EGYPTIAN JOURNAL OF AQUATIC RESEARCH **ISSN: 1687-4285**
VOL. 34 NO. 1, 2008: 86-107

ECOLOGICAL INDICES AS A TOOL FOR ASSESSMENT EUTROPHICATION PROBLEMS IN ALEXANDRIA'S COASTAL WATER, EGYPT

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Keywords: Coastal water, Phytoplankton, Nutrient salts, Diversity index, Chlorophyll a.

ABSTRACT

Phytoplankton community and environmental conditions of Alexandria coastal waters from Kayet-Bay to Abu-Qir Bay were studied monthly from July 2002 to June 2003 after the construction of the new coastal road and termination of the Project of Alexandria wastewater (phase II). Salinity fluctuated between 33.82 PSU and 39.3 PSU, temperature between 16.9°C and 33.6°C, oxidizable organic matter (OOM) between 0.43mgO$_2$/L and 6.47mgO$_2$/l, dissolved oxygen (DO) between 0.71 and 7.03 mlO$_2$/L. The lowest and highest nutrient concentrations were 0.07 and 25.4 µg at/L for nitrate (NO_3^{-1}); 0.07 and 1.92 µg at/L for nitrite (NO_2^{-1}); 0.13 and 25.33 µg at/L for ammonia (NH_4^{+1}); phosphate (PO_4^{-3}) between complete depletion and 2.98 µg at/L and silicate (SiO_4^{-2}) between 0.66 and 33.77 µg at/L. All these factors create irregular pattern of phytoplankton growth (500-12.4x10^{6}unit/L) and serve as a good indicator of eutrophication level throughout the period of study. Phytoplankton species including wide spectrum from fresh-brackish (27 spp.) to marine water forms (65 spp.). Bacillariophyceae ranked the main group (98.60 % to the total community). It was mainly represented by *Skeletonema costatum* (74.73% to the total community), while the genera *Chaetoceros, Nitzschia* and *Rhizosolenia* (5.91%, 5.68% and 4.32% respectively), were considered frequent forms. Dinophyceae, Cyanobacteria, Chlorophyceae and Cryptophyceae were rare or scarce. Abu-Qir, Montazah and Sidi-Bishr harboured the highest phytoplankton density, while lowest density occurred at Sporting and Kayet-Bay stations. The highest counts were recorded in March and lowest in November. Species diversity ranged between 0.08-3.02 (nats), and Chlorophyll-*a* content fluctuated between 0.005-3.68µg/L. Trophic State Index (TSI) showed that, Miami and Gleem are considered as mesotrophic area; Abu-Qir, Montazaha, Mandara, Ber Massoud, Sidi Bishr, Sporting, Eastern Harbour and Kayet-Bay are considered as eutrophic area. While El-Shatby was hypertrophic area. Monthly variations showed that, the area was mesotrophic, except in winter when it was hypertrophic. Correlation and stepwise regression between phytoplankton and some physico-chemical parameters confirmed the dependence of phytoplankton growth on salinity, temperature and oxidizable organic matter.

1. INTRODUCTION

Alexandria's coastal ecosystem has undergone severe degradation over the past few decades from discharge of untreated or partially treated sanitary and industrial wastes (Hussein, 2000 & Shreadah *et al.,* 2006). At present, wastewater from the eastern and western zone of the city undergoes primary treatment at one of the wastewater treatment plants (Eastern and Western treatment Plant). The collector system from the central zone of the city is not connected to either of the two treatment plants. Row wastewater from the central zone is routed to the Kayet-Bay and El-Silsila Pump station, located near Anfoushi and Sporting with an average $93x10^6 m^3$/day and $58x10^6$ m^3/day, respectively, (Alexandria Wastewater Project phase II, 1997).

Generally phytoplankton species have a relatively short life-cycle and therefore, they are able to respond quickly to environmental changes, thus the phytoplankton counts and species composition can be used as indicators of water quality.

Chemical characteristics of Alexandria coastal water were previously studied by several authors, (e.g. EL-Sharkawi, 1978; Nessim, 1989 and 1991; Nessim *et al.,* 2005 and Shreadah *et al.*, 2006). The Phytoplankton was studied by many investigators among them (Dowidar, 1965; Aleem and Dowidar, 1967; Dowidar, 1974; Dorgham *et al.,* 1987; Halim *et al.,* 1980; Samaan and Gergis, 1983; Dowidar, 1984; El-Sherif, 1993 and 1994; Zaghloul, 1994; Zaghloul and Siam, 1996 and Hussein, 2000). However, the rapid changes in water quality and biotic components require frequent follow-up at short time intervals. Thus, the present work deals with the study of physico-chemical condition, phytoplankton community composition, diversity index and chlorophyll-*a* content along Alexandria coastal water from Abu-Qir to Kayet-Bay (Fig. 1). In order to record the changes that have occurred there, to evaluate the changes in eutrophication related problems.

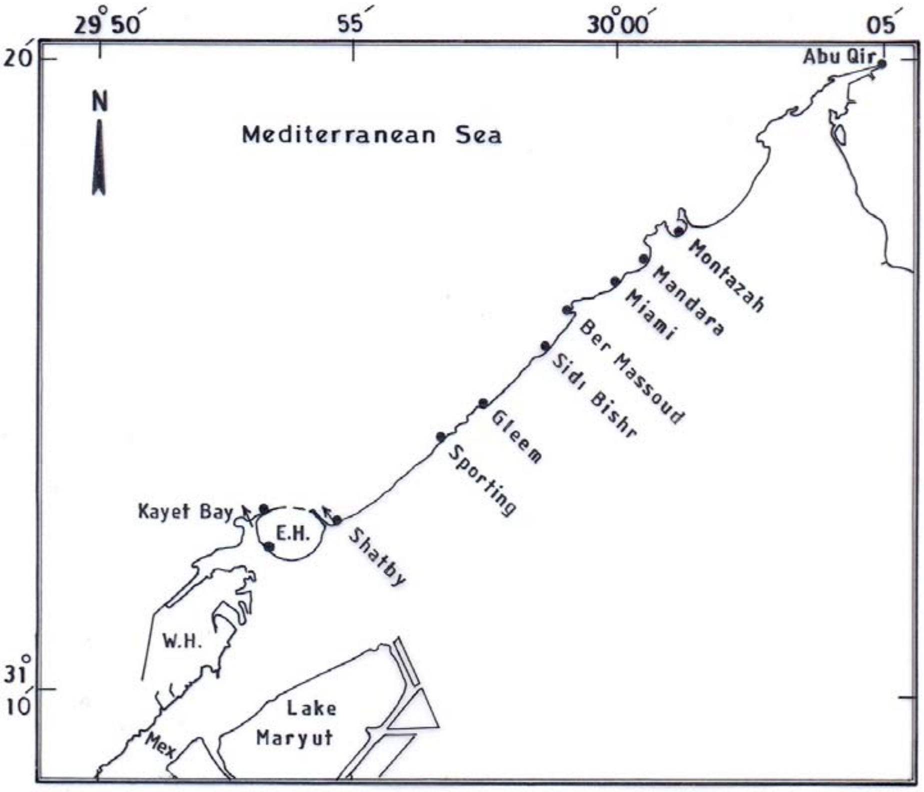

Fig. (1): Alexandria beaches (Sampling stations).

2. MATERIAL AND METHODS

The study area extends for about 25 km between Kayet Bay and Abu-Qir East of Alexandria and included eleven sampling stations, at depths not exceeding 4 meters (Abu- Qir- Montazah - Mandara - Miami - Ber Massoud - Sidi Bishr- Gleem- Sporting- El-Shatby- Eastern Harbour (E.H) and Kayet-Bay) (Fig. 1).

Water samples were collected monthly from July 2002 to June 2003, at eleven coasts (Fig.1). Surface samples were taken at 20 cm below water surface using Ruttener sampler with a capacity of three litres for both phytoplankton community and physico-chemical parameters.

Water transparency was measured with Secchi disc of 25 cm diameter. Water temperature was measured by an ordinary thermometer graduated to 0.1°C. The pH values were measured in situ using portable pH meter. Dissolved oxygen (DO) and salinity (PSU) were determined according to (Strickland and Parsons, 1972). The biological oxygen demand (BOD) was carried out according to the standard method for examination of water and wastewater (American Public Health Association A.P.H.A.,1985). Oxidizable Organic matter (OOM) was determined by the method of Carlberg (1972).

