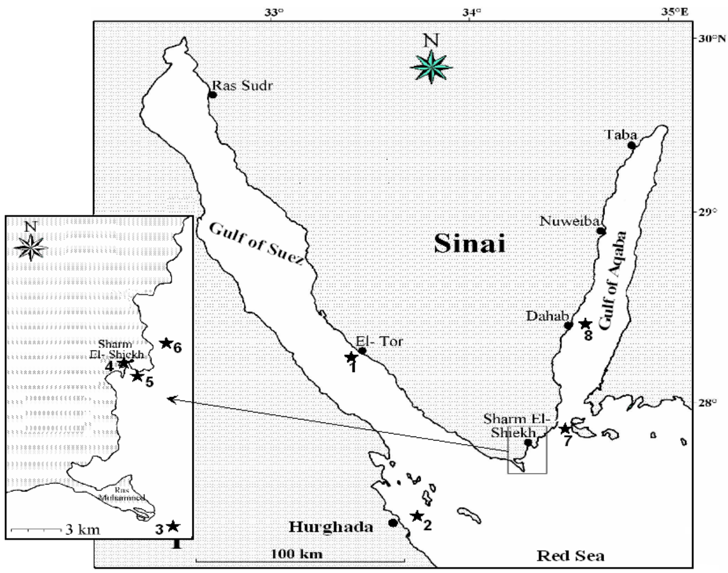

Fig. 1: Sampling sites along certain Egyptian coasts of the Red Sea.

For phytoplankton investigation, 10 liters of surface water were collected, preserved in 4% neutral formalin and concentrated by decanting. Sub-sample of 10 ml was settled in a counting chamber of Hydrobios inverted microscope and cell count was performed using Utermöhl's technique (Utermöhl, 1958). The entire chamber bottom was scanned at 10X for large and/or rare species. The smaller and dominant species were counted at magnifications of 20X and counts were expressed as individual/l. Many keys and reference books were used for identification (Hendey, 1964; Taylor, 1976; Dodge, 1982; Tomas, 1996). Similarity matrix (S) was performed to deduce the variation between sites. The similarity coefficient was calculated by the Bray and Curtis formula (Field *et al.*, 1982) using PRIMER program Version 5.2.

RESULTS

The values of measured physico-chemical parameters and chlorophyll *a* at the studied sites were averaged for the three regions as follows: The Gulf of Suez (sites 1 and 2), the southern of Sinai Peninsula (sites 3-6) and the Gulf of Aqaba (sites 7 and 8), and are shown in Table (1).

Table 1: The average values of studied physico-chemical parameters and chlorophyll *a* at Gulf of Suez (I), southern of Sinai Peninsula (II), and Gulf of Aqaba (III) sites during autumn 2007- summer 2008.

Seasons	**Autumn**			**Winter**			**Spring**			**Summer**		
Sites	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**
Temperature (°C)	26.1	26.1	25.5	22.1	21.8	21.6	22.8	23.6	23.5	29.8	30.9	29.6
DO (mg/l)	6.9	7.2	7.3	7.2	7.3	7.4	7.0	7.1	6.9	6.4	6.6	6.5
Nitrate (µM)	0.42	0.48	0.38	0.09	0.11	0.07	1.25	1.40	0.91	0.94	1.13	0.91
Nitrite (µM)	0.011	0.013	0.010	0.012	0.012	0.013	0.110	0.113	0.095	0.025	0.035	0.020
Phosphate (µM)	0.015	0.015	0.013	0.300	0.328	0.210	0.610	0.718	0.500	0.205	0.443	0.240
Silicate (µM)	1.20	1.75	1.08	2.00	2.96	1.55	0.38	0.61	0.38	0.18	0.25	0.15
Chlorophyll *a* (µg/l)	0.115	0.145	0.125	0.125	0.150	0.120	0.155	0.148	0.125	0.960	0.963	0.900

In the investigated area, temperature and dissolved oxygen showed low variation among sites. Surface water temperature ranged between the minimum average value of 21.6 ºC in winter and the maximum of 30.9 ºC in summer, while dissolved oxygen fluctuated between 6.4 mg/l at the Gulf of Suez in summer and 7.4 mg/l at the southern of Sinai Peninsula in winter. Low nutrient concentrations were observed throughout the whole year with the highest values at the southern of Sinai Peninsula. The averages of nutrients were fluctuated between minima of 0.07, 0.010, 0.013 and 0.15, and maxima of 1.40, 0.113, 0.718 and 2.96 µM for nitrate, nitrite, phosphate and silicate, respectively. Chlorophyll *a* was rather low throughout the whole study area. Seasonally, summer was the most productive season giving a maximum chlorophyll a value of 0.963 µg/l at the southern of Sinai Peninsula, while low values was detected in the other seasons, particularly in autumn.

