NUTRIENTS AND PHYTOPLANKTON DISTRIBUTIONS DURING SPRING IN THE AEGEAN SEA

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GOLFE DE KAVALA
GOLFE D'ALEXANDROUPOLIS
SELS NUTRITIFS
PHYTOPLANCTON

RÉSUMÉ — Les paramètres physicochimiques et la distribution du phytoplancton pendant la poussée printanière du phytoplancton sont étudiés dans le golfe de Kavala et d'Alexandroupolis où se jettent des rivières. La salinité, la température et les sels nutritifs sont influencés par le déversement irrégulier des rivières et une corrélation significative avec la croissance du phytoplancton est mise en évidence. La structure hydrographique près de la rivière Evros est hétérogène. Les données numériques de l'abondance du phytoplancton à l'intérieur de la zone d'influence de la rivière Evros sont plus élevées que dans la Méditerranée Orientale. La structure de la communauté du phytoplancton est dominée par les Diatomées *Rhizosolenia hebetata* dans le Golfe de Kavala, tandis qu'une poussée très intense de *Skeletonema costatum* est observée dans le golfe d'Alexandroupolis. Les relations entre les paramètres du phytoplancton, en particulier la dominance et la diversité sont également discutées.

GULF OF ALEXANDROUPOLIS
GULF OF KAVALA
NUTRIENTS
PHYTOPLANKTON

ABSTRACT — Physico-chemical parameters and phytoplankton distributions were studied during the spring phytoplankton bloom in Kavala and Alexandroupolis Gulfs, both influenced by river waters. Salinity, temperature and nutrients were affected by uneven river discharges and some significant correlations with phytoplankton growth were found. The hydrographical structure near the Evros River is heterogenous. The numerical data of phytoplankton abundance inside the Evros River plume were higher than those of the Eastern Mediterranean. Phytoplankton community structure was dominated by the diatom *Rhizosolenia hebetata* in Kavala Gulf, whereas, a very intense bloom of *Skeletonema costatum* was observed in Alexandroupolis Gulf. The relationships between phytoplankton parameters especially dominance and diversity are also discussed.

INTRODUCTION

It is most often the availability of nutrients such as nitrogen and phosphorus that controls the rate of organic production by marine phytoplankton (Thomas, 1966; Ignatiades, 1969; Ryther and Dunstan, 1971). In the eastern Mediterranean Sea, the low influx of nutrients from land drainage and the characteristic circulation pattern normally result in a small phytoplankton crop and low rate of primary production (Becacos-Kontos, 1968). However continued increases in the influx of phytoplankton nutrients into coastal environments especially in enclosed seas such as the Mediterranean, can have harmful effects on marine communities. An increase in nutrients is often accompanied by an increase in phytoplankton standing-crop and a decrease in stability and taxonomic diversity, since species with the higher intrinsec rates of natural increases become dominant (Margalef, 1967).

There are few publications on phytoplankton and environmental factors in coastal and semi-closed areas in various parts of the Aegean (Blasco, 1974; Ignatiades, 1974; Friligos and Koussouris, 1984). As there is no information about phytoplankton, hydrography and nutrients in the Gulf of Alexandroupolis and Kavala, in the north Aegean Sea, this study was undertaken in March 1982. The aim of this work is to study the nutrients and phytoplankton distributions in the north Aegean Sea.

MATERIAL AND METHODS

Alexandroupolis and Kavala Gulfs are located in the northern part of the Aegean Sea. The bulk of the run off comes from the river Evros in the Alexandroupolis Gulf, while only a minor amount of the Nestos River freshwater reaches the gulf of Kavala from the east (Fig. 1), both draining agricultural areas. The annual mean flow rate are of the order of 103 $m^3.s^{-1}$ and 58 $m^3.s^{-1}$ for Evros and Nestos respectively (Therianos, 1974). In addition Kavala Gulf is also affected by the phosphate fertilizer factory at Nea Karvali.

