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IMPACT OF POLLUTION ON PHYTOPLANKTON IN A COASTAL MARINE ENVIRONMENT

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ABSTRACT

The phytoplankton community structure was studied for a year cycle in a polluted area (Kayet Bey region), Alexandria, Egypt. Monthly and regional variations of the physico-chemical characteristics were studied and correlated with variations of the species composition of the phytoplankton community.

The Shannon-Weaver diversity reflects an inverse relationship to the degree of dominance of the main species and with the magnitude of the standing crop. A simple mathematical equation describing the dependence of diversity on the variations of species dominance is given.

The phytoplankton-zooplankton distribution illustrated an inverse relationship between them during the different months.

Multiple regression equation of both phytoplankton standing crop and diversity were computed to quantify them in relation to the most correlative environmental factors.

Results indicate that Kayet Bey region attained high level of water eutrophication, due to domestic pollution. Several species were recorded as indicators of eutrophication. The magnitude of the phytoplankton standing crop was significantly high (236×10^3 unit.l^{-1}) compared to other areas of the Mediterranean Sea.

INTRODUCTION

In recent years, the problem of sewage pollution of Alexandria coastal waters has become a matter of national concern. Signs of this kind of pollution have already been observed in the last few years along the shores of Alexandria. Admittedly, the disposal of the untreated sewage even in the open sea may be harmful with regard to its possible hygienic and aesthetic effect and its impact on fauna and flora in marine environment. The effect is directly proportional to the quantity and quality of the sewage discharged and the capacity of the environment to assimilate, degrade and disperse these allochthonous pollutants.

Alexandria City is one of the more densely populated regions of the Eastern Mediterranean Sea (about 3.5 million inhabitants). A considerable amount of the city domestic sewage is discharged into the coastal waters through a major outfall at Kayet Bey, in addition to 18 minor out-falls. An average amount of more than 0.5 x 10^6 m^3 waste is estimated to be discharged daily into the sea without any treatment and thus represents a serious source of pollution in the region.

The phytoplankton community in the Egyptian Mediterranean waters off Alexandria has attracted the attention of several authors (El-Maghraby & Halim, 1965; Aleem & Dowidar, 1967 and Halim et al., 1980). Most of these studies were concerned with the qualitative and quantitative structures of the different phytoplankton components in shore waters as well as in the Eastern Harbour of Alexandria. Previous observations covered year-cycles without tackling the problem of pollution in the area and its impact on the phytoplankton. However, Halim et al. (1980), Zaghloul & Halim (1990 & 1992), Zaghloul (1994 a&b) followed the species composition and standing crop in a semi-closed area (Eastern Harbour and Western Harbour) as an eutrophic bey in addition to Dorgham et al. (1987) in the open sea west of Alexandria.

The present work traces the temporal and spatial distribution of phytoplankton communities at Kayet Bey region as affected directly by the sewage effluents discharged from Kayet Bey sewer. In addition, diversity index in relation to the environmental conditions, as well as phytoplankton-zooplankton relationship were estimated.

Regression models of both phytoplankton standing crop and diversity index as a function of the most correlative environmental conditions are also computed.

MATERIAL AND METHODS

Water samples of phytoplankton and zooplankton were collected monthly during the period from September 1987 to August 1988 from surface and near bottom layers at nine selected stations representing an area of about 4 km^2 in front of the opening of Kayet Bey sewage pumping station (Fig. 1). Results of the physico-chemical parameters, as well as zooplankton population were previously published by Zaghloul & Nessim (1990) and Nessim & Zaghloul (1991).

Quantitative estimation of phytoplankton standing crop was performed at the surface and near bottom layers, using the sedimentation method (Ultermohl, 1931). The samples were preserved in 4% neutral formalin. The different species were identified and counted as unit per liter. Water stability was calculated according to UNESCO, 1987.

Species diversity was estimated according to the equation of Shannon and Weaver (1963),

$$H = -\sum_{I=1}^{n} Pi \ \ln \ Pi$$

where Pi = importance probability for each species (n/N is the proportion of i, the ni species) to the total number of phytoplankton cells (N). The results were expressed as "nats".

The dominance index (d) was also calculated using the Bergen-Parker dominance index (c.f. Chellappa, 1989).

$$d = n_{max.} / N_T$$

where:

$n_{max.}$ = number of individuals of the dominant species;
N_T = total number of individuals of all the species recorded.