Nutrient salts (nitrate NO_3^{-1}, nitrite NO_2^{-1}, ammonia NH_4^{+1}, phosphate PO_4^{-3} and silicate SiO_4^{-2} were determined colorimetrically (Grasshoff, 1976) and the results were expressed in µg at/L. For estimating the trophic status of Alexandria coastal water, trophic state Index (TSI) was calculated according to Carlson (1977). This index was based on the interrelation ships of Secchi depth reading (TSI_{SD}), Chlorophyll-*a* concentration in µg/L ($TSI_{Chl\text{-}a}$) and total phosphorus in µg/L (TSI_{TP}), and calculated as follows:

$$TSI_{SD} = 10\,[6-(\mathrm{Ln}\ SD/\mathrm{Ln}\ 2)] \quad SD\ (m)$$

$$TSI_{Chl\text{-}a} = 10[6-(2.04-0.68\ \mathrm{Ln}\ Chl\text{-}a/\mathrm{Ln}2)] \quad Chl\text{-}a\ (\mu g/L)$$

$$TSI_{TP} = 10\,[6-(\mathrm{Ln}\ (48/TP)\ /\mathrm{Ln}2)] \quad TP\ (\mu g/L)$$

$$TSI = TSI_{SD} + TSI_{Chl\text{-}a} + TSI_{TP}$$

Estimation of the magnitude of phytoplankton counts was carried out by using the sedimentation method (A.P.H.A., 1985), the different species were identified, counted and estimated as unit/L. Chlorophyll-*a* content was measured by the method of Strickland and Parsons (1972). Species diversity was calculated according to Shannon and Weaver equation (1963).

Correlation coefficients between phytoplankton and the prevailing physico-chemical conditions were computed at a confidence limit of 95% (n= 132) to estimate the most effective environmental parameters.

3. RESULTS AND DISCUSSION

3.1. Physico-chemical parameters

3.1.1. Physical conditions

3.1.1. 1. Water transparency

Water transparency usually sustained lower values due to the shallowness of the stations sampled, high phytoplankton content as well as presence of suspended inorganic matter. Coastal waters are ecologically very important (Morel and Priear, 1977) that contain constituents other than phytoplankton, such as suspended sediments and dissolved organic matter (Shanmugam and Ahn, 2007). The quantity and quality of light in water column is affected by the depth of the water column, the presence of dissolved coloured substances, and scattering due to suspended particles including the phytoplankton (Edmondson, 1980).

Transparency ranged from 0.5 meter (Montazah, Ber Massoud & El-Shatby in March) and 3.5 meter (Miami in September) with an average of 1.4 meter (Table 1). Monthly variations showed that, the changes in Secchi depth readings could be correlated with the phytoplankton abundance. Low readings recorded during March with an average 0.8m, may be due mostly to the effect of high phytoplankton density ($4.4x10^6$ unit/L), as well as the relatively high concentrations of nutrient salts (11.03 and 9.79 µg at/L for total nitrogen and silicate, respectively), low salinity (34.17 PSU) and pH value (7.7 -8.1) . However, high average reading was recorded during October (2.23 meter) were accompanied with relatively low phytoplankton density ($0.35x10^6$ unit/L). Statistically a significant negative relationship was found between Secchi depth, phytoplankton density and chlorophyll-*a* (r = -0.26 and -0.27, $p < 0.05$ respectively, n= 132). The change in Secchi-disc readings has been used to assess the rate of eutrophication and may act as limiting factor for the development of phytoplankton (Stout, 1978). The correlation between water transparency and physico-chemical parameters, showed a significant positive correlation with temperature and pH value (r = 0.5, 0.4, $p \leq 0.05$ n= 132 respectively).

3.1.1.2. Surface water temperature

Water temperature is the most variable factor affecting the planktonic community; it showed spatial variations from one site to another. It ranged from 16.9°C (Abu- Qir, February) to 33.6°C (Eastern Harbour, September), with an annual average 25.41°C. A clear trend of increase in surface water temperature in both, the average and range from Abu-Qir to Eastern Harbour (Table1). Variations in temperature affects the activity of bacteria, decomposition of organic matter or nutrient recycling and liberation as well as solubility of dissolved gases including Oxygen in sea water (Sieburth,1968), also it has a pronounced effect on the rate of phytoplankton photosynthesis as well as periodicity and abundance of phytoplankton species (Behrendt, 1990). The data indicated that water temperature was significantly positive correlated with transparency, salinity, pH value and nitrate concentration (r = 0.495, 0.228, 0.239 and 0.264, $p \leq 0.05$ n=132, respectively) and negatively correlated with total phytoplankton density, Chlorophyll-*a*, diversity and dissolved oxygen (r = -0.321, - 0.216, -0.289 and – 0.504 $p \leq 0.05$ n= 132, respectively).

3.1.1.3. Salinity

Salinity is considered a sensitive parameter for measuring the rate of dilution; it reflects the degree of contamination in aquatic environment. Variation in salinity appeared to be the key to all changes in water quality and plankton abundance (Dorgham *et al.,* 2004). In the studied area salinity ranged from 33.82 PSU (El-Shatby, September) to 39.3 PSU (Miami, April) with an average of 36.48 PSU (Table 1). This value is higher than that previously recorded at the same area 34.85 PSU during 1988 – 1989 (Nessim, 1989 and El-Sherif, 1994) and similar to the result of Zaghloul & Siam (1996). This confirms a detectable improvement in Alexandria coastal water quality. A slightly more saline water was detected along the eastern region from Montazah to Sporting (Table 1, Fig. 2) than the western area (El-Shatby, Eastern Harbour & Kayet-Bay), because the latter area was under the influence of outfalls waters.

Table (1): Average and range of physico-chemical parameters and phytoplankton counts along Alexandria coastal water during July 2002-June 2003.