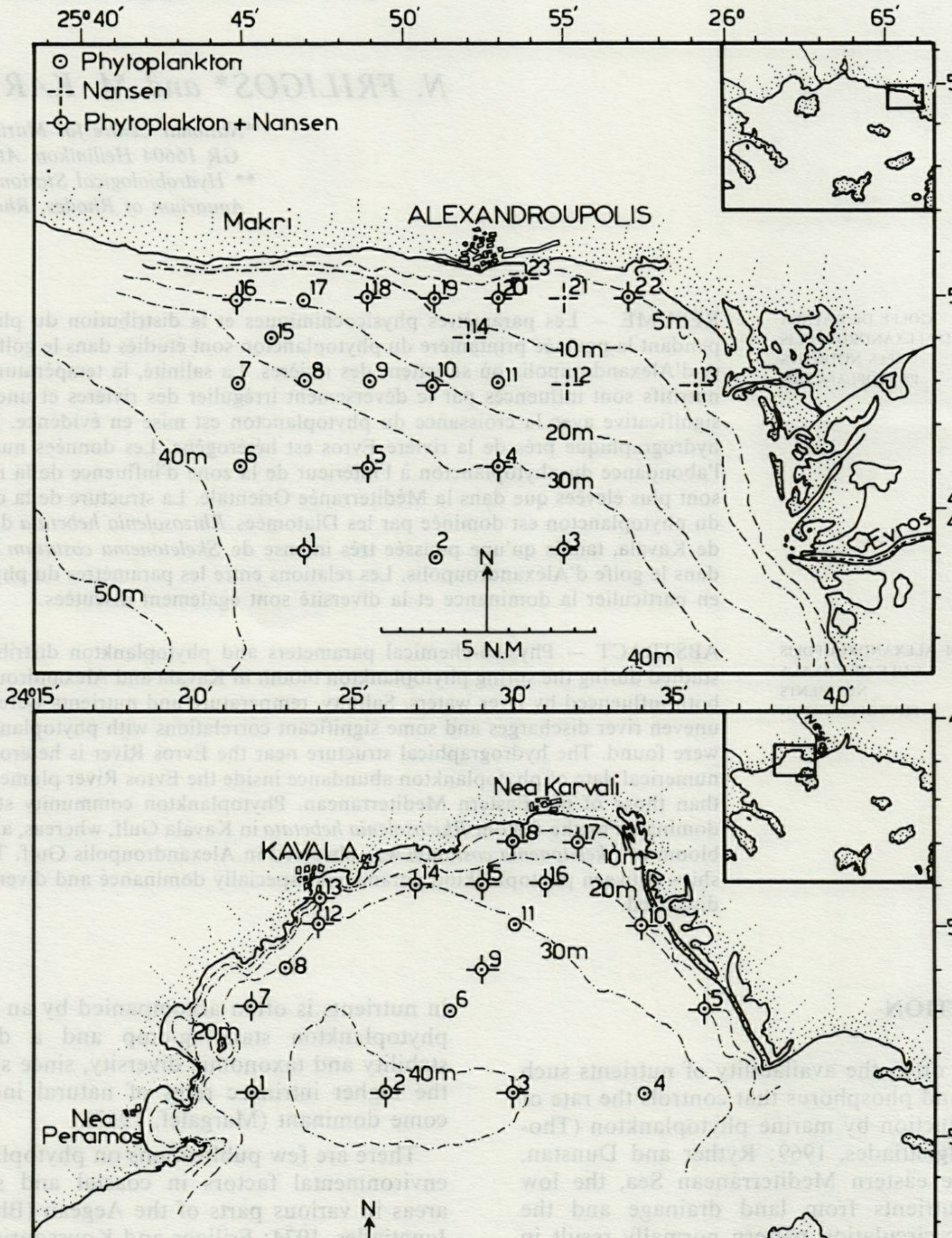

Fig. 1. Location of the hydrographic and phytoplankton stations in the Alexandroupolis and the Kavala Gulfs.

Twenty three sampling stations were located in Alexandroupolis and eighteen in Kavala Gulf. Oceanographic casts were carried out by the Hydrographic Boat « Naftilos » in March 1982. Water samples were collected from 1,10,20,30 and 40 m by using Nansen water bottles. Temperatures at individual depths were determined by reversing thermometers attached to Nansen bottles, considered accurate to ± 0.02°C. Water samples were drawn from the Nansen bottles into glass bottles for salinity analyses, there were made after sea cruise on a digital inductively coupled salinometer against standard sea water, estimated accurate to ± 0.01 ‰. Dissolved oxygen analysis was made aboard ship and samples for nutrients were taken and frozen for later analysis with a Technicon Autoanalyser. Chlorophyll *a* filtered through Whatman GF/C filters was measured by fluorescence. Methods used for dissolved oxygen, nutrients and chlorophyll *a* were those described by Friligos and Koussouris (1984).

For the corrections of errors the method used was that of Satsmadjis (1978), who reported that the average coefficient of variation of the four standards covering the whole range of concentrations were : ammonia 7 %, phosphate 5 %, silicate 7 %, nitrite 3 % and nitrate 7 %.

Only surface samples of phytoplankton were collected with Nansen bottles and fixed with lugol and examined by an inverted microscope (Lund *et al.*, 1958). The structure of the phytoplankton community was expressed through dominance and diversity indices. Dominance was calculated according to the formula :

$$\delta = \frac{100\ (n_1 + n_2)}{N}$$

where δ is the dominance index equal to the percentage of the total standing crop contributed by the two most important species (McNaughton, 1967). Species diversity was calculated according to Margalef's (1967) formula derived from the information theory :

$$D = \frac{1}{N} \log_2 \frac{N\,!}{N_a\,!N_b\,!..N_s\,!}$$

where N_a, N_b,... N_s are numbers of individuals in the species and N is the total number of individuals in the collection.

RESULTS

The variation of average salinity and temperature as a function of depth in both gulfs are depicted in Figure 2. Average represents values for all stations in every gulf at the same depth. The average temperature was very narrow (10.2-11.8°C). The average salinity spread was 35.0-37.5 ‰ with the lowest values on the surface and the highest at the bottom, a typical pattern for river estuaries. The O_t figures establish that the water column was stratified, with

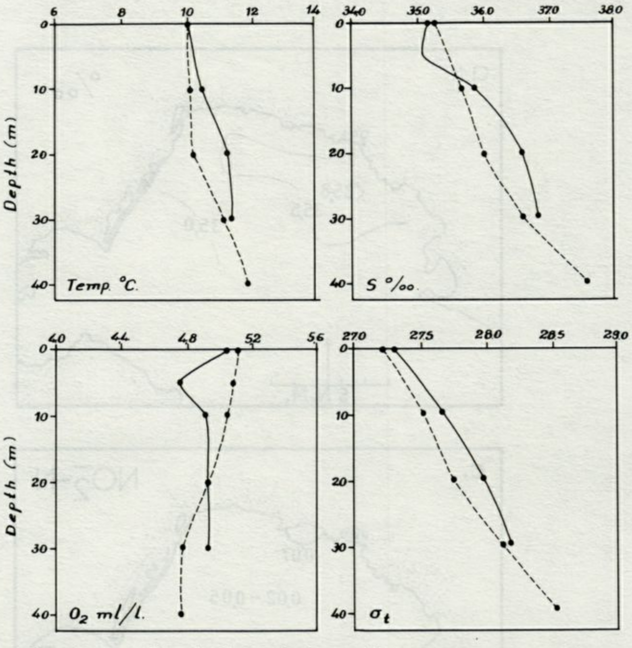

Fig. 2. — Vertical variation of average temperature, salinity, dissolved oxygen and density in the Alexandroupolis (—) and the Kavala (.....) Gulfs.