The phytoplankton species recorded in the present study was 181 species comprised mainly of dinoflagellates and diatoms (Table 2). Among dinoflagellates, 116 species belonging to 21 genera were recorded. Of them, *Ceratium* was the most important genus in terms of the number of species (34 species, 29% of the dinoflagellates) followed by *Protoperidinium* (21 species, 18% of the dinoflagellates). Diatoms were represented by 60 species belonging to 28 genera. The most diversified genera were *Chaetoceros* (9 species) and *Rhizosolenia* (8 species). In addition, 2 species of Cyanobacteria, 2 species (from 2 genera) of coccolithophores and 1 species of silicoflagellates were recorded. The diversity of phytoplankton varied among sites and seasons. The highest species number was recorded at site 3 with a total number of 130 species (85 dinoflagellates and 41 diatoms), followed by sites 7 and 8 (Gulf of Aqaba). The lowest number of phytoplankton species was recorded at site 1 (Gulf of Suez) with a total number of 88 species (46 dinoflagellates and 40 diatoms).

As shown in Figure (2), the phytoplankton population was more diversified in autumn particularly at sites 3 and 7 (106 and 105 species, respectively) followed by summer especially at site 7 (94 species). Dinoflagellates displayed high diversity all over the year except in winter recording the highest number of species in summer at site 7 (75 species). On the other hand, the highest number of diatoms appeared in winter while low numbers were recorded in spring and summer.

Table 2: Phytoplankton species recorded at certain Egyptian coasts of the Red Sea during autumn 2007-summer 2008.

Phytoplankton Species/Sites	1	2	3	4	5	6	7	8	Phytoplankton Species/Sites	1	2	3	4	5	6	7	8
Dinophyceae									*C. tripos* (O. F. Muller) Nitzsch	*	*	*	*	*	*	*	*
Amphisolenia bidentata Schroder	*	*	*	*	*	*	*	*	*C. vultur* Cleve		*	*		*	*	*	
Ceratium arietinum Cleve			*	*	*			*	*Ceratocorys armata* (Schutt) Kofoid	*	*	*		*		*	
C. belone Cleve			*			*	*	*	*C. gourreti* Paulsen			*				*	
C. breve (Ostenfeld & Schm.) Schroder	*	*			*	*	*	*	*C. horrida* Stein	*		*	*	*		*	*
C. candelabrum (Ehrenberg) Stein	*	*	*	*	*	*	*	*	*Citharistes regius* Stein	*		*		*	*		
C. carriense Gourret	*	*	*	*			*		*Dinophysis argus* Stein		*		*				*
C. contortum (Gourret) Cleve	*	*	*	*	*	*	*	*	*D. caudata* Saville & Kent	*							
C. contrarium (Gourret) Pavillard		*	*	*	*	*	*		*D. cuneus* Schutt							*	
C. declinatum Karst.		*	*	*	*	*	*	*	*D. doryphorum* Stein		*	*		*	*	*	*
C. deflexum (Kofoid) Jörgensen	*		*	*		*	*	*	*D. miles* Cleve			*	*		*		
C. egyptiacum Halim	*	*				*			*D. operculata* Stein							*	
C. extensum (Gourret) Cleve		*	*			*	*	*	*D. parvula* Schutt						*		
C. furca (Ehrenberg) Clap. & Lackmann	*	*	*	*	*	*	*	*	*D. porodictyum* Stein			*					
C. fusus (Ehrenberg) Duj.	*	*	*	*	*	*	*	*	*D. rapa* Stein					*			
C. gravidum Gourret		*							*D. sphaerica* Stein	*	*				*		
C. horridum Gran	*	*	*	*	*	*	*	*	*D. tripos* Gourret	*			*		*		
C. humile Jörgensen	*	*	*	*	*	*	*	*	*D. uracantha* Stein					*	*		
C. incisum (Karsten) Jörgensen		*		*	*	*	*	*	*Goniodoma polyedricum* (Pouch.) Jörgensen		*	*	*	*	*	*	
C. inflatum (Kofoid & Jörgensen			*			*		*	*G. sphaericum* Murray & Whitting		*	*	*	*	*	*	*
C. karstenii Paviilard					*	*			*Gonyaulax digensis* Kofoid							*	
C. kofoidii Jörgensen	*		*			*	*	*	*G. hyalina* Ostenfeld & Schmidt	*	*			*		*	*
C. lineatum (Ehrenberg) Cleve	*	*	*	*	*	*			*G. kofoidii* Pavillard		*	*	*		*	*	*
C. macroceros (Ehrenberg) Vanh.		*	*	*	*	*	*	*	*G. minuta* Kofoid & Michener			*	*			*	*
C. massiliense (Gourret) Jörgensen	*	*	*	*	*	*	*	*	*G. ovalis* Schiller			*	*				*
C. minutum Jörgensen	*	*	*	*		*		*	*G. polygramma* Stein		*	*	*	*	*	*	*
C. pavillardi Jörgensen						*			*G. scripssa* Kofoid			*		*		*	*
C. pentagonum Gourret	*		*		*				*G. spinifera* (Clap.&Lackmann) Diesing			*	*	*		*	
C. platycorne Daday					*	*			*G. turbynei* Murray & Whitting	*		*		*		*	
C. pulchellum Jörgensen	*	*							*Gymnodinium arcticum* Kofoid			*					
C. reflexum Cleve	*	*	*				*	*	*Gyrodinium britannia* Kofoid & Swezy		*	*		*	*	*	*
C. schmidti Jörgensen		*			*				*Histioneis depressa* Schiller	*		*		*	*	*	*
C. teres Kofoid	*	*	*	*	*	*	*	*	*H. longicollis* Kofoid								*
C. trichoceros (Ehrenberg) Kofoid	*	*	*	*	*	*	*	*	*Oxytoxum areolatum* Rampi	*						*	
O. constrictum (Stein) Butschli			*	*		*			*P. sphaericum* (Murr.& Whitt.) Balech		*				*	*	*
O. frenguellii Rampi		*						*	*P. steinii* Jörgensen	*		*		*	*	*	*
O. gladiolus Stein							*	*	*Pyrocystis fusiformis* Thompson & Murray	*	*	*	*	*	*	*	*