		Abu-Qir	Montazah	Mandara	Maimi	Ber-Massoud	Sidi Bishr	Gleem	Sporting	El-Shatby	Eastern Harbout	Kayet Bay	Total average
Transparenrcy (m)	Average	1.5	1.13	1.38	1.89	1.07	1.63	1.36	1.48	0.9	1.42	1.65	1.4
	Range	1-2.75	0.5-2	0.5-3	1-3.5	0.55-1.5	0.7-2.5	1-2.5	0.5-2	0.5-1.5	0.6-25	0.5-2.5	
Temperature (°C)	Av.	24.29	24.78	24.95	25.14	25-27	25.26	25.43	25.68	26.06	26.3	26.34	25.41
	Range	16.9-30.8	17-31.8	17-32	17.1-32	17.1-32	17.2-32.5	17.2-32.5	17.4-32	17.4-33	17.5-33.6	17.5-33.	
Salinity (PSU)	Av.	36.19	36.65	36.61	36.68	36.72	36.15	36.89	36.81	36.15	35.89	36.56	36.48
	Range	34.25-38.26	34.4-39.12	34.09-38.13	33.48-39.3	33.01-38.82	33.43-39.11	34.27-38.59	34.61-38.46	33.82-38.96	34.35-39.01	34.33-38.59	
PH	Range	7.70-8.62	7.78-8.81	7.92-8.8	7.8-8.77	7.9-8.68	7.76-8.78	7.68-8.8	7.82-8.73	8.0-8.44	8.01-8.62	8.09-8.44	
Dissolved oxygen (mlO_2/L)	Av.	4.91	4.62	4.13	4.12	4.5	4.21	4.75	4.17	4.1	3.27	3.19	4.18
	Range	3.91-6.01	2.01-7.01	1.8-6.6	2.01-5.6	1.95-6.61	1.8-6.01	3.1-6.6	2.2-7.03	2-6.93	1.2-5.31	0.7-5.41	
Biological oxygen demand (mlO_2/L)	Av.	1.84	1.55	1.48	1.62	1.48	1.38	1.88	1.64	1.59	1.48	1.3	1.57
	Range	0.51-4.91	0.22-4.3	0.08-5.01	0.2-5.0	0.22-5.19	0.11-3.29	0.1-4	0.5-4.79	0.41-3.5	0.9-2.33	0.31-3.19	
Oxidizablle organic malter (mgO_2/L)	Av.	1.54	1.71	1.68	1.53	1.67	1.96	2	2.05	1.96	2.13	2.05	1.84
	Range	0.57-2.91	0.57-3.13	0.71-3.41	0.43-3.13	0.43-3.55	1.21-3.41	0.78-4.41	0.57-6.47	0.64-3.13	0.85-5.12	85-3.9	
Nitrate NO_3^{-1} (µg at/L)	Av.	7.08	4.12	5.05	5.78	4.51	4.89	4.73	6.87	6.68	5.28	6.42	5.58
	Range	1.35-25.30	0.07-10.08	1.13-17.09	1.78-25.4	1.14-12.92	1.15-10.86	1.59-15.37	2.07-22.15	3.16-21.84	2.27-15.14	1.64-24.85	
Nitrite NO_2^{-1} (µg at/L)	Av.	0.66	0.53	0.5	0.56	0.54	0.64	0.53	0.62	0.93	0.77	0.7	0.634
	Range	0.36-1.15	0.24-1.13	0.07-0.96	0.24-1.03	0.14-0.96	0.02-1.58	0.07-1.06	0.24-1.27	0.45-1.92	0.36-1.27	0.12-1.92	
Ammonia (NH_4^{+1}) (µg at/L)	Av.	6.6	4.16	3.68	3.22	4.14	4.42	4.56	5.00	6.75	6.47	4.59	4.96
	Range	1.25-17.29	0.13-12.56	1.03-7.31	0.82-8.04	0.95-10.62	0.9-19.87	1.1-25.33	1.55-21.07	0.2-20.43	1.38-12.9	1.63-11.27	
Phosphate (PO_4^{-3}) (µg at/L)	Av.	0.295	0.289	0.307	0.233	0.26	0.737	0.325	0.473	0.725	0.474	0.551	0.42
	Range	0.07-1.42	0.07-1.21	0-1.78	0.07-0.5	0-0.78	0.14-2.96	0.07-1.0	0-1.85	0-2.53	0-1.28	0-2.98	
Silicate SiO_4^{-2} (µg at/L)	Av.	8.44	7.05	5.24	7.27	7.33	7.48	9.16	7.03	7.7	7.52	6.01	7.29
	Range	2.04-20.68	1.32-14.58	1.38-15.13	0.77-19.86	1.32-15.68	0.66-18.48	1.38-33.77	2.2-13.75	1.98-16.23	1.65-13.75	0.83-13.86	
Total Phytoplankton (unit/L)	Av.	$1.3x10^6$	$1.2x10^6$	$0.38x10^6$	$0.4x10^6$	$0.9x10^6$	$1.2x10^6$	$0.6x10^6$	$0.15x10^6$	$0.49x10^6$	$0.38x10^6$	$0.3x10^6$	$0.68x10^6$
	Range	$3900-12.4x10^6$	$8280-6.8x10^6$	$5540-2.9x10^6$	$5200-1.3x10^6$	$3500-6.4x10^6$	$4500-8.2x10^6$	$3500-3.8x10^6$	$1400-0.7x10^6$	$2560-4.7x10^6$	$6200-3.1x10^6$	$500-2.3x10^6$	

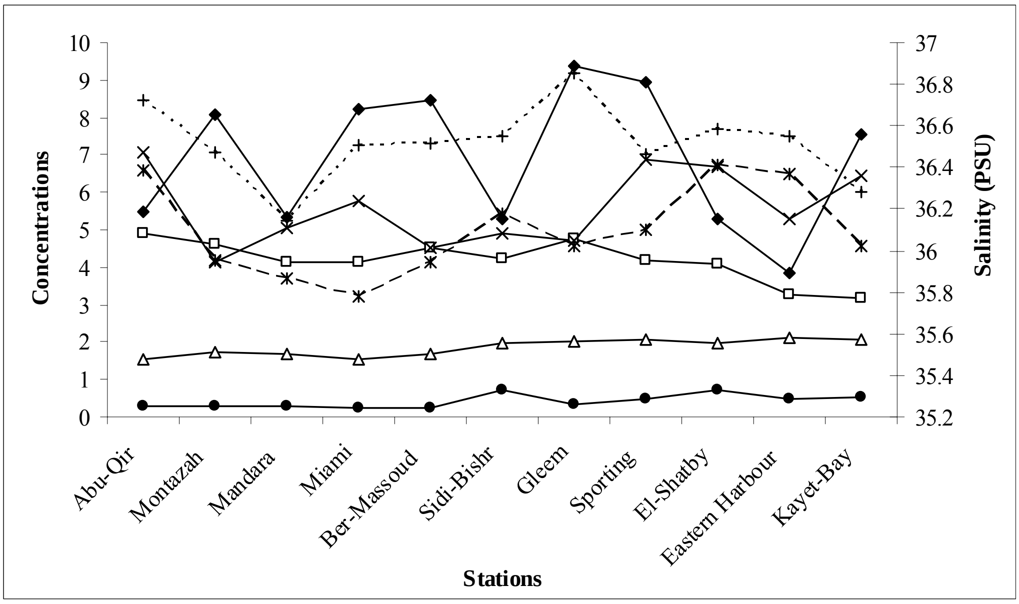

Fig. (2): Annual Averages of physico-chemical parameters along Alexandria coastal water at different stations from July 2002 to June 2003.

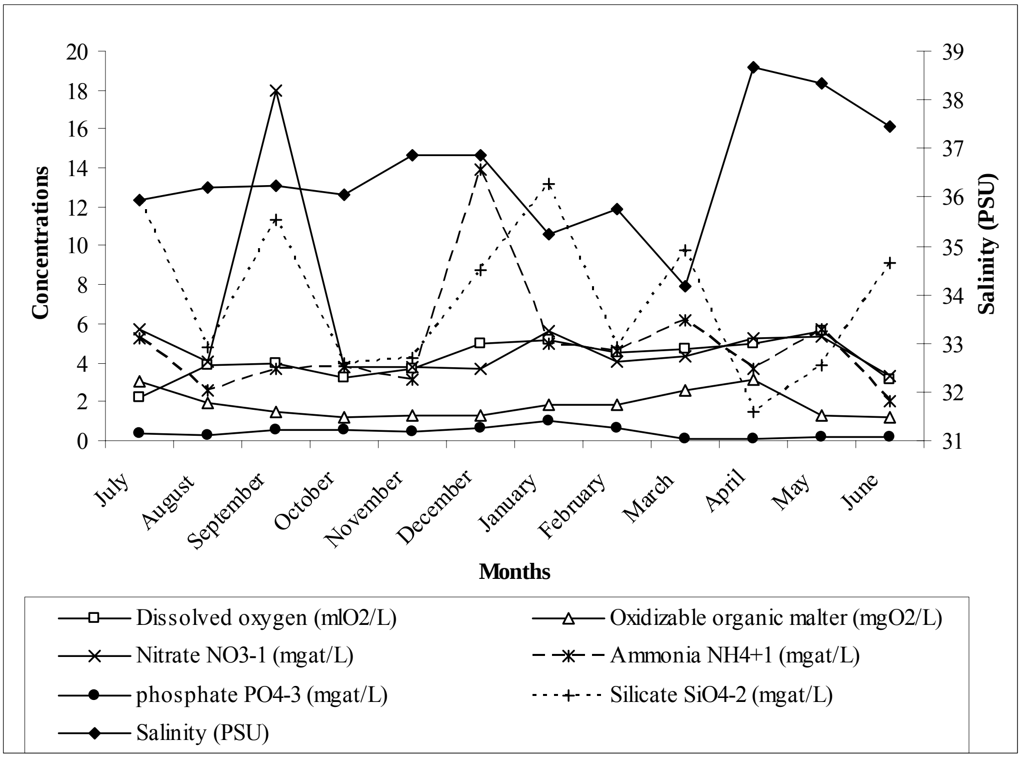

Fig. (3): Monthly average of physico-chmical parameters along Alexandria coastal water of all different stations from July 2002 to June 2003.

Monthly variations showed that, higher values were recorded during summer; April, May, June; (38.66, 38.34 and 37.47 PSU, respectively), while the lower in winter; January, February and March (35.23, 35.76 & 34.17 PSU respectively). This is may be due to a function of the climatic characteristics of high evaporation and lack of rain in the summer months (Fig. 3).

Salinity was positively correlated with water temperature and Secchi-disc readings (r = 0.228 and 0.175 $p \leq 0.05$ n= 132, respectively), and negatively correlated with total phytoplankton, total Bacillariophyceae and Chlorophyll-*a*, (r = -0.375, - 0.374 and - 0.273 $p \leq 0.05$ n= 132, respectively). Phytoplankton density is strongly affected with salinity, because phytoplankton was flourished in low salinity but unable to grow quickly enough to build up a large population by higher salinities (Purdie, 2002). Some euryhaline and eurythermal marine diatoms can grow quickly in eutrophic conditions under a variety of water salinity (Huang *et al.*, 2004).