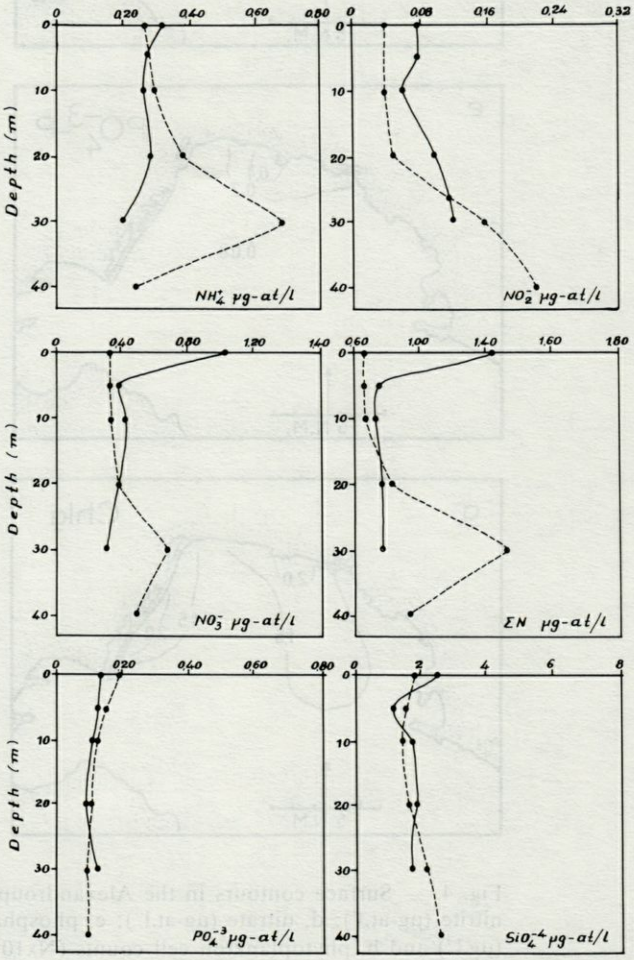

Fig. 3. — Vertical variation of average nutrients (N, P, Si) in the Alexandroupolis (—) and the Kavala Gulfs (.....).

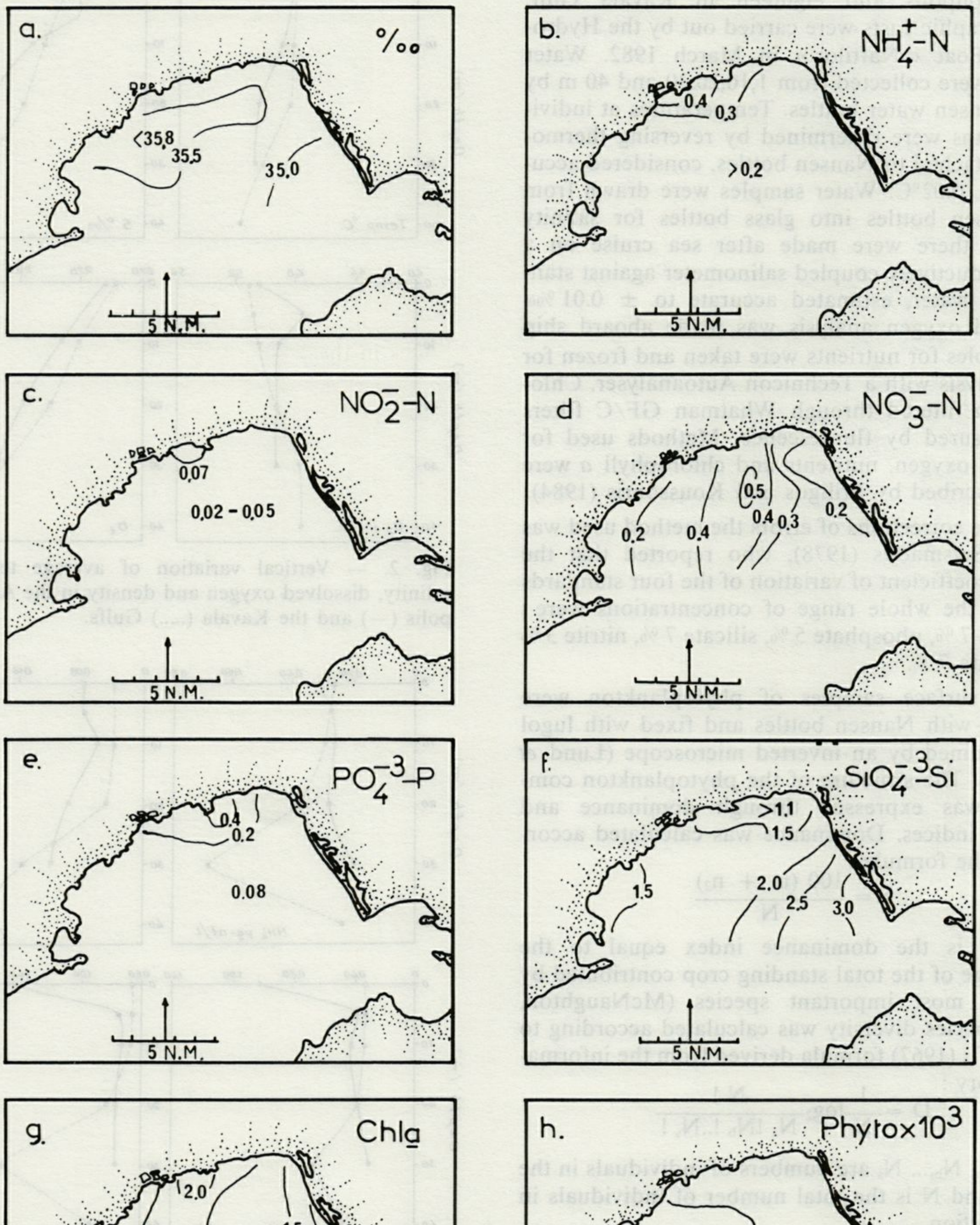

Fig. 4. — Surface contours in the Alexandroupolis Gulf. a, sanility (‰); b, ammonia (μg-at.l^{-1}); c, nitrite (μg-at.l^{-1}); d, nitrate (μg-at.l^{-1}); e, phosphate (μg-at.l^{-1}); f, silicate (μg-at.l^{-1}); g, chlorophylle *a* (μg.l^{-1}) and h, phytoplankton cell counts (N×10^3 cell.l^{-1}).

the pycnocline related to salinity (Fig. 2). The dissolved oxygen content progressively decreased with depth and ranged from 4.7 to 5.1 ml.l^{-1} (Fig. 2).

The average nutrient vertical variation is depicted in Figure 3. Silicate and nitrite exhibited a similar vertical variation. Except phosphate, other nutrients increase with depth. Silicate rose with ammonium and nitrate, but fell with increased salinity.

