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Phytoplankton distribution in the southeastern Mediterranean Sea (Egyptian waters) in summer and winter 2005

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Abstract

Species composition and abundance of phytoplankton were studied along the Egyptian waters of the southeastern Mediterranean Sea during summer and winter, 2005. A total of 88 species belonging to 48 genera were recorded and classified as 50 species of diatoms (91% of total phytoplankton counts), 19 species of dinoflagellates (6.2%), 10 species of chlorophytes (2.3%), eight species of cyanophytes (0.36%) as well as one species of silicoflagellates. Winter was found to be high productive with a more than 16 fold increase in phytoplankton counts compared to summer (average of 83759 and 5029 unit/l, respectively). This may be the result of high wind speed, high upwelling, and vertical mixing that characterize the Mediterranean waters during winter, as well as the migration of several Indo-Pacific species through Suez Canal that found favourable habitats in the Levantine waters. The diversity of species in the whole water column averaged 3.13 and 1.97 nats during summer and winter, respectively. The results indicated that pH values varied within narrow limits (8.05 to 8.38). High values of dissolved oxygen were recorded in winter (7.2 to 8.18 mg/l) and coincided with the highest abundance of phytoplankton. High ammonium values were measured during summer, specifically at the Abu-Qir area (20.3 µM NH_4-N), where a pronounced decrease in phytoplankton abundance was observed (4343 unit/l). The high load of ammonium could be related to impacts of the Abu-Qir fertilizer company in this area. The levels of dissolved phosphate (0.03-0.41µM PO_4-P) and nitrite (0.04-0.32 µM NO_2-N) were low both in summer and in winter, while nitrate and silicate were only measured in summer (average values of 1.6 µM NO_3-N and 1.65 µM SiO_4-Si, respectively). Statistically, the total counts of phytoplankton during summer and winter were directly correlated with both dissolved oxygen ($r = 0.71$ at $p < 0.05$) and nitrite ($r = 0.67$), but were inversely correlated with water temperature ($r = -0.77$) and salinity ($r=-0.72$). This reflects the high phytoplankton abundance observed during winter and at the locations that were under the direct impact of land-based nutrient sources.

Keywords: phytoplankton, diversity, nutrient salts, southeastern Mediterranean

1. Introduction

The Mediterranean Sea has a surface area of 2.5 million km^2, a coastal length of 46,000 km, average depth 1500m, average temperature from W to E of from 15 to 30ºC, and average salinity from W to E of from 36.2 to 39‰ (Zenetos *et al*., 2003). The Mediterranean climate features a warm, dry summer period over the entire basin, with substantial rainfall in the north and aridity in the south (EEA, 1999). The Mediterranean Sea is characterized by an oligotrophic state, rich in oxygen and poor in nutrients, with oligotrophy increasing from west to east. However, the Mediterranean Sea has unusual biodiversity compared to other temperate seas (FAO, 2003). The highest productivity levels occur along the coasts, near major cities, and river estuaries, whereas the lowest levels occur in the southeastern Mediterranean (Krom *et al*., 2003). The Mediterranean coastal zone is subjected to human activities including habitation, industry, agriculture, fisheries, military facilities and tourist resorts. It is obvious that there is some conflict over the use of natural resources. Most of these activities may contribute to coastal eutrophication in some regions of the Eastern Mediterranean. Urbanization and tourism activities lead to sewage pollution along the coastal zone (UNEP, 1999). Industries are located at intervals all round the Mediterranean basin. There are a number of pollution hotspots generated by heavy industry complexes and large commercial harbors. Many phytoplankton species are thought to have entered the Mediterranean from the Red Sea through the Suez Canal (UNEP, 1990). Early observations of the eastern Mediterranean phytoplankton composition are those of Dowidar, 1974; Dowidar, 1984; Halim, 1974; Halim, 1990; Samaan and Gergis, 1983; El-Sherif and Gharib, 1994 and El-Sherif and Zaghloul, 1994. The latter identified 112 taxa of phytoplankton, among which 76 species were of diatoms, 21 species of dinoflagellates, as well as some rare species of chlorophytes, cyanophytes and silicoflagellates.

The aims of the present work are to study the abundance, species composition, and diversity of phytoplankton during two different climatic periods, summer and winter, 2005, in the southeastern Mediterranean waters. This study was also conducted to evaluate the trend of fertility and human impacts as a result of fresh water discharge from Rosetta Branch of the Nile River and other industrial effluents discharged into this area.

2. Material and methods

2.1. Area of study

This work was carried out during the two cruises of Salsabil Research Vessel of the NIOF (National Institute of Oceanography and Fisheries), which extended from Suez to Alexandria, passing through Suez Canal during summer (June) and winter (December) 2005. Two basins were chosen for sampling. Basin A includes Sahl El-Tina (Stations 1 and II), Damietta (III and IV) and Basin B includes Rashid (V and VI) and Abu-Qir (VII) as shown in Figure 1.

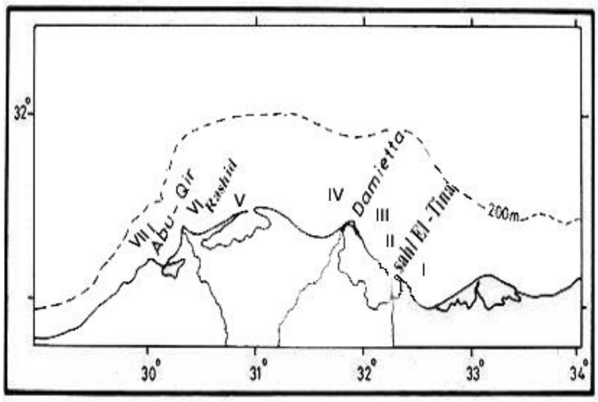

Figure 1: Positions of the sampling stations.