3.2. Chemical conditions

3.2.1. Hydrogen ion concentration (pH value):

The values of pH in Alexanderia coastal water were on alkaline side, fluctuating between 7.68 (Gleem, March) and 8.81 (El-Montazah, October). Temperature stimulates phytoplankton photosynthesis, consuming CO_2 and increasing pH value. Agreement too many previous findings (Nessim and Zaghloul, 1991; El-Sherif 1993 and 1994; Zaghloul and Siam, 1996; Hussein, 2000), a significant positive relationship was found between pH values and temperatures (r= 0.24, $P\leq 0.05$, n= 132). The relatively high pH values detected during warm months are mostly correlated with the rise in temperature (Hutchinson,1973). pH value were also positively correlated with transparency and biological oxygen demand (r = 0.412, and 0.237 $p \leq 0.05$ n=132) and negatively correlated with silicate (r = 0.251, $p \leq 0.05$ n= 132).

3.2.2. Dissolved Oxygen (DO)

Dissolved oxygen is an important parameter for identification of different water masses assessing the degree of pollution in a certain aquatic ecosystems. Eutrophication characterized by diurnal formation of oxygen by photosynthesis in the eutrophic layer, and consumption by respiration at night in the lower layers including the sediments. This imbalance is responsible for the deleterious effect of eutrophication. Dissolved oxygen values fluctuated between 0.70 ml O_2/L (Kayet-Bay, October) and 7.03 ml O_2/L (Sporting, May), with an annual average of 4.18 ml O_2/L, (Table 1). Low dissolved oxygen values were reported during most months particularly at Kayet-Bay and E.H. stations, where many values were less than 2.8 ml O_2/L, reflecting symptoms of eutrophication (Stachowitsched and Avcin, 1988; Hussein, 2000). Monthly average showed that the highest concentrations were recoded during April and May i.e.5.01 & 5.59 ml O_2/L, respectively (Fig. 3). Spatial average variations showed more or less the same values (4.1-4.9 mlO_2/L) except Eastern Harbour and Kayet- Bay stations, where their averages were 3.27 & 3.19 ml O_2/L, respectively (Table 1 and Fig. 2). These values were similar to that previously recorded by Zaghloul and Siam (1996) and lower than that recorded by El-Rayis (1973). Correlation coefficient showed that, the dissolved oxygen values were negatively correlated with transparency and temperature (r = -0.28 and -0.504, $p \leq 0.05$ n= 132). Temperature is one of the most important factors affecting on oxygen solubility.

3.2.3. Biological Oxygen Demand (BOD)

The determination of BOD is the most useful method in estimating the amount of biodegradable organic matter present in the aquatic environment. The values were ranged between 0.08ml O_2/L (Mandara, July) and 5.19ml O_2/L (Ber- Massoud, December) with annual average of 1.57ml O_2/L (Table 1). High values were recorded at most stations during December with an average of 3.99 ml O_2/L. Spatial distribution showed that, higher values were recorded at Abu-Qir and Gleem stations (1.84, 1.88 ml O_2/L, respectively). Correlation coefficient showed that the BOD value was positively correlated with pH value, DO and NH_4^{+1} (r = 0.237, 0.218 and 0.259 $p \leq 0.05$ n= 132, respectively) and negatively correlated with transparency and NO_3^{-1} (r= -0.177 and -0.235, $p \leq 0.05$ n= 132, respectively).

3.2.4. Oxidizable Organic Matter (OOM)

The impurities present in domestic sewage consist of inorganic and organic matter entranced by the liquid flow in the form of suspended solids or in the form of soluble organic matter in the water, one of the main characteristics of domestic sewage is biodegradability. The oxidizable organic matter values of sampled stations showed wide variations which ranged between 0.43 mg O_2/L (Miami, September & Ber-Massoud, May) and 6.47mg O_2/L (Sporting, July). The annual average reached 1.84mg O_2/L (Table 1). This is slightly higher than that previously reported by Nessim and Zaghloul (1991) which amounted 1.66 mg O_2/L and 1.54mg O_2/L by Zaghloul and Siam (1996) at the same area. Monthly variations showed that, high average values were recorded during July and April (3.04, 3.11mg O_2/L, respectively) (Fig. 3), while the lower average value was recorded during June (1.17mg O_2/L). Regional variations showed that the highest average values were recorded at Sporting, Eastern Harbour & Kayet-Bay (2.05, 2.13 and 2.05mg O_2/L, respectively) as shown in figure (2). The salinity values were reduced at the last two stations due to the increased amount of sewage water discharged. This may be responsible for the high, OOM values recorded and the decreased phytoplankton density. Correlation coefficient showed that OOM was negatively correlated with salinity and transparency (r = -0.167 & -0.212, $p \leq 0.05$ n= 132, respectively), but was positively correlated with total phytoplankton density, total Bacillariophyceae and total Dinophyceae (r= 0.235, 0.033 and 0.304 $p \leq 0.05$ n= 132, respectively).

3.2.5 Nutrient Salts

Nutrient loads are directly dependent on human activities, which in turn depend on the growth of the world's human population. Consequent, human-induced eutrophication is in a way related to the increase in human population (De Jonge *et al.*, 2002).

3.2.5.1. Dissolved Inorganic Nitrogen:

3.2.5.1.1. Nitrate NO_3^{-1}

The most important form of nitrogen is nitrate, which formed 49.94% of the total dissolved inorganic nitrogen compound in the study area. This element is considered as important nutrient source for phytoplankton growth (Parsons *et al.,* 1990). Nitrate concentrations ranged between 0.07μg at/L (El-Montazah, March) and 25.4μg at/L (Miami, September), with an annual average of 5.58μg at/L (Table 1). This is higher than the results recorded earlier at the same area (3.0 μg at/L) during 1988-1989 (Nessim, 1991) and during 1995 (Zaghloul and Siam, 1996). The regional distribution showed that, the highest average value was recoded at Abu-Qir (7.08μg at/L), then decreased westward reaching its minimum average of 4.12μg at/L at Montazaha and then increased gradually up to (6.87, 6.68 and 6.42μg at/L at

Sporting, El-Shatby and Kayet-Bay, respectively) (Fig. 2). The maximum concentration was recorded during September (18µg at/L) (Fig. 3) and was companied with lower phytoplankton density (92 x 10^3unit/L), the same finding was recorded by Zaghloul and Siam (1996) at the same area. The lowest average value was observed in June (3.34µg at/L) (Fig. 3). Nitrate concentrations correlated positively with transparency, temperature and silicate (r= 0.179, 0.264 and 0.376, $p \leq 0.05$ n=132, respectively) and negatively correlated with BOD, salinity and diversity (r= -0.235, -0.235 and -0.19, $p \leq 0.05$ n=132, respectively).

3.2.5.1.2. Nitrite (NO_2^{-1})

Nitrite is an intermediate between nitrate and ammonia; it formed about 5.67% of the total dissolved inorganic nitrogen. Its concentration fluctuated between 0.07µg at/L (Mandara, May) and 1.92 µg at/L El-Shatby and Kayet-Bay,September), with an annual average of 0.634µg at/L. Higher concentrations were recorded at El-Shatby, Eastern Harbour and Kayet-Bay (0.93, 0.77 and 0.70 µg at/L, respectively) (Fig. 2). Monthly variations showed that the highest average value was recorded during September (1.08µg at/L), while the lowest one was in May (0.23µg at/L)

3.2.5.1.3. Ammonia (NH_4^{+1})

Ammonia represented 44.39% of the total dissolved inorganic nitrogen, it showed a wide range of variation from 0.13µg at/L (Montazah, October) as affected by phytoplankton uptake (2060 x 10^3 unit/L) and 25.33µg at/L (Gleem, December) accompanied with low phytoplankton density (10.9 x 10^3unit/L). The annual average reached 4.96 µg at/L (Table 1). This was higher than that previously recorded during 1995 (1.6µg at/L) by Zaghloul and Siam (1996) at the same area. Regional distribution of average values along the Alexandria coastal water showed that the high concentrations were recorded at Abu-Qir, El-Shatby and Eastern Harbour (6.6, 6.75 & 6.47 µg at/L respectively) (Fig. 2). Regarding the monthly variations, December represented the highest average value (13.9 µg at/L) (Fig. 3) this was paralleled to low phytoplankton counts 15 x 10^3 unitl/L, while the lowest one occurred in June (2.02µg at/L), when relatively high phytoplankton density were recorded (0.8 x 10^6 unit/L). This may prove that ammonia is the form of nitrogen preferred by algae and when ammonia concentration was depleted to <0.15 µg at/L, nitrite will be utilized (UNEP UNESCO/FAO, 1988). Ammonia was positively correlated with BOD and silicate (r=0.259 and 0.171, $p \leq 0.05$ n= 132) and negativity correlated with temperature (r= 0.239, p <0.05 n=132).