In particular, surface samples showed the greatest variation and the contour mapping of surface salinity nutrients and phytoplankton cell counts reveals pronounced spatial variability. Salinity values are given in Figures 4 and 5. An area can be defined in Alexandroupolis Gulf outside the Evros River plume with salinity values greater than 35.0 ‰, whereas Kavala Gulf appeared rather homogenous with the salinity values ranging between 34.7-35.8 ‰. Temperature did not vary greatly, (temperature range 9.7-10.7°C for both gulfs) and dissolved oxygen concentrations in Alexandroupolis Gulf are shown in Figure 4. Ammonium values varied between 0.10 and 1.50 μg-at.l^{-1} with higher concentrations inside the Evros River plume. The nitrite values ranged from 0.03 to 0.20 μg-at.l^{-1} and those of nitrate from 0.20 to 3.00 μg-at.l^{-1} with enhanced values inside the Evros River plume. The phosphate and silicate distributions was similar to that of other nutrients. The phosphate concentrations varied from 0.08 to 0.20 μg-at.l.$^{-1}$ and those of silicate from 0.40 to 11.00 μg-at.l^{-1}. The nutrient distribution pattern in Kavala Gulf (Fig. 5) seemed to be different. The values of different forms of inorganic nitrogen presented a similar distribution and in the port of Kavala were higher. Ammonium, nitrite and nitrate levels had the following ranges respectively, 0.20-0.50 μg-at.l^{-1}, 0.03-0.07 μg-at.l^{-1} and 0.20-0.80 μg-at.l^{-1}. The phosphate content varied from 0.10 to 0.40 μg-at.l^{-1}. The greatest values were observed near the fertilizer factory at Nea Karvali (st. 18). The silicate values ranged from 1.20 to 3.70 μg-at.l^{-1} with enhanced values in the vicinity of the Nestos River.

In the Alexandroupolis Gulf surface abundance of phytoplankton was maximum inside the Evros River plume (2.0-10.5 x 10^6 cell.l^{-1}) and along the Northern Alexandroupolis coast which is the shallowest area of the gulf (Fig. 4). Offshore stations seemed to be rather oligotrophic (cell number about 10^4 cell.l^{-1}). In the Kavala Gulf (Fig. 5) values less than 2 x 10^5 cell.l^{-1} were found in the middle part of the gulf and the lowest values less than 10^5 cell.l^{-1} occurred in the western selection of the gulf. At the eastern part stations, abundance greater than 2.0 x

Table I. - Range, mean, standard deviation and coefficient of variation of surface hydrographic parameters in Alexandroupolis and Kavala Gulfs.

Areas	Temperature °C	Salinity %	O_2 ml/1	NH_4-N μg-at/1	NO_2-N μg-at/1	NO_3-N μg-at/1
Inside Evros River plume	10.09 - 10.21 x = 10.15 ± 0.08 (0.8 %)	34.23 - 34.99 x = 34.65 ± 0.31 (0.9 %)	4.97 - 5.22 x = 5.08 ± 0.08 (1.8 %)	4.97 - 5.22 x = 0.60 ± 0.51 (86.0 %)	0.07 - 0.23 x = 0.12 ± 0.07 (57.1 %)	0.38 - 2.92 x = 2.04 ± 1.39 (69.2 %)
Outside Evros River plume	9.75 - 10.50 x = 10.17 ± 0.25 (2.5 %)	34.44 - 35.97 x = 35.51 ± 0.47 1.3 %)	4.92 - 5.22 x = 5.02 ± 0.08 (1.6 %)	0.14 - 0.27 x = 0.20 ± 0.05 (24.3 %)	0.03 - 0.18 x = 0.06 ± 0.05 (79.1 %)	0.18 - 2.76 x = 0.54 ± 0.78 (144.5 %)
Kavala Gulf	9.95 - 10.68 x = 10.23 ± 0.25 (2.5 %)	34.74 - 35.63 x = 35.31 ± 0.21 (0.6 %)	4.97 - 5.24 x = 5.09 ± 0.09 (1.8 %)	0.20 - 0.48 x = 0.28 ± 0.09 (32.3 %)	0.03 - 0.07 x = 0.04 ± 0.01 (26.1 %)	0.20 - 0.77 x = 0.33 ± 0.16 (47.3 %)

Areas	Ninorg. μg-at/1	PO_4-P μg-at/1	Total P μg-at/1	Ni:P atoms	SiO_4-Si μg-at/1	Si:P atoms
Inside Evros River Plume	0.79 - 5.21 x = 2.73 ± 1.84 (67.4 %)	0.12 - 0.24 x = 0.14 ± 0.05 (37.3 %)	0.23 - 0.75 x = 0.41 ± 0.23 (57.8 %)	6.6 - 29.4 x = 18.4 ± 10.2 (56 %)	0.87 - 11.87 x = 4.57 ± 4.27 (93.4 %)	7.3 - 49.5 x = 28.2 ± 15.8 (56 %)
Outside Evros	0.41 - 3.12 x = 0.80 ± 0.82 (103.4 %)	0.08 - 0.12 x = 0.10 ± 0.02 (19,5 %)	0.13 - 0.44 x = 0.27 ± 0.009 (32.1 %)	3.4 ± 26.0 x = 7.7 ± 6.7 (87 %)	0.37 - 4.62 x = 1.35 ± 1.22 (90.8 %)	4.6 - 38.5 x = 13.2 ± 10.2 (78 %)
Kavala Gulf	0.44 - 1.32 x = 0.66 ± 0.24 (36.0 %)	0.08 - 0.57 x = 0.18 ± 0.14 (79.9 %)	0.21 - 1.40 x = 0.45 ± 0.30 (66.8 %)	1.3 - 8.6 x = 4.90 ± 2.2 (46 %)	1.12 - 3.62 x = 1.74 ± 0.65 (37.7 %)	2.8 - 45.3 x = 15.3 ± 11.7 (77 %)