Table 2: Continued.

O. constrictum **(Stein) Butschli**			*	*		*			*P. sphaericum* **(Murr.& Whitt.) Balech**		*				*	*	*
O. frenguellii **Rampi**		*						*	*P. steinii* **Jörgensen**	*		*		*	*	*	*
O. gladiolus **Stein**							*	*	*Pyrocystis fusiformis* **Thompson & Murray**	*	*	*	*	*	*	*	*
O. milneri **Murray & Whitting**			*				*	*	*P. hamulus* **Cleve**		*	*		*	*	*	*
O. scolopax **Stein**		*	*	*	*	*	*	*	*P. lunula* **(Schutt) Schutt**			*	*	*	*	*	*
O. sphaeroideum **Stein**								*	*P. pseudonoctiluca* **Thompson Murray**		*	*	*	*	*	*	*
O. tesselatum **Schutt**			*	*	*				*Pyrodinium schillerii* **(Matz.) Schiller**	*		*	*	*	*	*	
Palaeophalacroma unicinctum **Schiller**	*	*	*	*	*	*	*	*	*Pyrophacus horologium* **Stein**			*	*			*	*
Peridiniopsis asymmetrica **Mangin**	*		*	*	*	*		*	*P. steinni* **(Schiller) Whall et Dale**			*	*				
P. lenticula **Stein**	*								*Scrippsiela faeronies* **(Pauls.) Balech & Soares**			*	*	*	*	*	*
Podolampas bipes **Stein**		*	*		*	*			*S. trochoidea* **(Stein) Loeb. III**		*	*	*	*	*	*	*
P. palmipes **Stein**		*	*	*	*		*	*	**Diatoms**								
Prorocentrum compressum **(Bail.) Abe ex Dodge**	*	*	*	*	*	*	*	*	*Actinoptychus undulatus* **(Bail.) Ralfs**		*	*					
P. gracile **Schutt**	*	*	*	*	*	*	*	*	*Amphora coefaeformis* **Agardh**			*					
P. maximum **Schiller**	*	*	*	*	*	*	*	*	*Campylodiscus décorus* **Breb.**	*			*				
P. micans **Ehrenberg**		*	*	*	*	*	*	*	*Chaetoceros compressum* **Lauder**	*	*	*	*	*	*	*	*
P. obtusa **Pavillard**	*		*	*	*	*	*	*	*C. brevis* **Schutt**	*	*	*	*	*	*	*	*
Protoceratium aereolatum **Kofoid**				*					*C. coarctatus* **Lauder**	*	*		*	*		*	*
P. reticulatum **Buetschli**		*			*	*	*		*C. curvisetum* **Cleve**	*	*	*		*	*	*	*
Protoperidinium brochii **Kofoid & Swezy**		*	*	*	*	*	*		*C. decipiens* **Cleve**	*	*	*	*	*	*	*	*
P. cerasus **Paulsen**		*	*	*	*	*		*	*C. laciniosus* **Schütt**	*	*	*	*	*	*	*	*
P. conicum **Ostenfeld & Schm**			*		*		*	*	*C. lauderi* **Ralfs**	*	*	*	*	*	*	*	*
P. crassipes **Kofoid**	*	*	*	*	*	*	*	*	*C. lorenzianum* **Grunow**	*	*	*	*	*	*	*	*
P. curvipes **Ostenfeld**		*	*				*	*	*C. tetrastichon* **Cleve**	*	*	*	*	*	*	*	*
P. depressum **Bailey**		*	*	*	*	*	*	*	*Climacodium fraunfeldianum* **Grunow**			*		*			*
P. diabolus **Cleve**		*	*	*	*	*	*	*	*Cocconeis scutellum* **Ehrenberg**	*		*	*				
P. divergens **Ehrenberg**	*	*	*	*	*	*	*	*	*Corethron cryophylum* **Castracane**						*		
P. excentricum **Paulsen**	*	*	*	*	*		*	*	*Cosciodiscus centralis* **Ehrenberg**	*	*	*	*	*	*	*	*
P. globulus **Stein**		*	*	*	*	*	*	*	*C. eccentricus* **Ehrenberg**	*			*	*	*	*	
P. grande **Kofoid**					*			*	*C. lineatus* **Ehrenberg**		*	*			*		
P. granii **(Ostenfeld) Paulsen**			*		*			*	*C. oculus-iridis* **Ehrenberg**	*	*	*			*	*	*
P. leonis **Pavillard P. n**	*		*	*	*	*	*	*	*C. perforatus* **Ehrenberg**		*	*			*	*	
P. oceanicum **Vanhoffen**	*	*	*	*	*	*		*	*C. radiatus* **Ehrenberg**		*	*	*	*	*	*	*
P. ovatum **Pouchet**			*		*		*	*	*Diplonies crabro* **(Ehrenberg) Wm. Smith**		*	*	*	*	*	*	*