3.2.5.2. Dissolved inorganic phosphate (PO_4^{-3})

Phosphate concentration was governed by the interaction of input of wastewater and the uptake by the heavy bloom of phytoplankton (Mingazzini *et al.,* 1992), so it was fluctuated between depletion at most stations particularly during March and April and 2.98µg at/L (Kayet-Bay, October), with an annual average of 0.42µg at/L (Table 1). This value was in between to that recorded during 1991 (0.3 µg at/L) by Abdalla *et al.* (1995) and that of 1989 (0.53 µg at/L) by Nessim (1991) and Zaghloul and Siam (1996). Depletion of phosphate at most stations in April may be related to uptake of phytoplankton (4.4 x 10^6unit/L), while the highest concentration was recorded during January (1.05µg at/L). Fluctuations in phosphate concentrations among stations were low. Sidi-Bishr and El-Shatby sustained high average values (0.74 and 0.73µg at/L, respectively), while the least average values were recorded at Sporting, Eastern Harbour and Kayet-Bay (0.5µg at/L). In the Mediterranean Sea, values are extremely low, typically below 0.05 µg at/L in the euphotic zone (Stirn, 1988).

3.2.5.3 Reactive silicate (SiO_4^{-2})

Silicate concentrations showed very wide fluctuation and it ranged between 0.66 µg at/L (Sidi-Bishr, April) and 33.77µg at/L (Gleem, July) with an average value of 7.29µg at/L (Table 1). This is two and half times higher than previous records at the same region (Zaghloul and Siam, 1996).

The irregularity in the silicate concentrations may be due to the assimilation by diatom and regeneration by solution from diatom frustules (Stefansson, 1968), regeneration of silicate is mostly a dissolution process, which occurs continuously at all depths (Levasseur and Therriault, 1987). Fluctuations among stations were low (Fig. 2), fluctuated between 5.24µg at/L (Mandara) and 9.16µg at/L (Gleem), where phytoplankton density reached $0.4x10^6$ and $0.6x10^6$ unit/L respectively. The high silicate concentrations were recorded during July and January (12.39 & 13.15µg at/L, respectively) accompanied with a relatively low phytoplankton density ($0.4x10^6$ and $0.2x10^6$ unit/L, respectively). Silicate correlated positively with chlorophyll-*a* (r= 0.233, p=0.007, n= 132).

The investigated area showed low oxygen concentration (0.71ml O_2/L), low water transparency (0.5m) and wide ranges of nutrients, nitrate (25.4µg at/L); ammonia (25.33µg at/L); nitrite (1.92µg at/L); phosphate (2.98µg at/L) and silicate (33.77µg at/L), all these factors create eutrophic condition.

3.3. Phytoplankton structure

3.3.1. Community composition and spatial distribution

A total of 92 phytoplankton taxa were identified along Alexandria coastal water during the study, belonging to wide ecological spectrum, extending from brackish-fresh water (27 taxa), to marine (65 taxa). Bacillariophyceae was the most dominant in terms of the number of taxa (36 genera, 65 species) and abundance (98.6%), Dinophyceae (1.01%), Cyanobacteria (0.28%), Euglenophyceae (0.1%) and Chlorophyceae (0.01%) were considered rare or scarce forms and represented by 27 species (Table 2).

Phytoplankton density fluctuated widely from 500 unit/L (Kayet-Bey, November) and $12.4x10^6$unit/L (Abu- Qir, March). The annual average amounted to 0.677 x 10^6 unit/l, and was higher than corresponding values previously recorded at the coastal water of Alexandria (Dorgham *et al.,* 1987; Zaghloul, 1994 and El-Sherif, 1994), and lower than that recorded during 1995 (Zaghloul & Siam 1996). The highest annual averages were recorded at Abu-Qir, Montazah and Sidi-Bishr ($1.3x10^6$, $1.3x10^6$ and $1.2x10^6$unit/L, respectively) (Fig.4).

Table (2): Number of species (N), percentage (%) of different groups, annual average values of total phytoplankton counts, diversity, chlorophyll-*a* and trophic state index along Alexandria coastal water from July 2002 to June 2003.

Stations / Groups	Abu-Qir		Montazah		Mandara		Miami		Massoud		Sidi-Bishr	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Bacillariophyceae	49	99.35	43	99.26	43	96.88	43	97.95	40	99.00	36	98.81
Dinophyceae	12	0.37	15	0.56	12	2.91	13	1.60	11	0.80	12	0.39
Cyanobacteria	4	0.17	4	0.16	4	0.17	2	0.12	3	0.17	5	0.65
Euglenophyceae	1	0.09	1	0.01	1	0.04	1	0.32	1	0.03	1	0.11
Chlorophyceae	1	0.02	1	0.01				0			1	0.04
Cryptophyceae							1	0.01			1	0.002
Total number	67	100	64	100	60	60	60	100	55	100	56	100
T.phyt. (unit/l)	1.29x10^{6}		1.26x10^{6}		0.377x10^{6}		0.38x10^{6}		0.93x10^{6}		1.23x10^{6}	
Diversity (nats)	1.67		1.37		1.58		1.46		1.54		1.44	
Chlorophyll-*a* (mg/l)	0.32		0.26		0.50		0.45		0.29		0.23	
Trophic state index	51.34		56.47		52.57		44.84		58.44		62.46	

Cont. Table (2):

Stations / Groups	Gleem		Sporting		Shatby		Eastern Harbour		Kayet Bey		Average	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Bacillariophyceae	35	99.20	45	96.82	41	98.77	50	94.10	44	98.61	65	98.60
Dinophyceae	9	0.58	13	1.92	12	0.83	14	5.38	8	0.75	17	1.01
Cyanobacteria	4	0.15	4	1.11	4	0.33	4	0.23	3	0.33	7	0.28
Euglenophyceae	1	0.07	1	0.15	1	0.07	1	0.28	1	0.31	1	0.1
Chlorophyceae											1	0.01
Cryptophyceae											1	0.0004
Total number	49	100	63	100	58	100	69	100	56	100	92	100
T.phyt. (unit/l)	0.64x10^{6}		0.153x10^{6}		0.49x10^{6}		0.38x10^{6}		0.3x10^{6}		0.68x10^{6}	
Diversity (nats)	1.41		1.51		1.5		2.01		1.6		1.55	
Chlorophyll-*a* (mg/l)	0.23		0.22		0.39		0.37		0.22		0.32	
Trophic state index	49.45		60.15		74.47		63.85		59.27			

Sporting and Kayet-Bay stations sustained the lowest phytoplankton average counts ($0.15x10^6$ and $0.30x10^6$ unit/L, respectively), both stations were affected directly or indirectly with waste water discharge, also zooplankton grazing has been postulated to play at times an effective role in regulating the phytoplankton cycle and causes losses in the density (Dorgham *et al.,* 2006).

Bacillariophyceae was the most dominant group at all stations (Table 2), while the other groups formed the rest, so phytoplankton counts and Bacillariophyeae all of them correlated with water transparency, temperature, salinity and OOM with the same ratio approximately ($r= - 0.257, 0.321, -0.375$ and 0.235 $p \leq 0.05$; $n= 132$, respectively).

