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Research Article

Phytoplankton Species' Succession and Nutrients in the Southern Black Sea (Bay of Sinop)*

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Abstract: The succession, annual cycle and diversity of phytoplankton species and seasonal changes in nutrients in the southern Black Sea (around Sinop peninsula) were investigated between August 1995 and July 1996. One species of *Cyanophyceae*, 83 taxa of *Dinophyceae*, 1 species of *Prymnesiophyceae*, 5 taxa of *Dictyochophyceae*, 88 taxa of *Bacillariophyceae* and 1 species of *Euglenophyceae* were identified. A list of phytoplankton species together with annual variations was prepared. Changes in community structure, density and diversity are discussed in relation to the physico-chemical features of the water column.

Key Words: Black Sea, Sinop Bay, phytoplankton, succession, diversity, nutrient

Güney Karadenizdeki (Sinop Körfezi) Fitoplankton Tür Süksesyonu ve Nütrientler

Özet: Ağustos-1995 ve Temmuz-1996 arasında, güney Karadeniz kıyısal sularında (Sinop körfezi) fitoplankton türlerinin süksesyonu, yıllık döngüleri, çeşitliliği ve nütrientlerin mevsimsel değişimleri araştırıldı. Bir tür *Cyanophyceae*, 83 takson *Dinophyceae*, 1 tür *Prymnesiophyceae*, 5 takson *Dictyochophyceae*, 88 takson *Bacillariophyceae* ve 1 tür *Euglenophyceae* tayin edildi. Yıllık fitoplankton dağılımını içeren bir tür listesi hazırlandı. Kommunite yapısı, hücre yoğunluğu ve çeşitlilikteki değişimler su kolonunun fiziko-kimyasal özellikleri ile bağdaştırılarak tartışıldı.

Anahtar Sözcükler: Karadeniz , Sinop Körfezi, fitoplankton, süksesyon, diversite, nütrient

Introduction

The annual variations and community structure of phytoplankton species in the southern Black Sea are reported in detail for the first time in this investigation. Little research has been reported on this subject in the southern Black Sea (Benli, 1987; Feyzioğlu & Tuncer, 1994; Uysal & Sur, 1995). However, the phytoplankton of the northern Black Sea has been studied in detail by many researchers (Belegorskaya & Kondratieva, 1965; Skolka, 1977, 1978; Bologa, 1986; Mihnea, 1986; Gomoiu, 1992; Bodeanu, 1995). The Black Sea is known to be a region of moderate to high productivity since it is fed by a rich nutrient supply compared with other marine ecosystems in the world (Koblentz-Mishke et al., 1970). The development and dynamics of brackish-water phytoplankton depend on several environmental factors, among which the most important seems to be the extent of river flow (Skolka, 1977).

The maximum spring-autumn primary productivity (60% of the Black Sea production) is found on the north-west shelf. This section of the Black Sea receives 87% of the total freshwater input entering the whole system. The Black Sea receives a large quantity of freshwater from tributary rivers, with an estimated discharge volume of 341 km^3 per year (Pora, 1977). The freshwater originates from major rivers, such as the Danube, the Dniester, and the Dnieper, which carry industrial and domestic waste waters, reduce surface salinity and contribute large amounts of nutrients, detritus and pollutants. These factors create a large but variable area with a lower surface salinity, with a reduced transparency and an increased phytoplankton crop in the north-

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western part of the Black Sea (Bologa, 1986). Over the rest of the basin, especially in the eastern part, the hydrological properties are more stable than in other areas and the phytoplankton crop is much smaller (Serpopianu, 1973; Feyzioğlu & Tuncer, 1994; Uysal & Sur, 1995; Türkoğlu 1999, 2000).

The Black Sea is an intracontinental sea, situated between 40º 54′ and 46º 38′ N latitude and between 27º 27′ and 41º 41′ E longitude with a total area of 413,490 km^2 and a water volume of 537,000 km^3. It contains a north-east orientated shallow, with a maximum depth of 2258 m. However, the mean depth is only 1270 m because of the wide continental shelf along the north-western part of the basin, which totals more than 144,000 km^2 (35% of the total area).

The present study presents the succession, annual cycle and diversity of the phytoplankton species and fluctuations in physico-chemical characteristics such as nutrients, temperature and salinity in the southern Black Sea between August 1995 and July 1996.

Materials and Methods

In this study, the samples were collected with a 55 µm plankton net and Hydro-Bios Universal Series Water Sampler (5 litres) from the sampling stations (A1, A2, A3, A4, B1, B2, B3 and B4) in the neritic waters of the Sinop peninsula in the southern part of the Black Sea situated between 41º 59′ - 42º 01′ N latitude and 35º 08′ - 35º 09′ E longitude (Fig. 1). They were collected at monthly intervals between August 1995 and July 1996.