Correlation coefficient as well as stepwise multiple regression equations at a confidence limit 95% were evaluated for the surface samples of the whole integrated year (n = 108) to quantify the phytoplankton standing crop and diversity index in relation to the most correlative environmental factors.

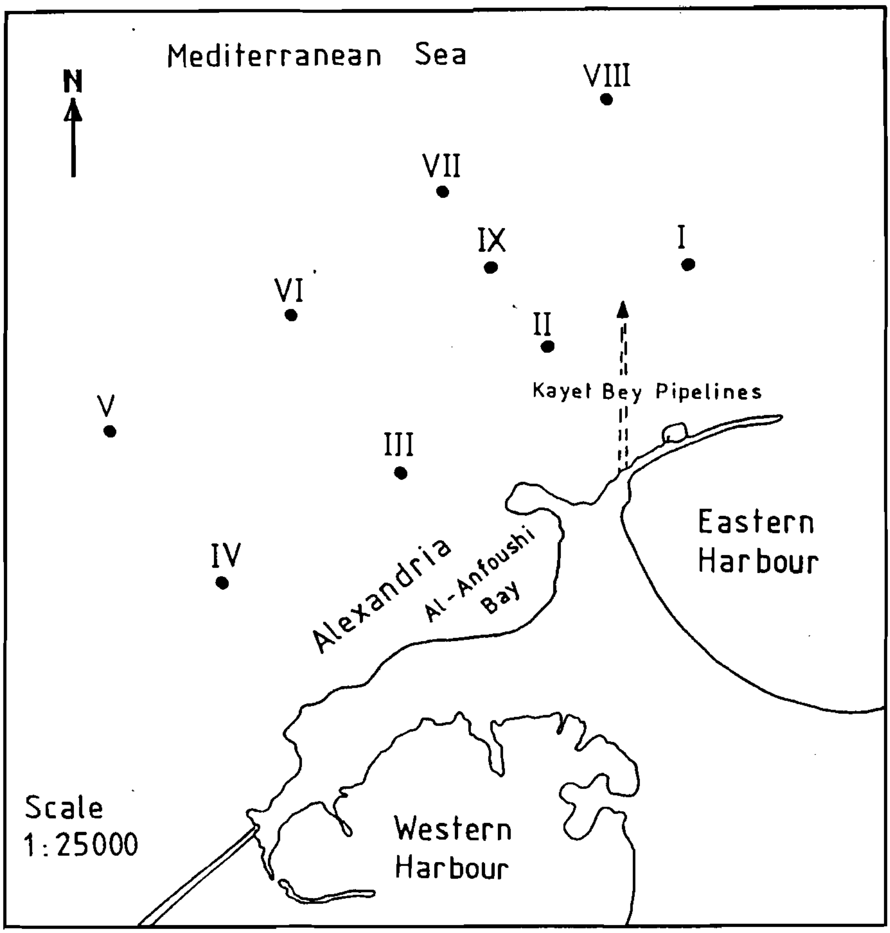


Fig.1 - Kayet Bey, Alexandria-sampling stations.

RESULTS AND DISCUSSION

1- Phytoplankton standing crop:

i- Community composition and spatial distribution:

The phytoplankton community of Kayet Bey region included 127 taxa belonging to Bacillariophyceae (71 spp.), Dinophyceae (24 spp.), Chlorophyceae (21 spp.), Cyanobacteria (7 spp.), Euglenophyceae (3 spp.) and one Silicoflagellate. However, few of them were responsible for the bulk of the population particularly Rhizosolenia spp. (47.38% by number to the total phytoplankton standing crop at surface water), Chaetoceros spp. (21.6%), Skeletonema costatum (9.33%), Prorocentrum spp. (6.19%) and Anabaena sp. (4.61%).

Bacillariophyceae dominated the other phytoplankton components and formed about 84.9% and 90.6% by number to the total phytoplankton at both surface water and near bottom layer respectively. Dinophyceae contributed 8.5% and 4.4%, Cyanobacteria constituted 4.7 and 0.99%. Chlorophyceae, Euglenophyceae and silicoflagellates were also frequently recorded.