Table 2: Continued.

P. ovatum **Pouchet**			*		*		*	*	*Diplonies crabro* **(Ehrenberg) Wm. Smith**		*	*	*	*	*	*	*
P. pallidum **Ostenfeld**			*	*	*	*	*	*	*Guinardia flaccida* **(Cast.) H. Peragallo**	*							*
P. pedunculatum **Schutt**		*	*	*	*	*			*Gyrosigma balticum* **(Ehrenberg) Cleve**	*				*	*		
P. pellucidum **Bergh**		*	*	*	*	*		*	*Hemiaulus hauckii* **Grunow**	*	*	*	*	*	*	*	*
P. pentagonum **(Gran) Balech**				*					*H. membranaceous* **Cleve**		*						
H. senensis **Greville**						*	*	*	*R. stolterfothii* **H. Peragallo**		*				*	*	*
Leptocylindrus danicus **Cleve**	*	*	*	*	*	*	*	*	*R. styliformis* **Brightwell**	*	*	*	*	*	*	*	*
Navicula membranacea **Cleve**			*	*	*	*	*	*	*Schroderella delicatula* **(H. Pergallo) Pavillard**	*			*		*	*	*
Nitzschia closterium **(Ehrenberg) W. Smith**	*	*	*	*	*	*	*	*	*Striatella unipunctata* **(Lyngbye) Agardh**	*							*
N. hungarica **Grunow**	*	*	*	*	*			*	*Surirella fastuosa* **Ehrenberg**		*	*					
N. longissima **(Breb.) Ralfs**	*	*		*		*			*S. gemma* **Ehrenberg**					*			*
N. lorenziana **Grunow**	*	*	*	*	*		*	*	*S. ovalis* **Breb.**	*						*	
N. panduriformis **Gregory**	*		*					*	*Synedra ulna* **(Nitzsch) Ehrenberg**	*	*		*	*		*	
Pinnularia trevelyana **Donkin**	*		*					*	*S. crystalina* **(Agardh) Kutz.**	*	*	*	*	*	*	*	*
Planktoniella sol **(Wallich) Schutt**		*	*	*	*	*	*	*	*Thalassionema nitzschioides* **Grunow**	*		*	*	*		*	*
Pleurosigma angulatum **Quekett**		*	*	*		*	*	*	*Thalassiosira decipiens* **(Grunow) Jörgensen**						*	*	
P. elongatum **W. Smith**	*		*				*		*Thalassiothrix longissima* **Cleve & Grunow**	*		*					
P. normanii **Ralfs**		*	*		*		*	*	*T. frauenfeldii* **(Grunow) Cleve&Grunow**		*	*	*		*		*
Pseudo-nitzschia delicatissima **(Celve) Heiden**	*		*	*			*	*	**Cyanobacteria**								
Rhabdonema adriaticum **Kutzing**		*					*		*Trichodesmium erythraeum* **Ehrenberg & Gomont**	*	*	*	*	*	*	*	*
Rhizosolenia alata **Brightwell**	*	*	*	*	*	*	*	*	*Trichodesmium* **sp.**	*	*	*	*	*	*	*	*
R.calcar-avis **M. Schultze**	*	*	*		*	*	*	*	**Coccolithophores**								
R. hebetata **Bailey**	*	*	*	*	*	*		*	*Syracosphaera mediterranea* **Lohmann**					*	*		*
R. imbricata **Breightwell**	*							*	*Coronosphaera* **sp.**			*	*				*
R. indica **H. Peragallo**	*	*				*	*		**Silicoflagellates**								
R. setigera **Brightwell**	*	*	*	*	*			*	*Dictyocha fibula* **Ehrenberg**			*					