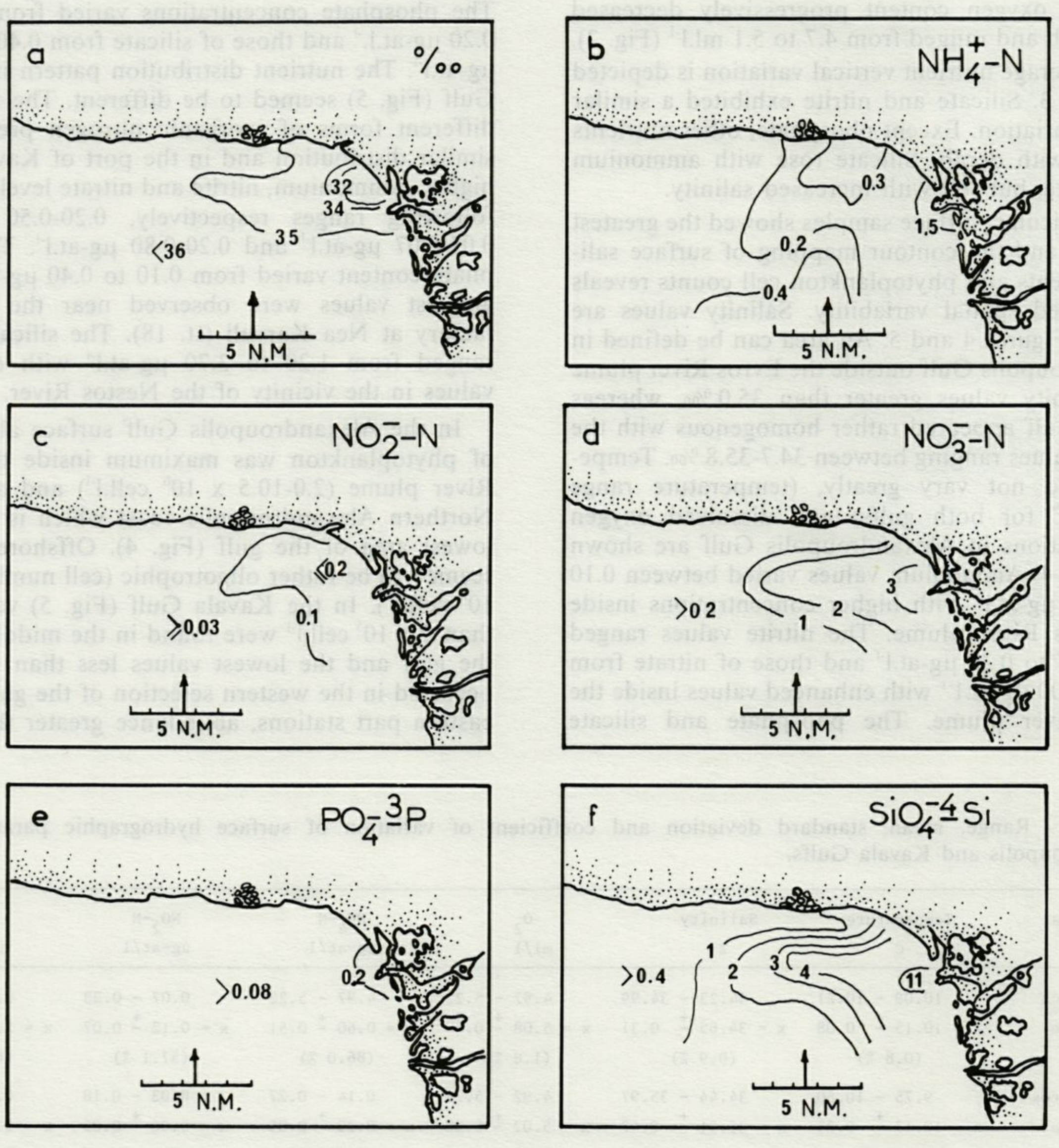

Fig. 5. — Surface contours in the Kavaka Gulf. a, salinity (‰); b, ammonia (μg-at.l^{-1}); c, nitrite (μg-at.l^{-1}); d, nitrate (μg-at.l^{-1}); e, phosphate (μg-at.l^{-1}); f, silicate (μg-at.l^{-1}); g, chlorophyll *a* (μg/l) and h, phytoplankton cell counts (N x 10^3 cell.l^{-1}).

10^5 cell.l^{-1} were observed and the highest concentration was 9.0 x 10^5 cell.l^{-1} at station 14, near the Kavala harbour.

Chlorophyll *a* follows the distribution pattern of the phytoplankton surface abundance (Figs 4 and 5). In the Alexandroupolis Gulf its concentration varied between 0.24 to 9.75 μg.l^{-1} and the Kavala Gulf between 0.32 to 2.04 μg.l^{-1}. The lowest values were observed far from the coast. The maximum values agree with others spring cholophyll *a* concentrations in the estuarine coastal areas in the Aegean Sea as in the Thermaikos Gulf (Friligos, 1977).

The main features in the surface distribution of nitrogen, phosphorus and silicon were very similar in the Alexandroupolis Gulf and varied in the opposite direction as the salinity. This suggests that the origin of the nutrients at least in the Alexandroupolis Gulf, was the run-off. Thus, the average ammonium nitrite, nitrate and silicate concentrations were greatest inside the Evros River plume (Table I). Note that, because of the presence of a fertilizer factory, at Nea Karvali, there was more phosphate and total phosphorus in the Kavala area. As a consequence, the N : P and Si : P ratios were lower outside the Evros River plume and in the Gulf of Kavala (Table I).

Relationships between the physical, chemical and biological parameters are shown in Table II. We observe that salinity was significantly correlated with cell number inside Evros River plume (Table II). Outside Evros River plume (Table II) temperature, ammonium and silicate were significantly correlated with cell number and diversity. Significant relationships were also found in Kavala Gulf between total phosphorus, ammonium, nitrite as well as cell number (Table II). Diversity index showed a decrease with increasing nutrient concentrations (Table II).