The annual average of the phytoplankton standing crop was much higher at the surface water (236.4×10^3 unit.l^{-1}) than that of the near bottom layer ($42 \times {}^3 10$ units.l^{-1}). These values are much higher than those previously recorded at El-Anfoushi area and the number of the phytoplankton species (127) appeared to be lower than in previous records (173 spp., Dorgham et al., 1987). This may be due to the increased amount of wastewater discharged, beside the disappearance of most stenohaline species (marine or fresh). This can be confirmed by the presence of several euryhaline freshwater forms (47 spp.), which exceed than previous records (13 spp., Dorgham et al., 1987).

About 81% of the recorded diatoms were confined to 4 genera (Rhizosolenia, Chaetoceros, Skeletonema and Cyclotella), while 6.7% of dinoflagellates belong to two genera (Prorocentrum and Peridinium). The freshwater species were dominated by blue green alga, Anabaena sp. and the chlorophytes, Pediastrum spp. and Scenedesmus spp.

The surface layer at Kayet Bey sustained a heavy growth of phytoplankton (Fig. 2) produced due to the continuous discharge of allochthonous nutrients and organic load from Kayet Bey sewer. This is responsible for the high standing crop at most stations, except at St. II, which is subjected to the direct impact of sewage effluent (Fig. 1). The near bottom layer harboured much lower density of phytoplankton standing crop as shown in Fig. (2).