2.2. Phytoplankton collection

Samples collections of phytoplankton were carried out by vertically hauling a plankton net with 20µm mesh size to an average depth of about 25 m (10 to 40 m depth range) at each of the different stations in the two basins. Concentrated samples of about 200 ml were immediately fixed with 4% neutral formalin solution. The total volume of the filtered water sample was calculated according to the formula; $\mathbf{V=\Pi r^2 d}$, where **r** is the radius of the net mouth (25 cm) and **d** is the depth to which the net was lowered (American public Health Association , APHA, 1989). In the laboratory, subsamples of 1 ml were transferred into a Sedjwick

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Rafter counting cell for identification and counting with an inverted research microscope.

2.3. Physico-chemical parameters

Two liters of water samples were collected from surface, middle and near bottom at each station of the investigated areas. Water temperature was measured by using a pocket thermometer graduated to 0.1ºC. The pH value of water samples was measured on deck immediately after sample collection using a model Orion 210 pocket pH meter. The salinity of water was measured in the laboratory by using an inductive salinometer (S.C.T. meter). Dissolved oxygen collection and determination were carried out according to Winkler's method as described in American public Health Association , APHA, 1995. Nutrient salts (nitrate, nitrite, ammonium, reactive phosphate and silicate) were determined according to the methods described by Strickland and Parsons (1972). Ammonium was collected and determined following International Oceanographic Commission, IOC (1983).

2.4. Statistical analysis

The phytoplankton species diversity was calculated with the equation of Shannon & Weaver (1963) and expressed as nats. The correlation matrices were calculated on a computer using the Statistica program, where the significant correlations were tested at 95% confidence levels.

3. Results and Discussion

3.1. Physico-chemical characteristics

3.1.1. Water temperature

Generally the seasonal variations in water temperature followed those of the prevailing climate conditions. Water temperature has a pronounced effect on the rate of phytoplankton photosynthesis as well as on periodicity and abundance of phytoplankton species (Behrendt, 1990). In the present study, temperature varied between a maximum of 27.69 ºC at the surface waters of St.I (of Basin A) during summer and a minimum of 20º C at 12-m depth of St.VII (of Basin B) in winter, giving the average values of 27 and 20.87 ºC in summer and winter, respectively. Ketchum (1983) indicated that the high temperatures prevailing in the eastern Mediterranean, as compared to those in its western basin, give this region a tropical character with regard to planktonic biota. Generally, the seasonal changes of temperature showed an inverse correlation ($r = -0.77$ at $p < 0.05$) with the phytoplankton counts. This agrees with many of the previous findings (Gotsis-

Skretas and Frilligos, 1985 and Kideys *et al*., 1989) from the Mediterranean Sea.

3.1.2. Hydrogen ion concentrations (pH)

Seawater pH plays an important role in many of life processes and is significantly affected by the photosynthetic activity of phytoplankton. The seawater pH was slightly alkaline and varied between 8.05 (29 m depth of St. II) in winter and 8.38 (10 m depth of St. VIII) in summer of the present study.

3.1.3. Salinity

As shown in Tables 1and 2, the highest salinity value (39.13‰) was measured at the surface waters of St.II (of Basin A) in summer, while the lowest value (37.9‰) was measured throughout the water column of St.VII during winter. The lowest value was a result of dilution from the effluents discharged into the Mediterranean in Abu-Qir area (Aboul-Dahab, 1989). The relatively high values of salinity in summer may be attributed to evaporation of water by the elevation of temperature. Maiyza (1988) indicated that evaporation is one of the controlling factors of salinity and consequently density and circulation pattern variations. In the present study, a close relationship was observed between temperature and salinity ($r = 0.97$ at $p < 0.001$). A significant inverse correlation was found between the total counts of phytoplankton and salinity ($r = -0.72$ at $p < 0.05$).

3.1.4. Dissolved Oxygen (DO)

Dissolved oxygen is very important to aquatic organisms, because it affects their biological processes. Dissolved oxygen is the best parameter available to indicate the effects of non-toxic pollution in an aquatic ecosystem (Lester, 1975). The present data indicated that DO fluctuated between 8.18 mg/l in the surface water of Abu-Qir in winter and 5.69 mg/l at 10-m depth of the same station during summer. This agrees with the results of Shreadah *et al*. (2006) who reported that DO ranged from 2.5 to 8.9 mg/l during winter at Abu-Qir area. In this work, the high DO values in winter (7.2-8.18 mg/l) were associated with high numbers of phytoplankton (average of 83759 unit/l), as compared with the low density of phytoplankton in summer (average of 5029 unit/l). These DO values reflect the high oxygen saturation at low temperatures in winter (20.4-21.3ºC) and agitation of waters by strong wind action, which characterizes the Mediterranean waters (Gruzado, 1985). The dissolved oxygen values exhibit a close correlation with phytoplankton abundance ($r = 0.71$ at $p < 0.05$). This result agrees with those obtained by Abdallah *et al*., 1995 and Gharib, 1998.

3.1.5. Nutrient Salts

Krom *et al*. (1992) and Kitsiou and Karydis (2000) reported that the open seawaters of the Mediterranean appear to be oligotrophic or even ultratrophic, except in areas where upwelling brings nutrient-rich waters to the surface. Eutrophication in the eastern Mediterranean is limited to the Adriatic and to some urban and industrial areas of the coastal zone. However, UNEP (1989) and UNEP (1999) stated that the Mediterranean is one of the most oligotrophic seas in the world.

3.1.6. Ammonium (NH_4-N)

As presented in Tables 1 and 2, a wide range of ammonium concentrations was recorded in the Egyptian waters of the southeastern Mediterranean, where the highest value of 20.3 µM was observed at the surface water of Abu-Qir in summer, as compared with 0.78 µM, a value recorded at 30 m depth of St. IV (of Basin A) during winter. This may be due to the high load of nitrogenous compounds discharged from the fertilizer company into this area, which increases its eutrophication level as compared with the mesotrophic levels determined at the areas of Rashid and Damietta (Environmental International Monitoring Programme, EIMP, 2000). This agrees with the data reported by UNESCO (1988) stating that in the waters directly polluted by sewage or substantially polluted by river discharge, the concentrations of ammonium are often higher than 20 µM. The high concentrations of ammonium during summer of the present study were accompanied by a significant decrease in phytoplankton numbers.