Table III presents an evaluation of the differences in abundance of these populations between the areas, in the Evros River plume the phytoplankton mean values (4.2 x 10^6 cell.l^{-1}) were undoubtedly much higher than the corresponding ones in the area outside it (1.2 x 10^6 cell.l^{-1}). Chlorophyll *a* concentrations, showed a similar distribution with phytoplankton abundance in the three areas. The t-tested for paired comparisons, showed that the « between areas » differences in concentrations of phytoplankton populations were significant, when it was compared the inside Evros River plume area with others. Only the differences in concentrations of phytoplankton populations were not significant outside the Evros River plume and Kavala area. The recorded similarity in phytoplankton abundance between the areas outside the Evros River plume and Kavala Gulf raised the question of whether the quantitative homogeneity was accompanied by qualitative homogeneity. Estimates of the species diversity showed substantial variation of these parameters between areas; its mean ranged from 0.14 to 2.29 bits. $indiv.^{-1}$ at the area inside Evros River plume, 0.28 to 3.03 bits. $indiv.^{-1}$ at the area outside Evros River plume and 1.56 to 3.45 bits. $indiv.^{-1}$ at Kavaka Gulf.

Areas	Cell number correlated with	Regression equation	Correlation coefficient
Inside Evros River plume	Salinity	log y = 7.97x - 271.0	0.88 (n = 5)*
Outside Evros River plume	Temperature	log y = -3.46x + 40.36	-0.71 (n = 8)*
	Ammonia	log y = 33.18x - 0.68	0.77 (n = 8)*
	Silicate	log y = -2.42x + 7.69	-0.81 (n = 8)*
Kavala Gulf	Total phosphorus	log y = 1.11x + 4.91	0.65 (n = 12)*
	Ammonia	log y = 1.61x + 4.88	0.60 (n = 13)*
	Nitrite	log y = 13.2x + 4.75	0.64 (n = 13)*

Areas	Diversity correlated with	Regression equation	Correlation coefficient
Outside Evros River plume	Temperature	D = 2.74x - 26.28	0.75 (n = 8)*
	Ammonia	D = -22.95x + 5.70	-0.72 (n = 8)*
	Silicate	D = 2.00x - 0.43	0.89 (n = 8)**
Kavala Gulf	Phosphate	D = - 2.32x + 3.14	-0.63 (n = 13)*
	Total phosphorus	D = - 2.11x + 3.50	-0.57 (n = 12)*

* Significant at the 5 % level
** Significant at the 1 % level

Table II. - Simple correlation between biological and physicochemical parameters.

Table III. - Range, mean, standard deviation and coefficient of variation of surface Chlorophyll *a* and surface phytoplankton in Alexandroupolis and Kavala Gulfs.

Areas	Chl-a ug/l	Abundance cell/l	Diversity bits/indiv.	t-tested for means abundance comparison	
1. Inside Evros River plume	$0.36 - 9.75$	$7.2\cdot10^{4} - 10.4\cdot10^{6}$	$0.14 - 2.29$	$t_{1-2} = 2.63$	$t = 2.06^{a}$
	$x = 3.80 \pm 5.17$	$x = 4.2\cdot10^{6} \pm 3{,}6\cdot10^{6}$	$x = 0.86 \pm 1.06$	$t_{1-3} = 4.73$	$t = 2.06^{a}$
	(136,2 %)	(85,4 %)	(123.0 %)		
2. Outside Evros River plume	$0.24 - 3.58$	$0.48\cdot10^{4} - 6.8\cdot10^{6}$	$0.28 - 3.03$		
	$x = 1.34 \pm 1.46$	$x = 1.\ 2\cdot10^{6} \pm 2.3\cdot10^{6}$	$x = 1.91 \pm 0.87$	$t_{2-3} = 1.73$	$t = 2.06^{b}$
	(108,3 %)	(193,1 %)	(45,5 %)		
3. Kavala Gulf	$0.32 - 2.04$	$8.80\cdot10^{4} - 0.97\cdot10^{6}$	$1.56 - 3.45$		
	$x = 1.44 \pm 0.43$	$x = 0.25\cdot10^{6} \pm 0.19\cdot10^{6}$	$x = 2.79 \pm 0.52$		
	(29,6 %)	(75,8 %)	(18,6 %)		

a significant at 0.05 level
b non-significant at 0.05 level

The phytoplankton taxa of quantitative importance are given in Table IV. Diatom concentrations are higher than flagellates in both gulfs by an order of magnitude. Diatom populations in Alexandroupolis Gulf approached 10^7 cell.l^{-1}. Dinoflagellates varied between 10^3 and 10^4 cell.l^{-1} in both areas whereas, coccolithophores and silicoflagellates appeared at very low levels.

The community structure is summarised in Tables 5 and 6 giving the dominant species at each station as well as the dominance and diversity indices. The most important species in Alexandroupolis Gulf varied from station to station; once the diatom *Skeletonema costatum* dominated, the dominance index was usually higher than 95 indicating a bloom of the species. The diatoms *Nitzchia closterium* and *Rhizosolenia hebetata* and *Skeletonema costatum* as well as the flagellate *Prorocentrum adriaticum* also showed a rather significant contribution to the phytoplankton community of the area. Great variation was observed in the diversity index throughout Alexandroupolis Gulf, with exceptionnally low values along the coastal stations where the bloom *Skeletonema costatum* was apparent. On the contrary, the diatom *Rhizosolenia hebetata* was the most dominant species throughout Kavala Gulf; *Nitzschia closterium* and *Prorocentrum adriaticum* appeared to be the second in dominance for the majority of the stations. The dominance index ranged between 50 and 70 in 12 out of 18 stations.

Simple correlation between phytoplankton variable such as standing crop (cell.l^{-1}), ratio of diatoms over flagellates, dominance and diversity indices was also attempted and the results are shown in Table VII. Some similarities were observed in both gulfs; standing crop was significantly correlated with D/F ratio and dominance with diversity. Cell number was aslo positively correlated with dominance and negatively with diversity in Alexandroupolis Gulf.

DISCUSSION

It can be assumed for temperate waters in general that the growth season normally starts with a diatom bloom in nutrient-rich waters, and that this bloom

Table IV. - Mean values and range (cell/l) of the most important groups in Kavala and Alexandroupolis Gulfs.