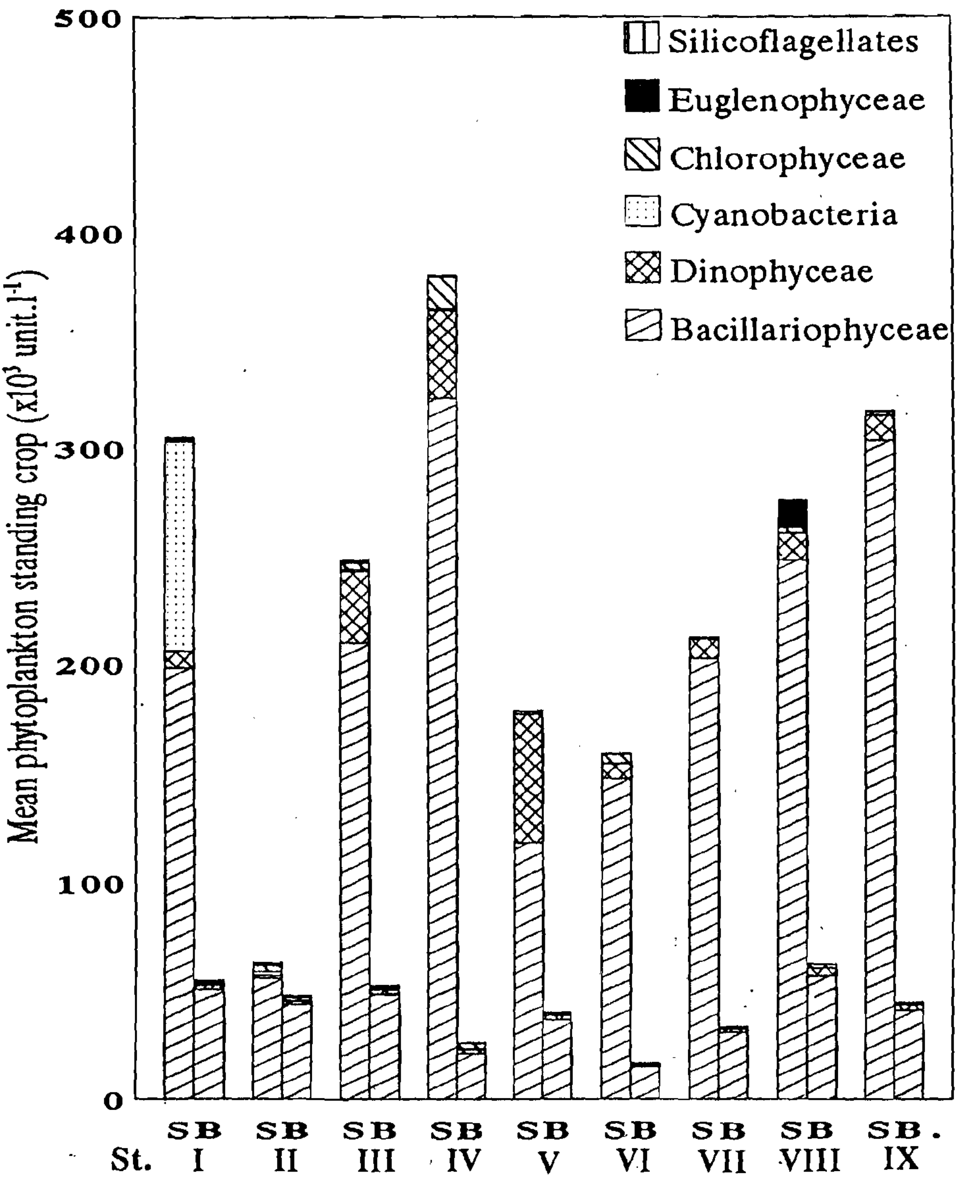


Figure 2 : Distribution of phytoplankton standing crop and main components (S = surface water, B = near bottom layer) at Kayet Bey region during September 1987 - August 1988.

ii- Seasonal variations:

The phytoplankton standing crop showed a high pronounced peak in September and a small one during summer (Fig. 3). Its magnitude and variability were governed by the stability of the two layered stratification. It was interrupted during the instability phase which prevailed in winter and early spring. September peak was mainly due to Rhizosolenia spp. which contributed about 75% by number of the total phytoplankton, as well as Prorocentrum spp. and Peridinium spp. which constituted together 18.5%. During September, the area was subjected to marked dilution which reduced the surface salinity to values fluctuating between 22.5‰ and 30‰ (Zaghloul & Nessim, 1990). On the other hand, the bottom water was less affected by sewage effluents and the water salinity remained over 34‰. Such month was characterized by higher water stability, as well as by high concentration of ammonia, oxidizable organic matter, phosphate, silicate, nitrate, and lower water transparency (Nessim & Zaghloul, 1991).

The community composition showed significant variations from one month to the other. Thus, the month of October was characterized by the dominance of Skeletonema costatum (73%) and to a much less extent of Anabaena sp., while in November, Anabaena was more dominant (65.0%) followed by Cyclotella meneghiniana (19.0%) and Sk. costatum (13.7%) as shown in Fig. (3).

The summer peak was dominated by Chaetoceros socialis (98%) in June and Rhizosolenia spp. (95.7%) during July. While in August these two mentioned genera formed together the main bulk and constituted respectively 44% and 37.6% of the total phytoplankton standing crop as shown in Fig. (3). The month of June was characterized by high values of water salinity, ammonia and water temperature. Chaetoceros socialis was previously recorded as the most dominant diatom in front of Damietta Branch during the flood season (Halim, 1960) and at the inshore stations of Abu Qir Bey (Samaan & Mikhail, 1990).

The dominant species of phytoplankton in the investigated area showed more or less significant spatial and seasonal variations. This can be distinguished into the following categories:

a) Species decreased in abundance in a seaward direction (Sts. V-VIII) in all seasons, these comprised Skeletonema costatum, Rhizosolenia delicatula, Rh. fragilissima, Prorocentrum micans, P. cordatum, P. triestinum, Chaetoceros affinis, Ch. socialis, Anabaena sp., Pediastrum spp. and Euglena spp. This trend reflects the tolerance of these species to domestic wastes.