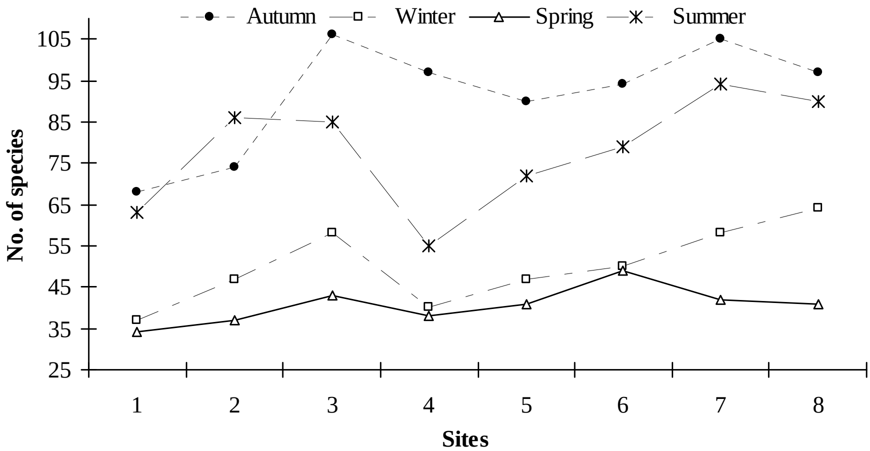

Fig. 2: The total number of phytoplankton species recorded at each site during autumn 2007-summer 2008.

The diversity and occurrence of the other groups (i.e. blue-green algae, coccolithophores and silicoflagellates) were very low. The standing crop of phytoplankton community was characterized by low density throughout the area of study, with an annual average of 4.5×10^3 individual/l. The spatial average of phytoplankton groups recorded throughout the whole study area during each season is shown in Fig. (3). On a seasonal scale, summer exhibited the highest phytoplankton cell count (average: 12.3×10^3 individual/l), while other seasons demonstrated low and close values with a minimum average value of 1.2×10^3 individual/l in autumn.

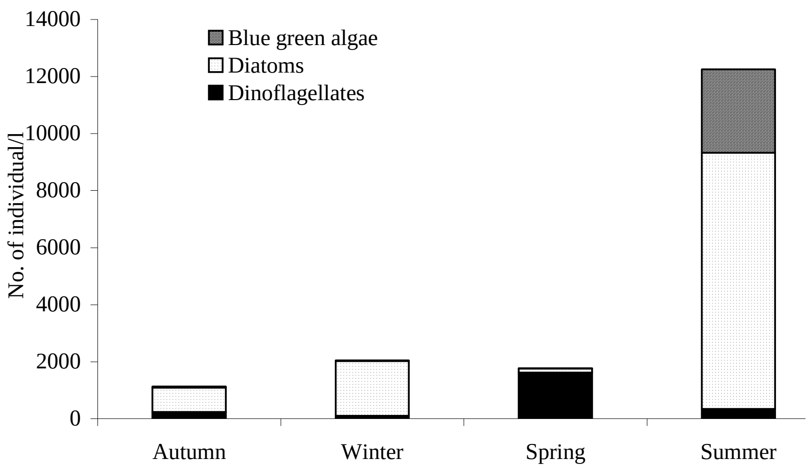

Fig. 3: Spatial average of phytoplankton groups (individual/l) throughout the whole study area during autumn 2007-summer 2008.