3.1.7. Nitrate (NO_3-N)

Nitrate is considered as the most stable inorganic nitrogen form in seawater. The variations of nitrate content usually reflect equilibrium between allocthanous inputs of nitrogen salts through sewage effluents, nitrogen fixation, nitrogen salts regenerated from the bottom, the loss of nitrogen by phytoplankton uptake, and bacterial denitrification (Calvert and Price, 1971). In the present study, dissolved nitrate was measured only in summer, with a relatively high value of 2.98 µM at the surface water of St. II as compared with the lowest value of 0.75 µM observed at 45-m depth of St. VII. Nitrate concentration averaged 1.60 µM. Mostafa (1985) reported that the levels of nitrate fluctuated between 1.69 and 2.43 µM in the Eastern Mediterranean waters. The increase in nitrate concentration was accompanied by an increase in both phytoplankton production and chlorophyll-*a* (Saad and Fahmy, 1984).

3.1.8. Nitrite (NO_2-N)

Nitrite has an intermediate oxidation state between ammonium and nitrate. Nitrite has the highest toxicological significance for human health, if present in perceptible concentration in diets. However, nitrite is usually not a significant nitrogen source for phytoplankton, and it is rarely present in measurable quantities in seawater (Wafar *et al*., 1986). A relatively high nitrite value of 0.32 µM was recorded at the surface water of St. V (of Basin B) during winter, whereas, the concentration of 0.04 µM was observed at 10-m depth of St. II in summer. Statistically, a strong positive correlation was found between the total counts of phytoplankton and nitrite ($r = 0.67$ at $p < 0.05$).

3.1.9. Reactive phosphate (PO_4-P)

Phosphorus is an important element for the growth and primary production of phytoplankton in aquatic systems. Marchetti (1984) stated that generally the phosphate concentrations in Mediterranean Sea surface water are extremely low, usually 0.03 µM or less. A large amount of phosphorus in water leads to eutrophication and becomes a potential source of pollution (UNEP, 1996). Typical concentrations for eutrophic coastal waters are above 0.15 µM, but for highly eutrophic systems concentrations can be greater than 0.3 µM. As presented in Tables 1 and 2, the levels of reactive phosphate varied between 0.41 µM in the surface water of St.II in summer and 0.03 µM at 29 m depth of the same station in winter.

3.1.10. Reactive silicate (SiO_4-Si)

3.2. Phytoplankton distribution

3.2.1. Summer

The general situation for phytoplankton numbers in the two basins suggests relatively low production in summer. The stations of Basin A (I, II, III and IV) were more productive, in which 54 species of phytoplankton were found as compared with 41 species in Basin B (stations V, VI and VII). About 20 phytoplankton species were observed only at the stations of Basin A. These included 11 species of diatoms (*Amphora marina*, *Rhizosolenia alata* f. *indica*, *Rhizosolenia robusta*, *Coscinodiscus radiatus*, *C. oculis-iridis*, *Fragillaria capucina*, *Biddulphia obtusa*, *B. smithii*, *Guinardia flaccida*, *Bacteriastrum delicatulum* and *Navicula* sp.); five dinoflagellate species (*Ceratium macroceros* var. *gallicum*, *Centrodinium intermedium*, *Protoperidinium globulus*, *Podalamps spinifer* and *Pyrocystis fusiformis*); two cyanophyte species (*Oscillatoria tenuis* and *Gomphospheria aponiana*) and two species of green algae (*Pleurotaenium trabecula* and *Oocystis borgei*). Whereas, five species of diatoms (*Gyrosigma balticum*, *Amphiprora paludosa*, *Surirella ovata*, *Rhizosolenia alata* and *Thalassionema nitzschioides*) and two dinoflagellate species (*Dinophysis caudata* and *Phalacroma rapa)* were recorded only at the stations of Basin B as shown in Table 6. The results revealed that a relatively high flourishing of phytoplankton occurred at Sahl El-Tina (average of 6995 unit/l), followed by Abu-Qir (average of 4343 unit/l), Rashid (average of 4307 unit/l), and Damietta (average of 4130 unit/l).

Rhizosolenia calcar avis was the dominant diatom (average of 698 cell/l), forming about 20% of total diatoms and about 14% of total phytoplankton abundance, followed by *Hemiaulus heibergii*, *Bacillaria paradoxa*, *Nitzschia delicatissima* and *Gyrosigma attenuatum* (average of 430, 338, 277 and 259 cell/l, respectively). El-Sherif and Zaghloul (1994) observed that *Pseudo-nitzschia delicatissima* was the major diatom species, forming about 91% of the total phytoplankton counts. Dinophyceae displayed a relative abundance of 23.4% of the phytoplankton numbers. *Ceratium puchellum* (average of 222 cell/l) and *Ceratium kofoidi* (average of 134 cell/l) were the two dominant species, which together formed 30.3% of total Dinophyceae abundance. Lakkis (1980) indicated that *Ceratium* spp., and *Protoperidinium* spp., were previously dominated in eastern Mediterranean waters. Generally, the dinoflagellates of the Mediterranean consist of cosmopolitan eurythermal species, together with tropical and subtropical species as well as a small group of autochthonous Mediterranean forms (Halim, 1990). Blue-Green algae (Cyanobacteria) were frequently observed in the phytoplankton community. *Phormidium* sp., and *Oscillatoria simplicissima* were the common cyanophyte species (average of 85 and 56 trichome/l, respectively). However, *Oscillatoria tenuis*, *O. simplicissima*, *Gomphospheria aponiana*, and *Spirulina laxa* were also observed. Chlorophytes were represented by *Pediastrum clathratum*, *Oocystis solitaria* and *Pleurotaenium trabecula* (averages of 28, 24 and 11 cell/l, respectively). Dowidar (1974) and Gergis (1983) reported *Pediastrum* sp. as a rare form in the Egyptian waters of eastern Mediterranean. *Dictyocha fibula* of silicoflagellate, was rare, and recorded at stations I and V with total average of 24 cell/l.