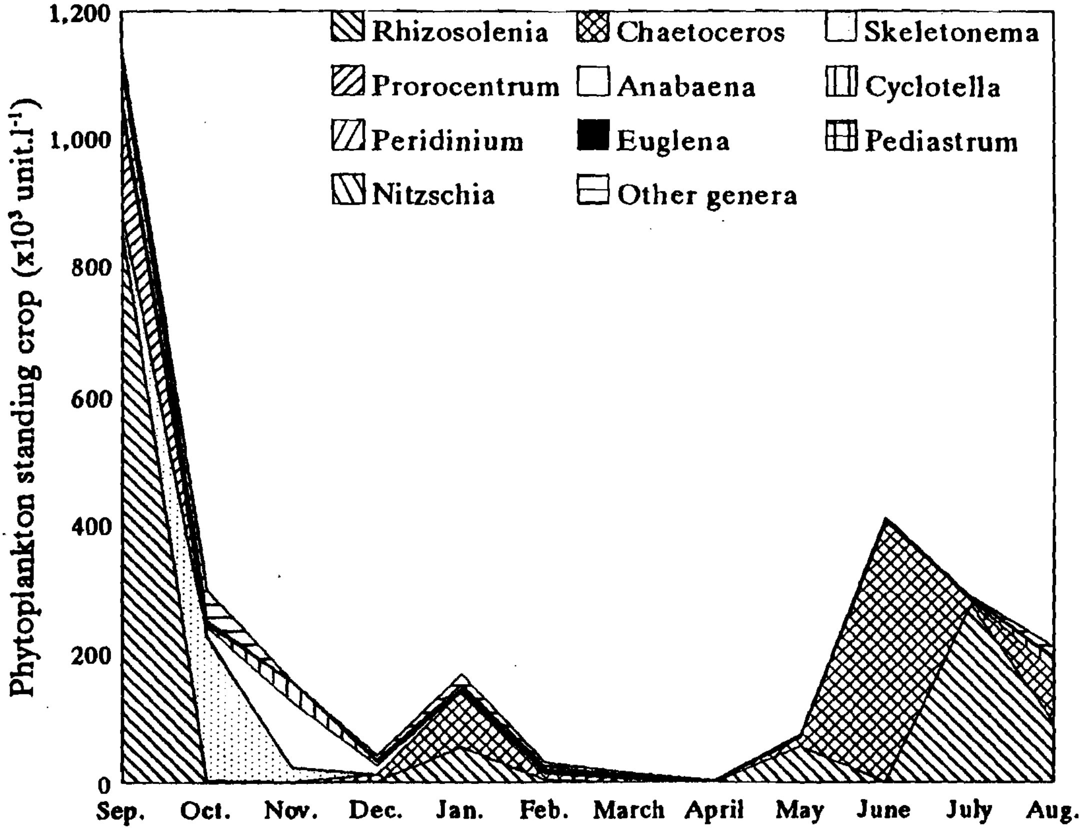


Figure 3 : Seasonal variations of phytoplankton standing crop (unit.l^{-1}) and main components in the surface water at Kayet Bey region during September 1987 - August 1988.

b) Species increased in abundance seaward and also with increasing depth, like Asterionella japonica, Lithodesmium undulatum, Ceratium spp., Thalassiosira decipiens and Thalassionema nitzschioides. The abundance of such species away from polluted areas may indicate their susceptibility to the municipal wastes.

Regarding the dominant species, Sk. costatum was mainly recorded during autumn with maximum persistence in October. This is met with a high content of oxidizable organic matter (10.24 mg $O_2.l^{-1}$). Its occurrence as indicator of eutrophication was admitted by Mihnea (1985) and Revelante and Gilmartin (1985). Many species of Euglenophyta were developed at a BOD range of 2-7 mg $O_2.l^{-1}$ (Mihnea, 1978). In the study area, euglenophytes dominated at high concentration of ammonia and organic matter, low values of water salinity, phosphate, silicate and Secchi-disc readings (Nessim & Zaghloul, 1991), as well as high water stability.

The dominance of a certain species in polluted waters in one or more seasons may be considered as an indicator species. Mihnea (1985) supposed that species expanding their biological cycle and representing constantly over 10% of the total community should be reckoned among the indicators. In this context species such as Sk. costatum, Rh. delicatula, Rh. fragilissima, Ch. affinis, Ch. socialis, Prorocentrum cordatum, P. triestinum and Euglena may be considered as eutrophication indicators.

iii) Phytoplankton and environmental conditions:

The correlation coefficient of phytoplankton standing crop and some physico-chemical parameters are given in Table (1). Thus, when the surface water salinity decreased as a direct effect of inland water discharge, resulting in an increase of phosphate which is required for the growth of Dinophyceae (Zaghloul, 1994 a&b), silicate (for the growth of diatoms) and oxidizable organic matter, the phytoplankton standing crop reached its optimum conditions. This was associated with higher water stability. All of these parameters reduced water transparency.

Stepwise regression models showed the dependence of phytoplankton standing crop on the most correlative environmental conditions as follows

Standing crop = 229826.8 + 93249.2 organic matter - 49662.7 nitrate
-15944.14 transparency + 1278.8 stability (Multiple R = 0.73).

This equation shows the importance of the positive effect of both water column stability and organic matter on the growth of phytoplankton, as previously indicated by Zaghloul, 1994a.

Table (1): Correlation coefficients between phytoplankton standing crop (S), diversity (H) and some physico-chemical variables.