The seasonal average standing crop of total phytoplankton at each site ranged between a minimum of 1.4×10^3 and a maximum of 7.7×10^3 individual /l at sites 8 and 4, respectively (Fig. 4).

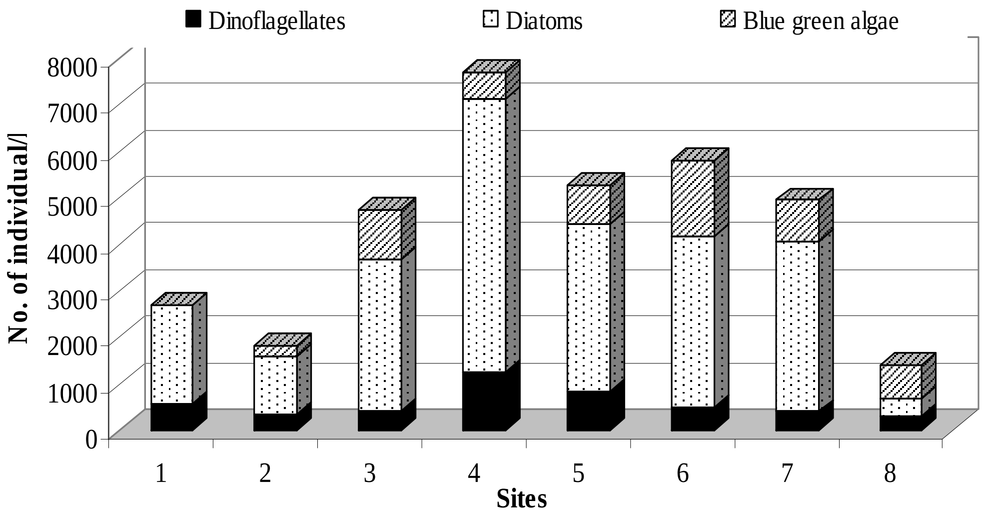

Fig. 4: Average seasonal density of phytoplankton groups (individual/l) at each sampling site during autumn 2007-summer 2008.

Diatoms showed approximately high densities at all sites comprising about 63.4-78.1% of the total phytoplankton, except at site 8 (22.1%). On the other hand, dinoflagellates predominated when the density of diatoms decreased. As shown in Fig. (5), the spatial distribution of phytoplankton standing crop demonstrated distinctive variations between the Gulf of Suez and both the Gulf of Aqaba and the southern Sinai Peninsula with different patterns of seasonal distribution. All sites which represent the southern part of Sinai Peninsula (3-6) showed relatively higher phytoplankton densities than that of both gulfs. A distinct peak of phytoplankton standing crop was observed in the southern part of Sinai Peninsula and the Gulf of Aqaba during summer with a maximum value of 23×10^3 individual /l at site 4 but with lesser density in the Gulf of Aqaba (4×10^3 individual /l). Conversely, the lowest abundance in the same area occurred during winter. In the Gulf of Suez, a relatively high phytoplankton production appeared during winter with a maximum value of 7×10^3 individual /l at site 1.