Generally, a total of 61 species representing 37 genera were recorded in summer and classified as 34 diatom species (71.0% of total phytoplankton counts), 18 species of dinoflagellates (23.4%), five species of cyanophytes (4.0%), three species of chlorophytes (1.2%), as well as one species of silicoflagellates. However, most of the observed green and blue-green species were previously recorded in the Gulf of Suez, Suez Canal and Red Sea (Nassar and Hamed, 2003; El-Sherif and Abo El-Ezz, 2000; Shams El-Din *et al*., 2005 and Nassar and Shams El-Din, 2006). This supports the migration of these species to the eastern Mediterranean as reported by Halim (1990).

Table 1: Levels of some water characteristics in the Egyptian waters of the south- eastern Mediterranean (Egyptian coast) during summer, 2005.

	Station	Depth (m)	Temp (^{0}C)	pH	Salinity (‰)	DO mg/l	NH_4 (µM)	NO_3 (µM)	NO_2 (µM)	PO_4 (µM)	SiO_4 (µM)
					Summer						
Sahl El-Tina	I	S	27.69	8.16	39.05	7.31	2.38	1.77	0.08	0.36	0.56
		10	27.67	8.19	39.08	6.80	3.92	1.63	0.23	0.19	1.36
		20	27.68	8.13	39.06	6.72	2.96	1.46	0.13	0.22	1.24
	II	S	27.28	8.20	39.13	7.14	3.02	2.98	0.08	0.41	1.54
		10	27.27	8.24	39.11	6.80	8.36	0.83	0.04	0.29	1.56
		Average	27.52	8.18	39.10	6.95	4.13	1.73	0.112	0.294	1.25
Damietta	III	S	27.25	8.21	38.94	6.63	3.83	1.63	0.10	0.07	1.32
		10	26.80	8.20	38.99	5.95	4.32	1.44	0.05	0.10	0.96
	IV	S	26.96	8.12	38.09	6.80	4.59	2.55	0.26	0.12	0.90
		10	26.80	8.15	38.87	6.80	3.69	1.29	0.15	0.14	1.20
		20	26.80	8.11	38.93	6.46	2.61	2.25	0.10	0.16	1.24
		28	26.69	8.13	38.91	6.29	2.88	2.25	0.10	0.16	1.58
		Average	26.88	8.15	38.79	6.49	3.65	1.90	0.126	0.125	1.20
Abu-Qir	VII	S	26.45	8.38	38.90	5.69	20.30	1.00	0.08	0.29	4.86
		45	26.10	8.32	39.10	6.74	2.30	0.75	0.05	0.11	1.68
		Average	26.27	8.35	39.0	6.21	11.3	0.875	0.065	0.20	3.27

Note. Rashid stations not sampled in summer and S = Surface

Table 2: Levels of some water characteristics in the Egyptian waters of the south- eastern Mediterranean during winter, 2005.

		Depth (m)	Temp (^{0}C)	pH	Salinity (‰)	DO mg/l	NH_4 (µM)	NO_2 (µM)	PO_4 (µM)
				Winter					
Sahl El-Tina	I	S	20.6	8.10	38.2	7.54	1.18	0.21	0.05
		10	21.6	8.12	38.2	7.20	1.02	0.18	0.04
	II	S	21.3	8.10	38.1	7.96	0.99	0.20	0.04
		29	20.6	8.05	38.1	7.08	0.87	0.16	0.03
		Average	21.0	8.10	38.15	7.44	1.02	0.187	0.04
Damietta	III	S	21.1	8.14	38.0	7.86	1.20	0.24	0.04
		14	21.1	8.10	38.0	7.32	1.12	0.21	0.03
	IV	S	21.0	8.12	38.0	8.16	0.99	0.22	0.04
		30	21.0	8.15	38.0	7.72	0.78	0.19	0.05
		Average	21.05	8.13	38.0	7.76	1.02	0.215	0.04
Rashid	V	S	20.8	8.16	37.9	8.84	1.36	0.32	0.04
	VI	40	21.3	8.15	38.0	7.96	1.22	0.27	0.06
		Average	21.05	8.15	37.95	8.40	1.29	0.295	0.05
Abu-Qir	VII	S	20.3	8.19	37.9	8.18	1.25	0.30	0.09
		12	20.4	8.19	37.9	7.52	1.18	0.26	0.08
		Average	20.35	8.19	37.90	7.85	1.215	0.28	0.085

Note. Nitrate and silicate were not measured in winter.

Table 3: Total of phytoplankton production during summer and winter, 2005.

Season / Group	Summer				Winter			
	Genus	species	Aver. counts	%	Genus	species	Aver. counts	%
Diatoms	19	34	3570	71.0	24	38	77265	92.24
Silicoflagellates	1	1	21	0.42	1	1	21	0.02
Dinoflagellates	10	18	1176	23.4	8	19	4343	5.18
Cyanophytes	4	5	201	4.0	4	5	121	0.14
Chlorophytes	3	3	61	1.2	4	7	2009	2.40
Total	37	61	5029	100	41	70	83759	100

Table 4: Number of phytoplankton species (sp.) and genera (G.) and their percentages in the two investigated basins in summer and winter, 2005.

	Basin A						Basin B					
Season	Summer			Winter			Summer			Winter		
Group	genus	species	%	Genus	species	%	genus	species	%	genus	species	%
Diatoms	16	29	77.54	21	34	86.78	15	23	71.28	17	30	98.0
Silicoflagellates	1	1	0.35	1	1	0.02	1	1	0.36	1	1	0.04
Dinoflagellates	9	16	16.71	8	19	8.39	8	13	24.85	4	12	1.78
Cyanophytes	4	5	4.0	4	5	0.18	3	3	2.85	2	2	0.11
Chlorophytes	3	3	1.4	4	7	4.63	1	1	0.64	1	1	0.04
Total	31	54	100	38	66	100	28	41	100	25	46	100

Table 5: The correlations between total counts of phytoplankton and some water characteristics in the whole water column of the study area.