As regards to the distribution, it was found that Bacillariophyceae contributed over 95% of total phytoplankton at all stations except the Eastern Harbour station , where it formed 94.1 % of the total community (Table 2), this station showed different community structure, where *Skeletonema costatum* was the most dominant taxon (74.73% to the total community). Some species appeared frequent such, *Nitzschia* (5.68%); *Rhizosolenia* (4.32%) and *Chaetoceros* (5.91%). The occurrence of *Skeletonema costatum* as indicator of eutrophication was recognized by many authors, Mihnea, (1985) and Revelante and Gilmartin, (1985) and in the Egyptian coastal waters (Dorgham *et al.,* 1987; Zaghloul, 1994; Hussein, 1994; Zaghloul and Siam, 1996, and Hussein, 2000). *Skeletonema costatum* formed over 50% of the total community at all stations except Eastern Harbour (12.62%) as shown in figure (4). This station showed different community structure than the other stations since the highest number of species are recorded (69 spp.) (Table 2), and its community was dominated by *Nitzschia delicatissima* (21.82%), *Rhizosolenia delicatula* (15.65%), *Rhizosolenia fragilissima* (12.66%), *Skeletonema costatum* (12.62%), *Rhizosolenia setigera* (11.55%), and *Thalassionema nitzschioides* (5.5%).In addition physico-chemical parameters were different; low salinity values (35.89 PSU), dissolved oxygen (3.27ml O_2/L) relatively high oxidizable organic matter (2.13mg O_2/L) and ammonia concentration (6.47µgat/L). This confirms that this station is the most diversified and eutrophied one (Hussein, 1994).

3.3.2. Monthly variations

Throughout Alexandria's coast the phytoplankton density showed the highest average density ($4.4x10^6$unit/L) during March, Bacillariophyceae was the most dominant group (99.69% to the total community), represented by 45 species dominated by *Skeletonema costatum* ($3.9 \text{ x } 10^6$unit/L; 88.25% to the total community); followed by *Chaetoceros affinis* (8.46%), the other 43 species appeared rare (Fig.5). The lowest phytoplankton density was recorded during autumn particularly in November ($7.5x10^3$unit/L), the leading genera were *Nitzschia,* and *Chaetoceros* (20.08 and 15.98% to the total community, respectively), while *Rhizosolenia* and *Protoperidinium* (4.09% and 4.63%, respectively) were frequent forms.

According to phytoplankton succession, a high pronounced peak was recorded during March at most stations particularly at Abu-Qir, Montazah, Ber-Massoud, Sidi-Bishr and El- Shatby stations ($12.4x10^6$, $6.85x10^6$, $6.4x10^6$, $8.2x10^6$ and $4.7x10^6$ unit/L, respectively) (Fig. 6). The most dominant species; was *Skeletonema costatum*, which formed more than 92% to the total community at these stations except Abu-Qir station (79.3%). So these stations considered as eutrophic area, and these confirmed with low salinity, (35.06, 34.4, 33.01, 33.43 & 34.53 PSU, respectively). The increasing phytoplankton blooms is perhaps the best indication of the onset of eutrophication as recorded by Cruzado (1978) and the community was still dominated by diatoms, and not altered to Cyanobacteria and/or other groups.

The community harboured various dominant species within the different months and stations as affected by the prevailing environmental conditions, so a small peak was recorded during October at Montazah, (2.1 x 10^6unit/L), dominated by *Nitzschia* (27.32%), particularity *Nit. delicatissima* 24.99%; *Chaetoceros* (21.24%),represented mainly by *Ch. curvisetus* 15.37% and *Ch. didymus* 5.43%; *Rhizosolenia* (17.26%),dominated by *Rh. fragilissima* 11.72 and *Rh. delicatula* 5.24% ;*Leptocylindrus minimus* 9.32%, and *Lep. danicus* (5.34%), another peak developed in January (1.6 x 10^6unit/l) and was dominated by *Nitzschia delicatissima* and *Thalassiosira rotula* (53.93% & 37.21% to the total community, respectively).

During February, phytoplankton density reached (3.8 x 10^6 unit/L, 1.5 x 10^6unit/l and 1.3 x 10^6unit/L) at Ber- Massoud ,Abu-Qir and Maimi, dominanted by *Skeletonema costatum* (93.1%, 81.53% and 77.56%, respectively) (Fig. 6). During April, the high counts appeared at Montazah and Gleem (2.9 x 10^6 and 3.8 x 10^6unit/L, respectively), *Sk. costatum* was the dominant species (63.37% and 98.95%, respectively). During June, a small peak was recorded at Gleem (1.05 x 10^6unit/L) and higher one was observed at Sidi-Bishr (6 x 10^6unit/L), the dominant species was also *Sk. costatum* (90.56%, 93.22% respectively). During July, phytoplankton density reached 3.1 x 10^6 unit/l, at Eastern Harbour and dominated by *Rhizosolenia* (57.65%), *Nitzschia* (26.5%) and *Thalassionema nitzschioides* (7.97%) (Fig. 6).

3.3.3. Diversity index of phytoplankton community

The diversity of most aquatic systems decreases with eutrophication, phytoplankton species diversity is reduced in highly productive systems (Trimbee and Prepas, 1987; Waston *et al.,* 1997). The estimated diversity showed wide fluctuations, ranging from 0.08 nats (Gleem, April) to 3.02 nats (Eastern Harbour, January) (Fig. 6), with an annual average 1.55 nats (Table 3). This was higher than that previously recorded during 1995 (1.4 nats) by Zaghloul and Siam (1996). The highest value (3.02 nats) was accompanied with low phytoplankton standing crop abundance (79.2 x 10^3 unit/L) and many species shared in the dominance, the leading species were *Nitzschia delicatissima* (11.49%), *Navicula cryptocephala* (10.35%), *Thalassiosira subtilis* (7.95%), *Nitzschia sigma* (7.07%), *Nit. seriata* (6.06%) and *Licmophora gracilis* (6.06%), *Euglena acus* (5.56%), and *Cyclotella meneghiniana* (4.29%). On the other hand, the lowest value (0.08 nats) was accompanied with high phytoplankton density (3.81 x 10^6unit/l) and only one species formed 98.95% (*Sk. costatum*) as shown in figure (6).

Due to great salinity fluctuations in Eastern Harbour, the size spectra of phytoplankton species were larger than those in the other stations, species diversity in the Eastern Harbour attained the highest annual average (2.01 nats), where 69 species were recorded and average phytoplankton density was 382.7 x 10^3unit/L (Table, 2 and Fig. 4). The community was dominated by several species *Nitzschia delicatissima* (21.82% to the total community), *Rhizosolenia delicatula* (15.65%), *Rhizosolenia fragilissima* (12.66%), *Skeletonema costatum* (12.62%), *Rhizosolenia setigera* (11.55%), *Thalassionena nitzschioides* (5.50%) and *Chaetoceros affinis* (2.76%). On the other hand the lowest diversity annual values was recorded at Montazah (1.37 nats), followed by Sidi-Bishr (1.44 nats) and Gleem (1.41 nats), where the dominance was represented by one species, i.e. .*Skeletonema costatum* (69.20%. 90.61% and 91.44% to the total community, respectively). This may be assigned of pollution.