	S	H	Transp.	Stab.	D.O.	Alk.	O.M.	BOD	S‰	NO_3	NO_2	PO_4	SiO_2
Phytoplankton		-0.51	-0.32	0.63	-0.16	0.23	0.50	0.33	-0.53	0.34	-0.24	0.41	0.60
Diversity	-0.51		0.17	-0.19	0.34	0.44					0.24	-0.22	

iv) Phytoplankton-zooplankton relationship:

The phyto-zooplankton interactions have been studied by many authors who found a tendency for zooplankton to be less abundant in areas of high algal concentration. Zaghloul and Nessim (1990) recorded the same inverse relationship between zooplankton density and chlorophyll a concentration in the area of investigation. Such inverse relationship between phytoplankton standing crop and zooplankton population have been noted in many other areas: north-western Mediterranean séa (Nival et al., 1975) and in north-eastern Mediterranean (Cattani & Corni, 1992). This inverse relationship is partly explained by the hypothesis of animal exclusion in phytoplankton patches (Hardy and Gunther, 1935) and/or by zooplankton grazing. Another possible cause may be attributed to the different reproduction rates of vegetal and animal populations. Phytoplankton grows faster (days or weeks even in the best condition).

The importance of predation in controlling phytoplankton populations has been stressed by several investigators (Prakash et al., 1971 and Beers and Stewart, 1967). It has also been observed that copepods (mostly Pseudocalanus, Acartia and larval stages) actively graze on Skeletonema so that its density was markedly reduced, while the larger Rhizosolenia increased in numbers (in Raymont, 1983). This may be the case in Kayet Bey region particularly in autumn as shown in Fig. 4.

Corkett and McLaren's review (in Raymont, 1983) indicates that long-spined Ceratium and spiny chain forming diatoms such as Chaetoceros may be less readily eaten. This appeared clearly in June (Fig. 4) when a small peak of zooplankton (mainly ciliates) was accompanied with a similar peak of phytoplankton (mainly Ch. socialis) which does not seem suitable as food items for ciliates.