	Diat.	Dino	Cyano	Chloro	Silico	Total phyto	Temp	pH	Sal.	DO	PO_4	NO_2	NH_4
Diat.	1.00												
Dino	0.50	1.00											
Cyano	**-0.75**	-0.42	1.00										
Chloro	**0.61**	0.60	-0.32	1.00									
Silico	0.09	0.14	0.05	-0.24	1.00								
Total Phyto.	**1.00**	0.57	**-0.74**	**0.66**	0.08	1.00							
Temp	**-0.76**	-0.59	**0.64**	-0.39	0.05	**-0.77**	1.00						
pH	-0.42	-0.39	0.08	-0.41	-0.13	-0.44	0.51	1.00					
Sal.	**-0.72**	-0.50	**0.63**	-0.26	0.00	**-0.72**	**0.97**	0.57	1.00				
DO	**0.73**	0.42	-0.48	0.11	0.34	**0.71**	**-0.84**	-0.54	**-0.86**	1.00			
PO_4	-0.59	-0.52	0.68	-0.34	0.11	-0.60	**0.79**	0.54	**0.82**	-0.52	1.00		
NO_2	**0.70**	0.29	**-0.64**	0.10	0.23	**0.67**	**-0.83**	-0.55	**-0.91**	**0.88**	**-0.67**	1.00	
NH_4	-0.56	-0.43	0.33	-0.30	-0.23	-0.56	**0.67**	**0.90**	**0.74**	**-0.75**	**0.63**	**-0.76**	1.00

Note. Marked correlations are significant at $p < 0.05$.

Table 6: Average counts of the recorded species of phytoplankton (unit/l) and their abundance in the two investigated basins during summer and winter, 2005.

Season / Group	Summer			Winter		
	Average counts	Basin A	Basin B	Average counts	Basin A	Basin B
Bacillariophyceae (cell/l)						
Amphiprora paludosa W. Smith	26	--	+	7.0	+	--
Amphora marina Smith	20	+	--	7.0	+	--
Asterionella japonica Cleve	--	--	--	579	+	+++
Bacillaria paradoxa Gmelin	338	++	+	140	+	+
Bacteriastrum delicatulum Cleve	18	+	--	50	+	+
Bacteriastrum sp.	--	--	--	7.0	+	--
Biddulphia longicruris Grevill.	24	+	+	--	--	--
Biddulphia obtusa Kütz	7	+	--	--	--	--
Biddulphia smithii (Ralfs) Peragallo	17	+	--	--	--	--
Biddulphia sp.	--	--	--	21	+	--
Campylodicus noricus var. hibernica	--	--	--	7.0	--	+
Cerataulina bergonii H. Peragallo	--	--	--	21	--	+
Chaetoceros coarctatus Lauder	97	+	+	--	--	--
Chaetoceros curvisetus Cleve	--	--	--	22786	+++	+++
Chaetoceros decipiens Cleve	165	+	+	7771	+++	+++
Chaetoceros lauderi Ralfs	--	--	--	90	--	+
Chaetoceros peruvianus Brightwell	--	--	--	418	+	++
Chaetoceros radicans Shütt	64	+	+	--	--	--
Chaetoceros tetrastichon Cleve	--	--	--	252	+	++
Chaetoceros sp.	--	--	--	643	++	+
Coscinodiscus centralis Ehr	--	--	--	69	+	+
Coscinodiscus granii Gough	186	++	+	--	--	--
Coscinodiscus oculus-iridis Ehr	41	+	--	105	+	+
Coscinodiscus radiatus Ehr.	28	+	--	91	+	+
Fragillaria capucina Desm.	18	+	--	7.0	+	--
Guinardia flaccida H. Peragallo	33	+	--	357	+	++
Gyrosigma attenuatum Ehr.	259	++	+	965	++	+
Gyrosigma balticum Ehr.	26	--	+	--	--	--
Hemiaulus heibergii Cleve	430	+	++	1333	+++	++
Leptocylindrus danicus Cleve	--	--	--	5190	+++	+++
Lithodesmium undulatum Ehr.	--	--	--	8100	+++	++
Lithylium sol	--	--	--	18	+	--
Navicula gracilis Cleve	59	+	+	66	+	+
Navicula sp	24	+	--	--	--	--
Pseudo-nitzschia delicatissima Cleve	277	++	+	--	--	--
Nitzschia Kutzingiana Hilse	--	--	--	7	-	+
Nitzschia pungens var. atlantica Cleve	--	--	--	7	+	--
Nitzschia sigma (Kütz) W. Smith	107	+	+	--	--	--
Pleurosigma angulatum Quekett	57	+	+	--	--	--
Rhizosolenia alata f. *indica* H. Peragallo	45	+	--	43	+	+
Rhizosolenia alata Brightwell	21	--	+	--	--	--
Rhizosolenia alata f. *gracillima* Cleve	133	+	+	1394	+++	+
Rhizosolenia calcar avis M. Schultze	698	+++	+	4300	+++	+++
Rhizosolenia imbricata var. *shrubsolei* Cleve	36	+	+	62	+	+

Table 6: Continued.