	Kavala Gulf		Alexandroupolis Gulf	
Taxa	Mean (cell/l)	Range (cell/l)	Mean (cell/l)	Range (cell/l)
Diatoms	2.2×10^{5}	$8.4 \times 10^{4} - 9.5 \times 10^{5}$	2.3×10^{6}	$1.8 \times 10^{3} - 7.6 \times 10^{6}$
Dinoflagell.	2.2×10^{4}	$4.2 \times 10^{3} - 5.5 \times 10^{4}$	1.2×10^{4}	$2.6 \times 10^{3} - 6.3 \times 10^{4}$
Coccolith.	7.5×10^{2}	$2.0 \times 10^{2} - 1.7 \times 10^{3}$	1.0×10^{3}	$5.0 \times 10^{2} - 3.1 \times 10^{3}$
Silicofl.	1.2×10^{3}	$2.0 \times 10^{2} - 3.4 \times 10^{3}$	1.4×10^{3}	$2.0 \times 10^{2} - 2.2 \times 10^{3}$

develops in a near exponential fashion untill the nutrients in the euphotic layer are consumed. Later the phytoplankton stocks are quite small; grazing contributes to this, and the supply of nutrients for further growth is in the main restricted to that brought about by the recycling of organic matter within the euphotic layer. Pycnocline or the stability of the water masses severely restrict the transport of nutrients from the nutrient-rich waters below. This stability (or a pycnocline not to deep), is necessary to prevent phytoplankton from being transported to the unfavourable light regimes at greater depths (Sverdrup, 1953). In estuaries and fjords, the stability is present early in the year (being salinity dependent), and a bloom may develop as early as in late March (Baarud *et al.*, 1974; Friligos, 1977; Saksaug, 1972).

The vertical distribution in the Alexandroupolis and Kavala areas (Fig. 2) shows a correlation between density and salinity. Obviously, the presence of freshwater plays an important part. Thus in estuary such as the Alexandroupolis Gulf the major freshwater input is at the head, where it forms a thin surface layer (Fig. 4). In contrast, the Kavala Gulf receives only minor amount of freshwater directly from the Nestos River. The outflowing water from Evros River can be well defined as an estuarine area sharply bounded as « Evros stream », well several kilometers seawards. The 35 ‰ salinity was accepted as boundary value since it represents the mean salinity for Alexandroupolis surface waters (Friligos, 1986). Inside the Evros River plume the low salinity waters are also characterised by their high amount of nutrients (Table I).

Variation of nutrient ratios (by atoms) in coastal waters and estuaries have been reported by many workers (Cooper, 1937 ; Ketchum *et al.*, 1958; Herman *et al.*, 1968; Friligos, 1977). The highest N : P ratio was found inside the Evros in water with the lowest salinity. This indicate the influence that fresh water run-off has on the relative concentration of inorganic nitrogen and phosphate. Also the fluctuations in the ratio of silicate to phosphate (by atoms) shows clearly the influence of river discharges. Inside the Evros River plume, the ratio increased through the gain in silicate and reduction of phosphate.

Phytoplankton abundance and taxonomic diversity depend upon the supply of nutrients in natural waters. This is indicated by our regression analysis (Table II) where cell number increases and diversity decreases with increasing nutrient concentrations except in the case of silicate. Cell number and diversity were highly correlated with temperature, ammonium and silicate outside the Evros River plume. Cell number was highly correlated with total phosphorus, ammonium and nitrite whereas, diversity was correlated with phosphate and total phosphorus in Kavala Gulf. However inside the Evros River plume there is a correlation between the cell number and the salinity but not with the nutrients concentration. Ammonium and silicate seem to play the most important role in controlling phytoplankton standing crop and diversity outside the Evros River plume. Ammonium also seems to be an important factor in the regulation of phytoplankton abundance and phosphate to affect phytoplankton diversity in the area of Kavala Gulf.

Significant differences between the inside Evros River plume and the other areas were noticed (Table III); the analysis of variance showed that the « between areas » differences in concentrations of phytoplankton populations were significant at 0.05 level. It is more likely that the differences in standing crop between the inside Evros River plume and

Table V. - Dominance (δ) and diversity (D) indices of phytoplankton in Alexandroupolis Gulf.

St.	Dominant species	δ	D
A 1	*Rhizosolenia hebetata* (Hen.) Gran *Phaeocystis puchetti* (Lagerheim)	50.81	2.41
A 2	*Nitzschia closterium* (Ehr.) W. Sm. *Prorocentrum adriaticum*	67.61	2.49
A 3	*Skeletonema costatum* (Gr.) Clev. *Rhizosolenia fragilissima* Berg.	41.82	2.45
A 4	*Phaeocystis puchetti* (Lagerheim) *Rhizosolenia hebetata* (Hen.) Gran	67.57	2.59
A 5	*Nitzschia closterium* (Ehr.) W. Sm. *Skeletonema costatum* (Gr.) Clev.	63.59	2.99
A 6	*Prorocentrum adriaticum* Schil. *Nitzschia closterium* (Ehr.) W. Sm.	95.43	1.36
A 7	*Rhizosolenia hebetata* (Hen.) Gran. *Nitzschia closterium* (Ehr.) W. Sm.	40.51	3.03
A 8	*Phaeocystis puchetii* (Lagerheim) *Rhizosolenia hebetata* (Hen.)Gran.	75.32	2.21
A 9	*Skeletonema costatum* (Gr.) Clev. *Prorocentrum adriaticum* Schil.	54.12	2.73
A10	*Skeletonema costatum* (Gr.) Clev. *Nitzschia closterium* (Ehr.) W. Sm.	99.27	0.14
A11	*Skeletonema costatum* (Gr.) Clev. *Rhizosolenia hebetata* (Hen.) Gran.	98.47	0.21
A15	*Skeletonema costatum* (Gr.) Clev. *Nitzschia closterium* (Ehr.) W. Sm.	86.26	1.38
A16	*Skeletonema costatum* (Gr.) Clev. *Rhizosolenia hebetata* (Hen.) Gran.	82.22	1.88
A17	*Rhizosolenia hebetata* (Hen.) Gran. *Skeletonema costatum* (Gr.) Clev.	60.65	2.76
A18	*Skeletonema costatum* (Gr.) Clev. *Nitzschia closterium* (Ehr.) W. Sm.	98.06	0.28
A19	*Skeletonema costatum* (Gr.) Clev. *Nitzschia closterium* (Ehr.) W. Sm.	97.61	0.53
A20	*Skeletonema costatum* (Gr.) Clev. *Nitzschia closterium* (Ehr.) W. Sm.	96.08	0.55
A2	*Skeletonema costatum* (Gr.) Clev. *Rhizosolenia hebetata* (Hen.) Gran.	98.28	0.22

Table VI. - Dominance (δ) and diversity (D) indices of phytoplankton in Kavala Gulf.