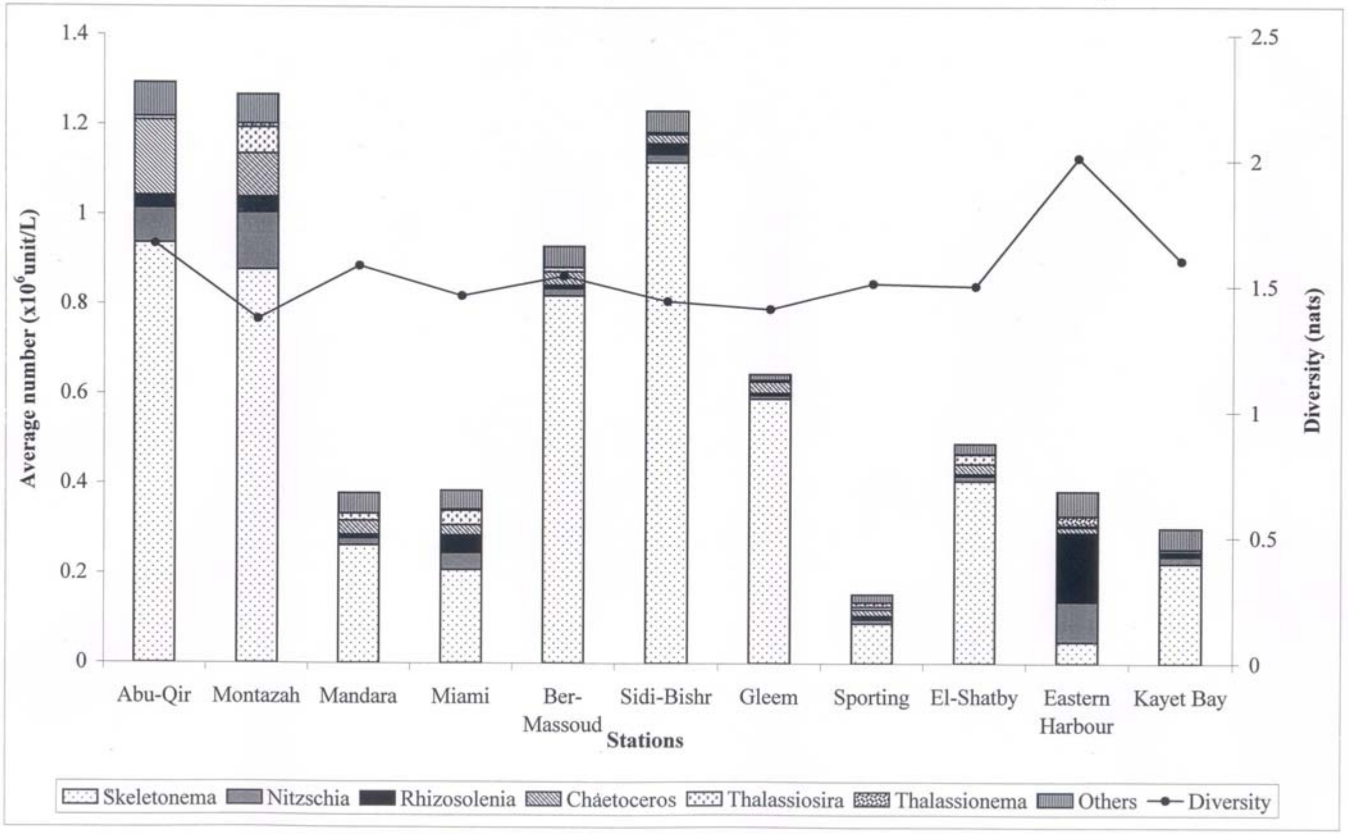

Fig. (4): Annual average values of total phytoplankton counts, diversity value at different stations along Alexandria coastal water from July 2002 to June 2003.

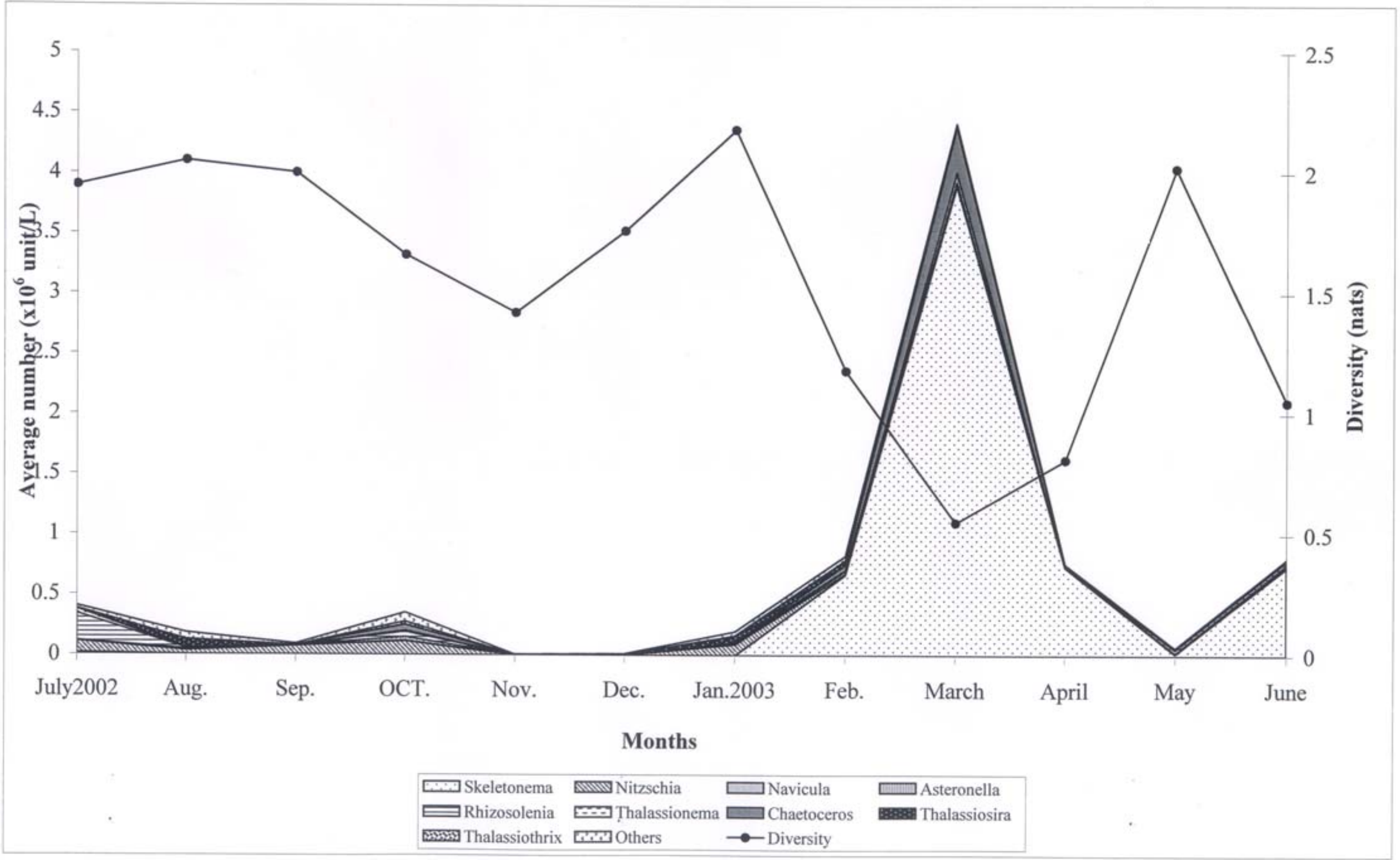

Fig. (5): Monthly average values of total phytoplankton counts and diversity value along Alexandria coastal water from July 2002 to June 2003.