Season / Group	Summer			Winter		
	Average counts	Basin A	Basin B	Average counts	Basin A	Basin B
Surirella ovata Kütz	24	--	+	--	--	--
Synedra ulna Nitzsch.	47	+	+	425	++	+
Thalassionema nitzscioides Grun.	35	--	+	--	--	--
Thalassiothrix frauenfeldii Grun.	--	--	--	16357	+++	+++
Thalassiothrix longissima Cleve	87	+	+	258	+	++
Dinophyceae (cell/l)						
Centrodinium intermidium Pavillard	9	+	--	--	--	--
Ceratium massiliense (Gourret) Jörjensen	117	+	+	61	+	+
Ceratium candelabrum Ehr.	91	+	+	43	+	+
Ceratium egyptiacum Halim	--	--	--	37	+	--
Ceratium extensum (Gour.) Cleve	79	+	+	--	--	--
Ceratium furca (Ehr.) Claparede	--	--	--	276	++	+
Ceratium fusus Ehr.	50	+	+	709	+++	+
Ceratium macroceros var. gallicum Kofoid	32	+	--	--	--	--
Ceratium kofoidi Jörjensen	134	+	+	2417	+++	++
Ceratium minutum Jorgensen	--	--	--	7	+	--
Ceratium puchellum Schröder	222	+	++	63	+	+
Ceratium trichoceros (Ehr.) Kofoid	94	+	+	111	+	+
Ceratium sp.	--	--	--	29	+	--
Ceratocorys gourreti Paulsen	94	+	+	7	+	--
Dinophysis caudata Savielle-Kent	28	--	+	252	++	+
Diplopsalis rotunda (Lebour) Wood	56	+	+	14	+	--
Goniaulax minuta Kofoid & Mich.	--	--	--	21	+	--
Protoperidinium globulus Stein	19	+	--	--	--	--
Protoperidinium cerasus Paulsen	--	--	--	113	+	+
Protoperidinium depressum Bailey	89	+	+	97	+	+
Protoperidinium sp.	--	--	--	50	+	+
Phalacroma rapa Stein	37	-	+	29	+	+
Podalamps spinifer Okamura	9	+	--	7	+	--
Pyrocystis fursiformis W. Thomson	19	+	--	--	--	--
Pyrophacus horologicum Stein	43	+	+	--	--	--
Chlorophyceae (cell/l)						
Chlorella vulgaris Beij	--	--	--	14	+	--
Oocystis solitaria Wittr.	24	+	--	--	--	--
Pandorina sp.	--	--	--	14	+	--
Pediastrum biwae Negoro	--	--	--	300	++	--
Pediastrum boryanum (Turpin) Mene.	--	--	--	121	+	--
Pediastrum clathratum Lemm.	28	+	+	--	--	--
Pediastrum duplex Meyen	--	--	--	248	++	--
Pediastrum simplex Meyen	--	--	--	1269	+++	--
Pleurotaenium sp.	9	+	-	--	--	--
Staurastrum gracile Ralfs	--	--	--	43	+	+
Cyanobacteria (unit or trichome/l)						
Chroococcus turgidus Kütz	--	--	--	7	+	--
Gomphospheria aponiana Kütz	10	+	--	--	--	--
Merismopedia punctata Smith	--	--	--	36	+	--
Oscillatoria simplicissima Gom.	56	+	+	21	+	+
Oscillatoria tenuis Agardh	17	+	-	7	+	--
Phormidium sp.	85	+	+	50	+	+
Spirulina laxa Smith	33	+	+	--	--	--
Silicoflagellates (cell/l)						
Dictyocha fibula Ehr.	21	+	+	21	+	+

Note. + = present, ++ = frequent, +++ = dominant and -- means absent.