St.	Dominant species	δ	D
K 1	*Rhizosolenia hebetata* (Hen.) Gran. *Nitzschia closterium* (Ehr.) W. Sm.	62.73	2.94
K 2	*Rhizosolenia hebetata* (Hen.) Gran. *Nitzschia closterium* (Ehr.) W.Sm.	52.50	3.45
K 3	*Rhizosolenia hebetata* (Hen.) Gran *Prorocentrum adriaticum* Schil.	65.33	2.61
K 4	*Rhizosolenia hebetata* (Hen.) Gran *Rhizosolenia delicatula* Cl.	44.57	3.14
K 5	*Rhizosolenia hebetata* (Hen.) Gran *Prorocentrum adriaticum* Schil.	46.51	3.51
K 6	*Rhizosolenia hebetata* (Hen.) Gran *Nitzschia closterium* (Ehr.) W. Sm	65.06	2.85
K 7	*Rhizosolenia hebetata* (Hen.) Gran *Rhizosolenia delicatula* Cl.	75.79	2.36
K 8	*Rhizosolenia hebetata* (Hen.) Gran *Rhizosolenia delicatula* Cl.	70.63	2.48
K 9	*Rhizosolenia hebetata* (Hen.) Gran *Rhizosolenia delicatula* Cl.	56.93	2.99
K10	*Rhizosolenia hebetata* (Hen.) Gran *Skeletonema costatum* (Gr.) Clev.	53.80	3.15
K11	*Rhizosolenia hebetata* (Hen.) Gran *Skeletonema costatum* (Gr.) Clev.	62.83	3.01
K12	*Rhizosolenia hebetata* (Hen.) Gran *Nitzschia closterium* (Ehr.) W. Sm.	56.31	3.15
K13	*Skeletonema costatum* (Gr.) Clev. *Nitzschia closterium*	61.37	2.75
K14	*Skeletonema costatum* (Gr.) Clev. *Rhizosolenia hebetata* (Hen.) Gran	92.71	1.56
K15	*Rhizosolenia hebetata* (Hen.) Gran *Skeletonema costatum* (Gr.) Clev.	80.04	1.82
K17	*Rhizosolenia hebetata* (Hen.) Gran *Nitzschia closterium* (Ehr.) W. Sm.	78.12	2.33
K18	*Rhizosolenia hebetata* (Hen.) Gran *Skeletonema costatum* (Gr.) Clev.	62.62	2.96

the other areas are due to the amount of nutrients and to differences in water column stability which is related to the freshwater run-off. The surface layer outside Evros River plume and Kavala Gulf are deeper than that found inside Evros River plume and are less stratified. In general the abundance values recorded at the different stations in the Kavala Gulf are comparable to maximum values obtained in the Mediterranean basin in Algeria (7.6 x 10^5 cell.l^{-1}), Monaco (1 x 10^5 cell.l^{-1}) and Crete (4.6 x 10^5 cell.l^{-1}) (Bernard, 1967) as well as Gulf of Naples (5 x 10^5 cell.l^{-1}; Carrada *et al.*, 1981). However the maximum values of abundance dominated by a few species in the Alexandroupolis Gulf amounted to 3.6-10.4 x 10^6 cell.l^{-1} are high even when compared to Egyptian Mediterranean phytoplankton populations three weeks after the annual Nile flood (2.4 x 10^6 cell.l^{-1}; Halim, 1960).

The average cell number in Alexandroupolis and Kavala Gulfs (Table IV) shows that diatoms dominate in the community often observed in Greek coastal waters (Ignatiades, 1979). Offshore stations in Alexandroupolis Gulf (1-6) did no show any particular trend as far as the dominance of a species is concerned (Tables V,VI). However in the stations spaced along the coastal areas of the Gulf *Sceletonema costatum* prevailed and in some cases formed 90 % of the phytoplankton community. The dominance of the diatom *Rhizosolenia hebetata* in Kavala Gulf is a rather unusual occurrence in Greek waters since so far only *Chaetoceros* species have been found dominant in phytoplankton assemblages of the Aegean Sea, during March 1967 (Ignatiades, 1969). Very high dominance of *Skeletonema costatum* in stations 13 and 14 is possibly associated with high phosphate concentrations prevailing in the vicinity of the Kavala harbour. Summer phytoplankton samples from other Greek coastal waters (Ignatiades, 1969) were poorer in standing stock levels (10^4 - 10^5 cell.l^{-1}) but richer in diatom species with domination of *Skeletonema* populations. Similar blooms of *Skeletonema costatum* have been reported by Ganapati & Raman (1979), Marshall *et al.*, (1981) and Hallegref (1981) during winter and spring.

Correlations of the standing crop, D/F ratio, dominance and diversity index (Table VII) seemed to be highly significant in most cases. D/F ratio and standing crop were mainly influenced by fluctuations of the diatom populations. Diatom blooms due to one or two species increase the D/F ratio and at the same time decrease diversity. Margalef (1967) maintains from studies on marine systems that productivity seems to show good correlation with species diversity. The high correlation (r = -0.91) between standing crop and diversity in Alexandroupolis Gulf emphasised the application of Margalef's ideas studied and contributes towards the ecological significance of Margalef's statement. Also, this opinion seems to be the case in our phytoplankton data; the dominance of *Skeletonema costatum* populations is coupled with low diversity of biota.

Table VII. - Correlations between phytoplankton biomass (cell/l), D/F ratio, dominance (δ) and diversity (D) in Kavala (upper triangle) and Alexandroupolis (lower triangle) Gulf.
df = 17; $r_{.05}$ = 0.46, $R_{.01}$ = 0.57.

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	cell/1	D/F	δ	D
cell/1		0.58**	0.29	- 0.36
D/F	0.55*		0.81**	- 0.81**
δ	0.83**	0.41		- 0.95**
D	- 0.91**	- 0.56*	- 0.82**	

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Further future studies on phytoplankton blooms can possibly reveal the ecological generalization of the above concepts in extreme conditions of community structure.

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