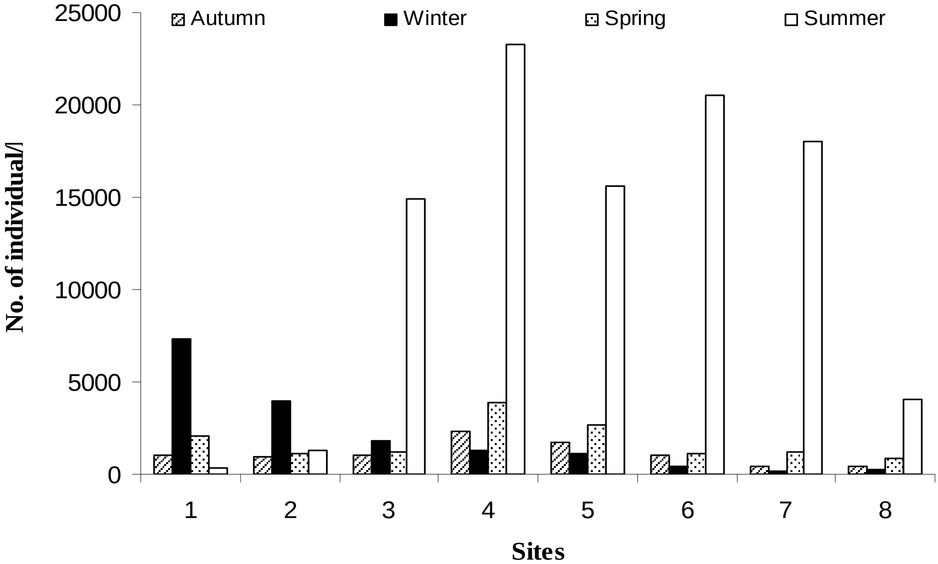

Fig. 5: Seasonal distribution of total phytoplankton standing crop (individual/l) at each sampling site.

The previously mentioned peak in summer is caused mainly by *Hemiaulus hauckii* and the two species of *Trichodesmium*. The first species represented about 73% of the total phytoplankton with an average of 9×10^3 individual/l. This species appeared with higher densities at sites 3-7. *Trichodesmium* constituted about 23.8% of the total count (average: 3×10^3 individual/l) with a maximum of 7×10^3 individual/l at site 6. In autumn, relatively high production of different species appeared at different sites. For example, at sites 3-6, *Nitzschia closterium* and *Pseudo-nitzschia delicatissima* predominated the phytoplankton community comprising about 33.7% and 26.7% of the phytoplankton count, respectively. On the other hand, *Rhizosolenia alata* and *R.* calcar-avis showed relatively high count at sites 1 and 2 constituting about 22.3% and 16% of the total count, respectively. In winter, *Rhizosolenia alata* (44.6%) and *Pseudo-nitzschia delicatissima* (19.2%) continued with relatively high count at sites 1 and 2 accompanied with *Thalassionema nitzschioides* (30%). Dinoflagellates showed the highest density in spring constituting 91.7% of the total count with an average of 2×10^3 individual/l. *Prorocentrum* and *Ceratium* were the most dominant genera. Of them *Prorocentrum gracil, P. maximum, Ceratium contortum* and *C. candelabrum* were the leader species with averages around 10^3 individual /l.

The cluster analysis was performed based on seasonal average of phytoplankton standing crop recorded at each site (Fig. 5). It is observed that stations of the studied area combined to form distinct groups. The resulting dendrogram can be objectively partitioned into two groups at the level ≈60% of the similarity index. First group included sites 1 and 2, while another group is further divided into two clusters at the level 68.4% of the similarity index. The first cluster included sites 3-6 and the second formed from sites 7 and 8. The dendrogram confirmed that the phytoplankton species composition and abundance in the Gulf of Suez differ greatly than that of the Gulf of Aqaba and the southern Sinai Peninsula. It is obvious that the similarity between the Gulf of Aqaba and the southern Sinai Peninsula was high (Fig. 6).

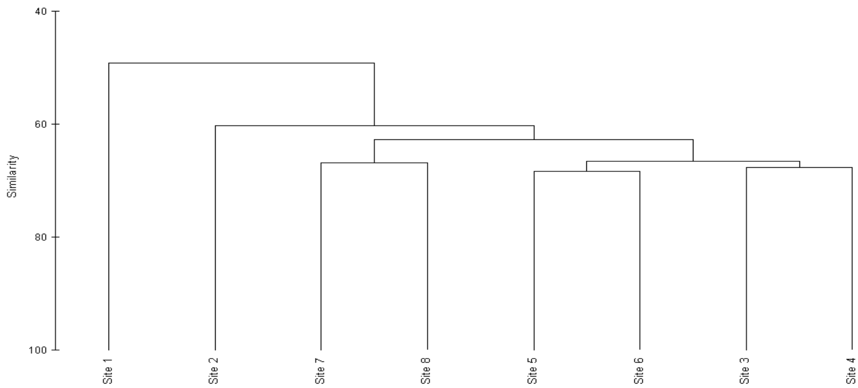

Fig. 6: Dendrogram, group average linkage, Bray Curtis of the similarities on abundance of different phytoplankton species between different sites.