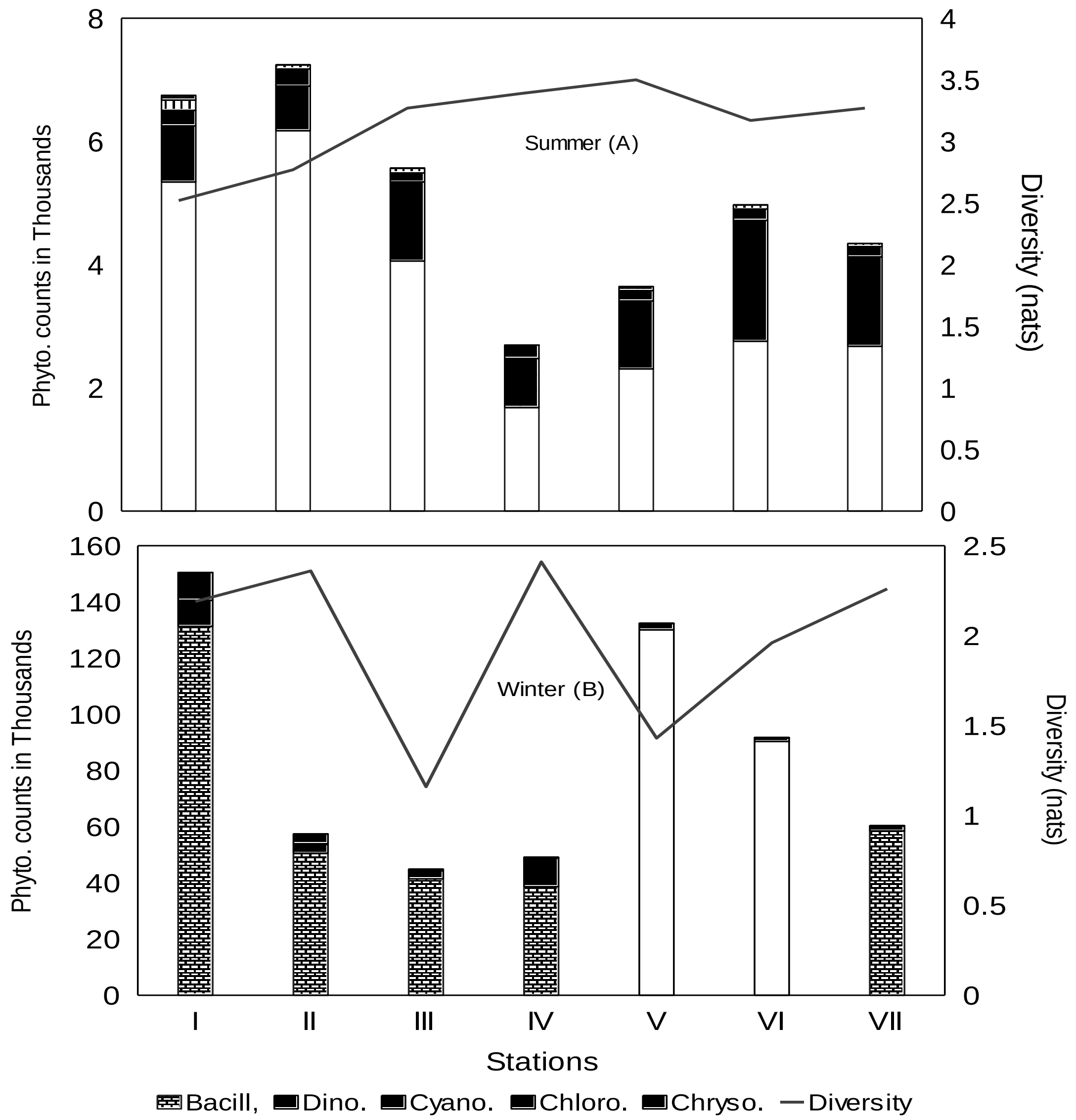

Figure 2: Abundance of the different phytoplankton classes (unit/l) and diversity of species (nats) in summer (A) and winter (B).

3.2.2. Winter

Winter was found to be high productive and with a more than 16 fold increase in phytoplankton numbers compared to summer (average of 83759 and 5029 unit/l, respectively) as shown in Table 3 and Figure 2. The results indicated that about 24 phytoplankton species were observed only at the stations of Basin A, which consisted of 8 species of diatoms (*Nitzschia pungens* var. *atlantica*, *Amphora marina*, *Amphiprora paludosa*, *Fragillaria capucina*, *Lithylium sol*, *Bacteriastrum delicatulum*, *Skeletonema costatum* and *Biddulphia* sp.), 6 species of green algae (*Pediastrum duplex*, *P. boryanum*, *P. biwae*, *P. simplex*, *Chlorella vulgaris* and *Pandorina* sp.), as well as three species of blue-green algae (*Chroococcus turgidus*, *Merismopedia punctata* and *Oscillatoria tenuis*). On the other hand, four species of diatoms (*Nitzschia Kützingiana*, *Campylodisus noricus*, *Orataulina bergonii* and *Chaetoceros lauderi*) were observed only at the stations of Basin B. A total of 66 phytoplankton species belonging to 38 genera were identified at the stations of Basin A as compared with 46 species and 25 genera at Basin B (Table 4).

The diatoms were the predominant group, and contributed about 92.24% of total phytoplankton abundance. The leading species were *Chaetoceros curvisetus* (average of 22786 cell/l), *Thalassiothrix frauenfeldii* (average of 16357 cell/l), *Lithodesmium undulatum* (average of 8100 cell/l) and *Chaetoceros decipiens* (average of 7771 cell/l). *Leptocylindrus danicus*, *Rhizosolenia stolterfothii* and *Rhizosolenia calcar avis* were frequently recorded. Lakkis, 1980 indicated that the genus *Chaetoceros* with 28 species was the most dominant diatom, followed by the genus *Rhizosolenia* (13 species) in eastern Mediterranean waters. Dinophyceae (5.25%) were recorded with moderate counts at all stations except stations IV and I, with high counts (10156 and 9250 cell/l, respectively) due to the large numbers of *Ceratium kofoidi* and *Ceratium fusus.* Green algae were represented by seven species and four genera. *Pediastrum simplex* was the leading species (average of 1269 cell/l), followed by *Pediastrum biwae, P. duplex* and *P. boryanum* with relative high counts at St. I. Blue-green algae were rarely observed, with five species belonging to four genera found in the phytoplankton. The silicoflagellates were represented only by *Dictyocha fibula*.

As presented in Figure 2, Rashid stations were the most productive, followed by Sahl El-Tina (average of 58190 and 55457 unit/l, respectively). Abu-Qir and Damietta stations had moderate counts (average of 32337 and 25563 unit/l, respectively). El-Sherif and Zaghloul (1994) indicated that Abu-Qir and Port-Said sectors sustained the highest phytoplankton crop, but the lowest counts were recorded at Damietta. They recorded 112 taxa of phytoplankton, among which 76 species were of diatoms contributing about 92% of total phytoplankton abundance, seven species of dinoflagellates contributed about 7%, and with other algal groups very rare representing together about 1.0% of the total phytoplankton counts.

Some leading of the diatoms species; *Chaetoceros curvisetus, Thalassiothrix frauenfeldii, Lithodesmium undulatum* and *Leptocylindrus danicus,* as well as *Pediastrum simplex* of green algae were widely distributed in winter, whereas they were completely absent during summer (Table 6). This indicates that most of these species favour the cold temperature of winter for high growth and flourishment. However, the phytoplankton standing crop in the present study was very high in winter (average of 83759 unit/l) as compared with the previous records of Savich (1970) (average of 8000 unit/l), El-Sherif (1994) (average of 9078 unit/l) and El-Sherif and Zaghloul (1994) (average of 2712 unit/l) in the southeast Levantine Mediterranean waters.

3.2.3. Species diversity

Shannon-Weaver diversity indices were generally high in summer compared with winter values. The highest value was 3.5 nats at St. V, calculated for data obtained near Rashid, Basin B when the highest number of species was determined. In the absence of distinct dominance by one or more algal species, the dominancy was shared by several algal species. The lowest value was 2.52 nats recorded at St.I near Sahl El-Tina, Basin A. This was apparently due to the low number of species and high counts of *Rhizosolenia calcar avis*, which formed 56.16% of total diatoms and 44.45% of total phytoplankton abundance. This was associated with the highest crop of phytoplankton at Sahl El-Tina, Stations I and II (6748 and 7241 unit/l, respectively). In winter, the lowest diversity value of 1.16 nats was observed at St.III, due to the high blooming of *Thalassiothrix frauenfeldii*, which comprised about 84.46% of total diatoms and 78.0% of total phytoplankton abundance. Other species were generally evenly distributed throughout the water column. On the other hand, the high diversity value 2.41 nats was obtained at St.IV due to the dominance of several species of diatoms *Thalassiothrix frauenfeldii* (12000 cell/l), *Rhizosolenia calcar avis* (8000 cell/l), *Gyrosigma attenuatum* (5000 cell/l), and *Leptocylindrus danicus* (5000 cell/l), as well as the dinoflagellate *Ceratium kofoidi* (8000 cell/l).