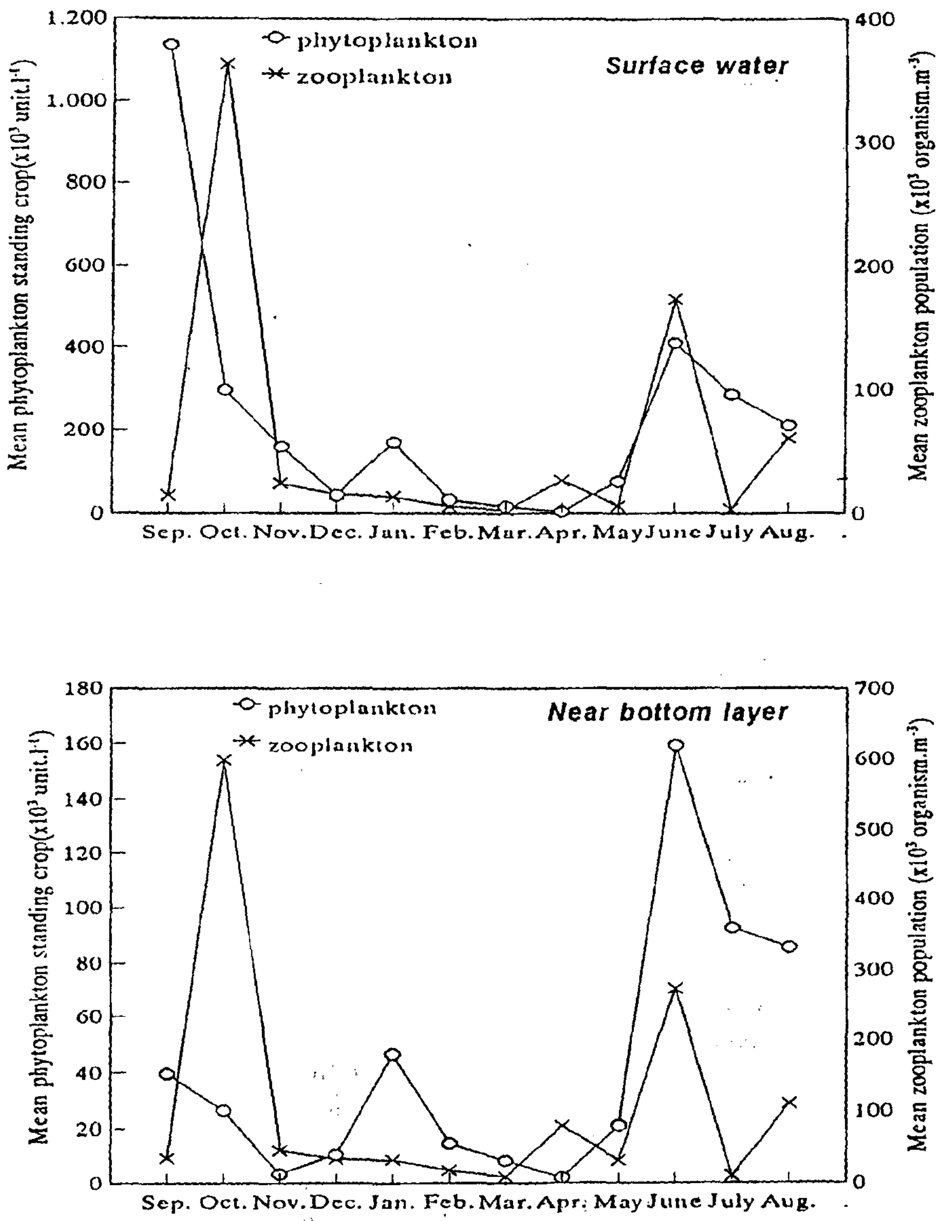


Figure 4 : Mean of phytoplankton standing crop and zooplankton population in the surface water and near bottom layer at Kayet Bey region during September 1987 - August 1988.

2- Diversity :

i) Annual diversity cycle:

Generally, phytoplankton diversity increases with depth at most stations all the year round. It ranged between 0.012 and 2.79 nats at the surface water and from 0.07 to 2.95 nats for near bottom layer. This indicates that the effect of pollution is more pronounced at the surface water.

Diversity index showed a reverse relationship with both phytoplankton standing crop (r=-0.51 and r=-0.71 at the surface water and near bottom layer respectively) and the degree of dominance (d) (r = -0.96, at surface water and r = -0.95 for near bottom layer). This appeared clearly during June and July, when minimum values of diversity was recorded (an average of 0.32 & 0.61 nats at the two months respectively) coinciding with high standing crop of phytoplankton (Fig. 3) due to the dominance of Ch. socialis (98%) in June and by Rhizosolenia fragilissima (84%) in July. On the other hand, the higher values of diversity were recorded during December (2.0 nats) and February (2.3 nats). This was accompanied by lower phytoplankton standing crop and many species shared in community composition (Fig. 3). Station I, being more stagnant, was characterized by lower diversity values during most of the year. This is attributed to the higher phytoplankton counts (Fig. 2) and few dominant species (mostly one or two) as well as higher water stability.

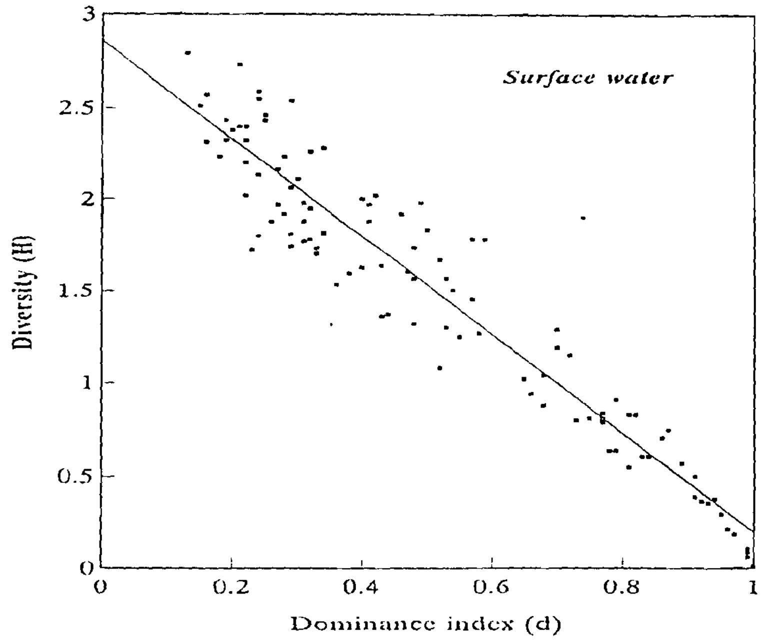
ii) Diversity-frequency relationship:

Figure (5) represents the reverse relationship between diversity (H) and degree of dominance (d) at both surface and near bottom layer. This relationship could be formulated in a form of equation as follows:

Diversity (surface water) = 2.87 - 2.68 d (r = -0.96)
Diversity (near bottom layer) = 2.96 - 2.74 d (r = -0.95)

iii) Diversity and habitat structure relationship:

The number of species occurring in a particular phytoplankton community depends on the interaction between several ecological factors (Margalef, 1978 and Hallegraeff & Reid, 1986 and Abdalla et al., 1992). The availability of resources is one of the most important ecological factors affecting species diversity. This effect was emphasized by numerous workers who have reported correlations between species diversity and some aspects of habitat structure (Borowitzkȧ, 1972; Margalef, 1978 and Cosser, 1988). According to the data of Nessim & Zaghloul (1991), Kayet



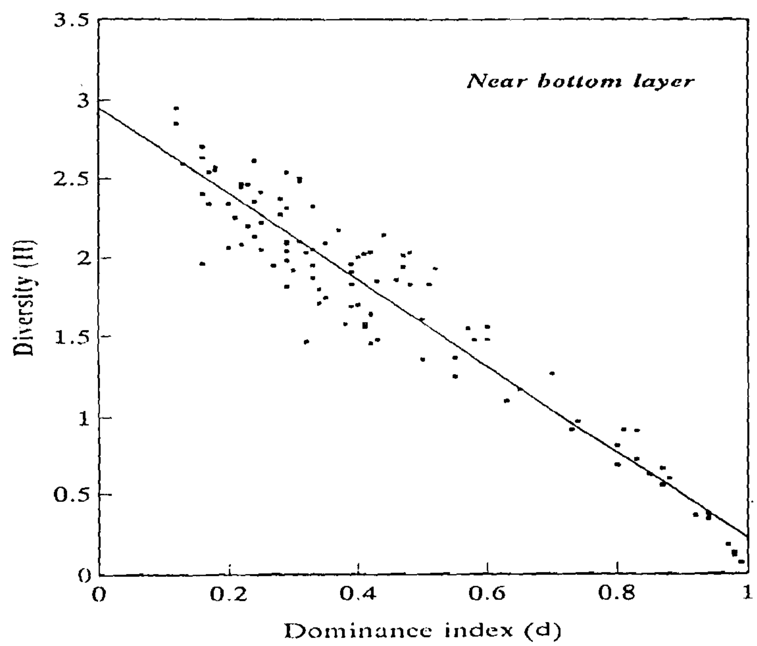


Figure 5 : Regression of diversity (H) on dominance index (d) in the surface water and near bottom layer at Kayet Bey reion during September 1987 - August 1988.

Bey region is characterized by high nutrient concentration with an average of 0.53 ug.at.l^{-1} of phosphate, 1.32 ug at.l^{-1} nitrate, 6.72 ml O_2.l^{-1} dissolved oxygen. Silicate ranged from 0.0-95.74 ug.at.l^{-1}. Such high nutrients are attributed to the huge amounts of wastewater, that creates eutrophication at times, particularly during autumn and summer (Fig. 3). The correlation coefficient of diversity versus some physicochemical parameters are given in Table (1).

A stepwise regression model showing the dependence of diversity on the most correlative environmental factors was developed; equation being .

Diversity = 2.77 + 0.18 dissolved oxygen - 0.72 total alkalinity - 0.04 phosphate
(Multiple R = 0.55).

From this model, it is clear that diversity mainly reflects the eutrophication phenomena in the area. Logically, eutrophication reflects the excess of phosphate introduced by the huge amounts of fresh water, characterized by high alkalinity values, which in turn stimulates photosynthesis producing more oxygen.

CONCLUSION

The investigated area receives huge quantities of untreated wastewater. Such water introduced large concentrations of nutrients causing eutrophication of water (cultural eutrophication). It also lowered the diversity values of the phytoplankton community, and showed certain preference on the dominance of some species. The seasonal cycle of phytoplankton was also correlated with variations of the prevailing environmental factors. Several phytoplankton species were admitted as being indicators of water pollution.

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