DISCUSSION

In the area of study, physico-chemical conditions follow the normal seasonal fluctuations of the northern Red Sea. Water temperature values clearly reflected the subtropical conditions of the area as reported by Morcos (1970). Furthermore, the low concentrations of nutrient salts and chlorophyll *a* indicated the oligotrophic condition of the investigated area as documented in the previous studies (Weikert, 1987). The high averages of nutrient salts and chlorophyll *a* that recorded at the southern of Sinai Peninsula reflected the high values at sites 4 and 5 and this could be related to the using of this area as a mooring park for touristic and fishing boats.

Since the previous studies which described the phytoplankton population structure and distribution of the northern Red Sea is limited, the complete picture of phytoplankton species composition of this area has been generally underestimated. So, the present study comes to provide information on the spatial and seasonal distribution of phytoplankton in the neritic water of certain Egyptian Red Sea. During the present study, 181 species of phytoplankton were recorded (116 dinoflagellates, 61 diatoms). The recorded number of species in this study is considerably lower than that of the previous studies (283 species) as recorded by Skaikh *et al.,* (1986). The relatively paucity of species number in the present work, particularly that of diatoms, in compared to dinoflagellates, may be related to the sampling strategy where samples were collected from the upper surface and/or from near shore waters. Moreover, the area of study is located north to 20° N which is characterized by lower diversity than the rest of the Red Sea as reported by Halim (1969) and Weikert (1987).

The recorded number of species at the southern of Sinai Peninsula (163 species, 90% of the total recorded species) was higher than that of the Gulf of Suez (133 species, 73%) and the Gulf of Aqaba (141 species, 78%). This is in agreement with the previous records which stated that the phytoplankton diversity of the Red Sea decrease gradually northward (Halim, 1969; Weikert, 1987). Most of the recorded species are cosmopolitan, tropical and sub-tropical forms, all of them are widely known in the Indo-Pacific region. Most of the dominant genera of phytoplankton assemblage (*Ceratium, Protoperidinium, Chaetoceros*, *Rhizosolenia* and *Nitzschia*) were more or less similar to other previous studies (Dowidar *et al.,* 1978; Skaikh *et al.,* 1986). Although the species number of dinoflagellates (116 species) exceeded that of diatoms (60 species), diatoms constituted the main bulk of phytoplankton community in terms of cell number. It contributed about 79.7% of the total phytoplankton with an annual average of 5.2×10^3 individual/l. Blue green algae and dinoflagellates occupied the second order in terms of cell count with relatively close annual averages (7.5 and 5.8×10^3 individual/l, respectively) comprising about 11.4 and 8.8% of the total phytoplankton, respectively.

Phytoplankton populations in the investigated area showed paucity in the number of individuals of each species. The standing crop of phytoplankton was relatively low ranging between less than 10^3 individual/l and 23×10^3 individual/l (average 7×10^3 individual/l). This is comparable to other works in the Red Sea (Skaikh *et al.,* 1986; Ismail, 2005) and considered as a general feature of tropical waters by some authors (Odum, 1971; Dowidar *et al.,* 1978). In general, sites 4 and 5 showed higher abundance than others and this is probably related to the shallowness and sheltering condition of the bay in addition to its high nutrient concentrations resulting from different human activities at these sites. Our results revealed that summer was the most productive season in contrary with the previous studies which stated that late winter-early spring or the period from December-February were characterized by high phytoplankton production throughout (Halim, 1969; Levanon-Spanier *et al.,* 1979; Skaikh *et al.,* 1986). This could be explained by two reasons: the first is that the northern Red Sea (region north of 20°N latitude) is not notably influenced by the Arabian Ocean monsoon which affects the southern Red Sea (Edwards, 1987). The second is due to the neritic condition of the area under investigation.

In the present study, the high production during summer resulted from massive outbreak of the diatom *Hemiaulus hauckii* and the cyanobacterium genus *Trichodesmium*. The high production of *Hemiaulus hauckii* was previously recorded in The Gulf of Aqaba (Post *et al.*, 2002), but is the first time to be reported in the southern of Sinai Peninsula region and this may be related to differ of time scale. The dominance of *Hemiaulus hauckii* and *Trichodesmium* during summer is usual in the oceanic water of tropical and subtropical regions (Gordon *et al.*, 1994). On the other hand, it is obvious from the spatial distribution of phytoplankton that Gulf of Suez differs in the dominant species and timing of abundance from both Gulf of Aqaba and the southern of Sinai Peninsula. In the Gulf of Suez, *Rhizosolenia alata* and *R. calcar-avis* appeared with high densities during winter and this may be related to the difference in habitat and environmental conditions among the Gulf of Suez and both Gulf of Aqaba and the southern of Sinai Peninsula.

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