Generally, the diversity of species in the whole water column resulted in averages of 3.13 and 1.97 nats during summer and winter, respectively. Lakkis (1980) reported that species diversity was much higher in eastern Mediterranean than the Red Sea. However, a reduction in the number of dominant species and species diversity, and an increase in cell numbers of one or two resistant algae were some of the changes observed in the phytoplankton populations of domestic and industrially polluted environments in the eastern Mediterranean (Umamaheswara Rao and Mohanchand, 1988).

4. Conclusions

Based on the present data concerning species composition and total phytoplankton abundance in the two seasons, the oligotrophic status is the most of striking feature of the study areas. The most frequently observed diatoms as well as dinoflagellates are species with low nutrient requirements and low temperature optima (Reynolds, 1984). A total of 88 species were identified from the different basins investigated over the two sampling periods, with 61 species were observed in summer and 70 species observed in winter. Diatoms contributed 71.0% and 92.2% of the total species number in summer and winter, respectively, while dinoflagellates contributed 23.4% and 5.18%, respectively. However, the majority of the diatoms recorded in the present investigation is cosmopolitan, littoral, and belong to the neritic warm water habitats as previously mentioned by Dowidar (1974). The sectors of Sahl El-Tina and Damietta were generally highly productive with 54 species in summer and 66 species in winter, as compared with the Rashid and Abu-Qir regions with 41 and 46 species in the two seasons, respectively. The results revealed that the eastern Mediterranean waters remain richer than the Red Sea in the phytoplankton density. This is most likely due to the large and open water body, high wind action, high upwelling and agitation of waters, which may increase the natural eutrophication in the eastern Mediterranean water column (UNEP, 1990; Gruzado, 1985 and UNEP/FAO/WHO, 1996) as well as the migration of several Indo-Pacific species through Suez Canal that found favourable habitats in the Levantine waters (Halim, 1990).

Statistically, the total counts of phytoplankton were directly correlated with dissolved oxygen ($r = 0.71$ at $p< 0.05$) and nitrite ($r = 0.67$), but inversely correlated with water temperature ($r = -0.77$) and salinity ($r=-0.72$). This reflects the high phytoplankton abundance during winter particularly at the locations Rashid and Sahl El-Tina that are situated under the direct impact of land-based nutrient sources.

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توزيع الهائمات النباتية الدقيقة في الجنوب الشرقي للبحر المتوسط (المياه المصرية) خلال موسمي الصيف و الشتاء 2005

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تم تقدير التكوين النوعي وسيادة الهائمات النباتية الدقيقة بمنطقه جنوب شرق البحر المتوسط في المياه المصرية خلال موسمي الصيف والشتاء 2005. أظهرت الدراسة وجود 88 نوعا من الهائمات النباتية، تم تصنيفها إلى 50 نوع من الدياتومات (مثلت حوالي 91% من إجمالي العدد الكلى)؛ 19 نوع من الطحالب السوطية (6.2%) وعشره أنواع من الطحالب الخضراء (2.3%) وكذلك ثمانية أنواع من الطحلب الخضراء المزرقة أو السيانوبكتريا (0.36%) بالاضافة إلى نوع واحد من الطحالب الصفراء الذهبية. لوحظ أن موسم الشتاء كان الأكثر خصوبة وازدهارا بالهائمات النباتية بمتوسط عددي 83759 وحدة لكل لتر مقارنه بمتوسط 5029 وحدة لكل لتر في الصيف أي أكثر من 16 ضعف العدد الكلى المسجل في موسم الصيف؛ وقد يرجع هذا إلى زيادة حركة وتقليب المياه في موسم الشتاء مما يزيد من خصوبتها بالاضافة إلى هجرة بعض الأنواع الطحلبية من المحيط الهادي خلال قناة السويس إلى البحر المتوسط حيث تتواجد البيئة والظروف الملائمة لازدهارها.

من جهة أخرى كان التباين النوعي للهوائم النباتية عاليا في موسم الصيف بمتوسط 3.13 ناتس مقارنة بمتوسط 1.97 ناتس في الشتاء بالرغم من الكثافة العالية للهوائم النباتية خلال موسم الشتاء؛ ووجد أن منطقة رشيد تليها سهل الطينة كانتا أكثر ازدهارا بالهائمات النباتية مقارنة بمناطق أبو قير ودمياط.

بالنسبة للعوامل البيئية فتراوحت قيم أيون الهيدروجين من 8.05 إلى 8.38؛ الأكسيجين الذائب كان عالياً نسبيا في موسم الشتاء (7.2-8.18 مليجرام لكل لتر) حيث التواجد الطحلبي الكثيف. لوحظ أن تركيزات الأمونيا الذائبة كانت عالية في موسم الصيف خاصة عند منطقه أبو قير حيث سجلت 20.3 ميكرومول لكل لتر نتيجة لصرف مخلفات شركه الأسمدة بجوار هذه المنطقة. كما وجد أن الفوسفات الذائب تراوح ما بين 0.3 و 0.41 ميكرومول لكل لتر و النيتريت من 0.04 إلى 0.32 ميكرومول لكل لتر؛ ولكن النترات والسيليكات فتم قياسها فقط في موسم الصيف حيث سجلت الأولى متوسط 1.6 ميكرومول لكل لتر والثانية متوسط 1.65 ميكرومول لكل لتر.

إحصائيا، وجد أن الأعداد الكلية للهائمات النباتية سجلت علاقة ارتباط إيجابية مع كل من قيم الأوكسيجين الذائب ($r = 0.67$ at $p < 0.05$) والنيتريت ($r = 0.71$ at $p < 0.05$) ولكن أظهرت علاقة ارتباط سلبية مع كل من درجه حرارة المياه ($r = - 0.77$) والملوحة ($r = - 0.72$).