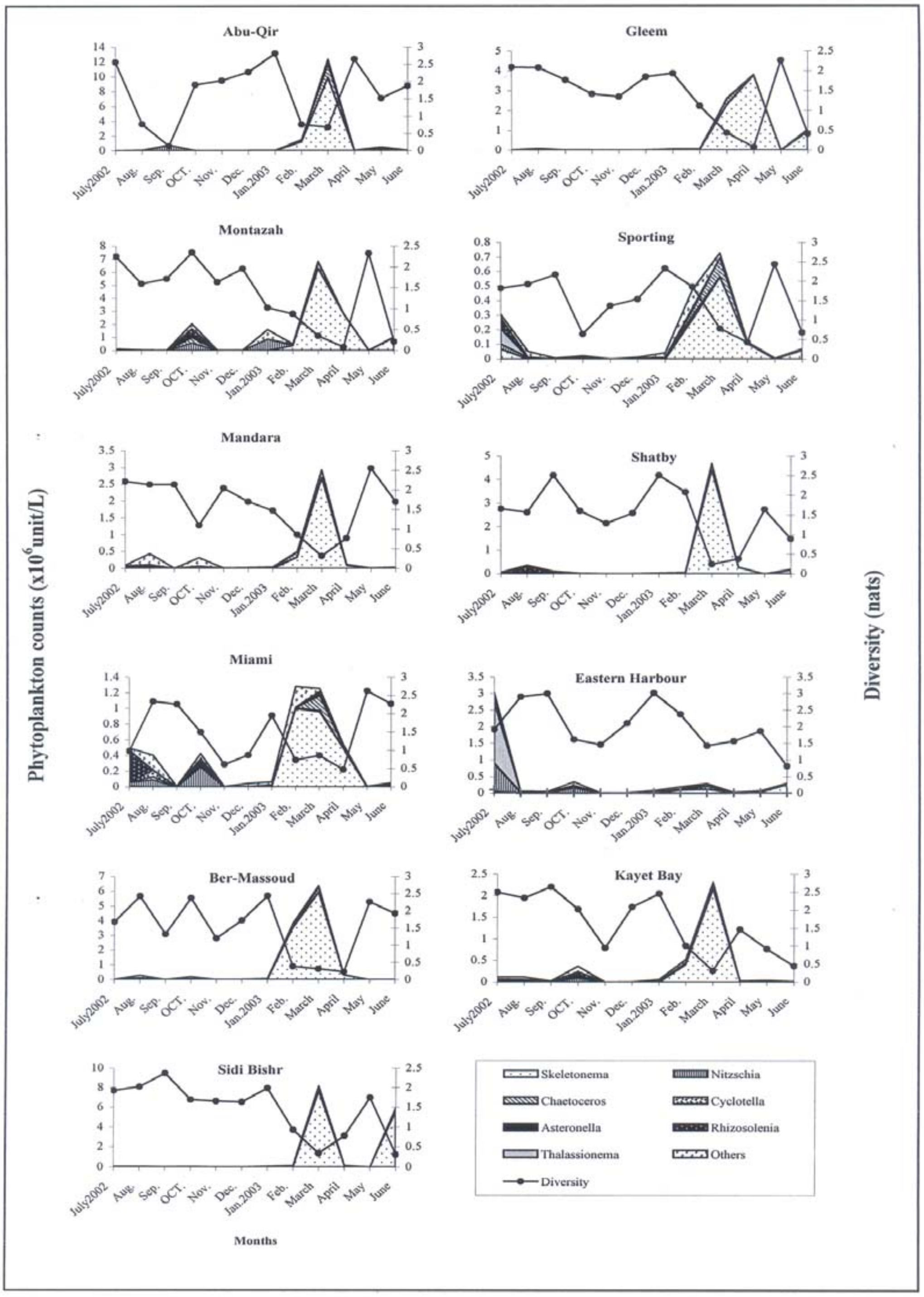

Fig. (6): Monthly variations of phytoplankton counts, its main components and diversity values at different stations along Alexandria coastal water.

Monthly average values showed that the high values were recorded during January (2.18 nats) when the average phytoplankton density was 0.2 x10^6 unit/L and number of species was 54 (Table 3). The January peak was also pronounced at most stations, particularly at Eastern Harbour (3.02 nats) (Fig. 6). While the lowest value was recorded during March (0.55 nats),and was accompanied with high phytoplankton density average 4.4 x 10^6unit/L (Table 3), *Sk. costatum* was the most dominant species (88.25%).

Diversity index showed a negative correlation with water transparency, temperature, nitrate and biological oxygen demand ($r= -0.17, -0.29, -0.19$ and -0.17 $P \leq 0.05$; $n= 132$) this reflects the eutrophication observed at some stations, characterized by high values of nutrient salts, which in turn stimulate phytoplankton density and decreased its diversity.

3.3.4. Chlorophyll-a content and Trophic State Index

Chlorophyll-*a* is a primary photosynthetic pigment used for the estimation of phytoplankton biomass in aquatic environment and it gives a good estimate of the current degree of eutrophication (Glooschen and Blanton, 1977). The typical concentration of chlorophyll-*a* is usually below 0.5µg/L at phytoplankton densities ranging between 10^4-10^5 cell/L (Stirn, 1988). In some eutrophied areas, chlorophyll-*a* ranges between 0.5-1.0µg/L (Friligos, 1988), extensive eutrophication phenomena occurring during algal blooms elevate trophic level, chlorophyll-*a* concentration above 1.0µg/L and phytoplankton density reached 10^7 cell/L.

Trophic state index (TSI) based on chlorophyll-*a* (µg. /L), Secchi depth (m) and total phosphorus µg/L (Carlson, 1977), gives a numerical scale as follows:

- Oligotrophic ≤ 40
- Mesotrophic 40 to 50
- Eutrophic >50
- Hypertrophic > 70

Chlorophyll-*a* showed wide fluctuations from 0.005µg/L (Gleem, November),Gleem station in this month considered as oligotrophic area (TSI 28.82) and 3.68 µg/L(Mandara, January), which considered as hypertrophic area (TSI 125.85). The annual average value of chlorophyll-*a* during present work attained 0.32 µg/L. This is lower than that previously recorded by Nessim, 1991 and Zaghloul and Siam 1996. Regional distribution showed that, the annual average was more or less similar at all stations, it ranged between 0.22µg/L (Sporting & Kayet-Bay) and 0.5µg/L (Mandara), as shown in Table (2).

According to trophic state index the studied area showed that, it was eutrophic area except Miami and Gleem (mesotrophic), while El-Shatby is a hypertrophic as shown in Table (2).

Monthly variations showed that all months were mesotrophic except winter season (January- March) was hypetrophic and Chlorophyll-*a* ranged from 0.1µg/L (December 2002) and 1.1 µg/L (January 2003), as shown in Table (3).

Correlation showed that chlorophyll-*a* positively correlated with silicate concentration ($r= 0.233$; $p \leq 0.05$; $n= 132$) and negatively correlated with water transparency, temperature and salinity ($r= -0.275, -0.216$ and -0.273 $p \leq 0.05$; $n=132$, respectively).

Stepwise Regression showed that, variations of salinity, temperature and oxidizable organic matter appeared to be the key of changes on phytoplankton abundance during the period of study.

Total phytoplankton (unit/L) = 15415204-366439 PSU – 73798 Temp. + 274401 OOM R^2= 22.26

Table (3): Number of species (N) of different groups and its percentage (%) to total phytoplankton counts, diversity chlorophyll-*a* and trophic state index along Alexandria coastal water during July 2002- June 2003.

Months / Groups	July		Aug.		Sep.		Oct.		Nov.		Dec.		Jan	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Bacillariophyceae	32	95.91	37	88.94	35	95.45	40	98.02	21	89.54	19	93.00	41	94.16
Dinophyceae	11	3.77	11	9.9	9	3.6	12	1.68	7	10.46	3	2.06	6	2.57
Cyanobacteria	3	0.30	3	0.92	2	0.6	1	0.20			5	4.53	6	2.04
Euglenophyceae	1	0.02	1	0.24	1	0.35	1	0.10			1	0.41	1	1.23
Chlorophyceae														
Cryptophyceae														
Total	47	100	52	100	47	100	54	100	28	100	28	100	54	100
Total phyt. (unit/l)	$0.4x10^6$		$0.18x10^6$		$0.09x10^6$		$0.35x10^6$		$0.007x10^6$		$0.01x10^6$		$0.2x10^6$	
Diversity (nats)	1.95		2.05		2.00		1.66		1.42		1.76		2.18	
Chlorophyll-*a* (mg/l)	0.14		0.35		0.26		0.3		0.12		0.10		1.07	
Trophic state index	47.17		55.59		51.95		52.58		47.82		51.89		93.17	

Cont. Table (3):

Months / Groups	Feb.		March		April		May		June		Average	
	N	%	N	%	N	%	N	%	N	%	N	%
Bacillariophyceae	43	98.40	29	99.69	33	99.31	30	86.31	20	98.67	65	98.6
Dinophyceae	6	0.11	12	0.25	10	0.45	13	13.38	13	1.07	17	1.01
Cyanobacteria	3	1.23	3	0.02	4	0.15	2	0.11	4	0.20	7	0.28
Euglenophyceae	1	0.26	1	0.04	1	0.02	1	0.16	1	0.01	1	0.10
Chlorophyceae					1	0.07			1	0.05	1	0.01
Cryptophyceae							1	0.04	1	0	1	
Total	53	100	45	100	49	100	47	100	40	100	92	100
Total phyt. (unit/l)	$0.82x10^6$		$4.4x10^6$		$0.76x10^6$		$0.06x10^6$		$0.8x10^6$		$0.68x10^6$	
Diversity (nats)	1.18		0.55		0.81		2.02		1.05		1.55	
Chlorophyll-*a* (µg/l)	0.21		0.51		0.3		0.2		0.22		0.32	
Trophic state index	67.83		77.16		57.00		44.72		44.01			

4. CONCLUSION

As the Project of Alexandria Wastewater phase (II) was terminated, water quality at some stations were improved . Physico-chemical condition of the study area showed a great variability, which may lead to an obvious drop of dissolved oxygen content, water transparency and salinity at some stations, wide range of nutrients occurred as well as increase in phytoplankton density, diversity index and marked changes in species dominance, which were admitted as being indicators of eutrophication such as *Skeletonema costatum, Chaetoceros* spp., *Nitzschia* spp. and *Rhizosolenia* spp. This study showed that all stations were considered as eutrophic area, except Miami and Gleem stations which may be considered as mesotrophic area, while El-Shatby area was hypertrophic one.

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