Qualitative samples were fixed with formaldehyde (final concentration of 2-4%) and quantitative samples were fixed with Lugol (for 5 litres, 12.5 cc) and were preserved at 2-4ºC in a refrigerator pending microscopic examination. Quantitative samples were taken over monthly periods from the surface water (0.5 m) at fixed sampling points. During the investigation, 150 qualitative and 120 quantitative samples were collected. For enumeration of the phytoplankton species, Uterhmohl Sedimentation Chambers, and Neubauer and Sedgwick-Rafter Counting Slides were used in combination according to the dimensions of the organisms (Guillard, 1978; Hasle, 1978; Venrick, 1978).

The water column was also sampled with Nansen bottles to determine nutrients; temperature, salinity, pH, conductivity and turbidity were measured (with a Horiba Model U-10 water quality checker). Salinity was measured as an autocorrelation of salinity and conductivity by Horiba. Analyeses of the major nutrients, inorganic nitrate (NO_3^- –N), nitrite (NO_2^-–N) and ammonia nitrogen (NH_4^+-N), and inorganic orthophosphate phosphorus (PO_4^{-3}-P) were carried aut according to the standard procedures of Strickland and Parsons (Strickland & Parsons, 1972). N:P ratios were calculated from (NO_2^- + NO_3^-) -N and PO_4^{-3}-P values. For estimation of diversity, the most stable index of Shannon-Weaver was used (Pielou, 1975; 1977; Dennis & Patil, 1977).

Grouping of phytoplankton species in terms of frequency coefficient was used following frequency groups to show the presence frequency of species in the community during the year. Frequency groups: 1-20%,

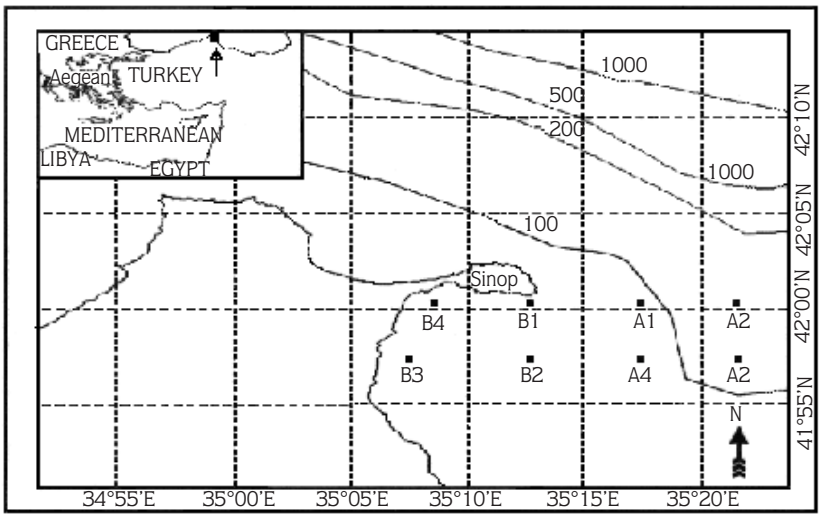


Fig. 1. The sampling stations.

21-40%, 41-60%, 61-80% and 81-100% for rare, common, abundant, very abundant and continuous (existent throughout the year) species in the community, respectively. Frequency was calculated with the following equality: $f = N_a : N_n \times 100$ (N_a: presence number of A species in total sampling or individual number of A species; N_n: total number of sampling or total individual number of whole species).

Before microscopic identifications, organic substances on the samples were removed using HNO_3 and H_2SO_4 for diatoms (Hasle, 1978) and sodium hypochlorite (Javelle water) for dinoflagellates (Taylor, 1978). The species were identified under phase-contrast research microscopes. The literature used for phytoplankton species identifications was Massuti and Margalef (1950), Tregouboff and Rose (1957), Patrick and Reimer (1966), Drebes (1974), Vinyard (1974, 1975), Cupp (1977), Rampi and Bernhard (1978, 1980), Koray and Gökpınar (1983), Gökpınar and Koray (1983), Sournia (1986), Ricard (1987), and Delgado and Fortuna (1991).

Results

Relationships between physical-chemical data and phytoplankton cell density

Temperature

During the sampling period, the first detectable increase in the temperature in the surface water was in April, and it continued to increase until August. The temperatures in the surface water varied between 20 and 25ºC in summer. However, the maximum temperature (25ºC) observed in summer continued for a short period (July and August). After a short period with a maximum of 25.0ºC in August, temperature decreased to the March value (6.0ºC) (Fig. 2).

According to the correlation results (Table 1), NH_4^+-N, turbidity, pH, conductivity, NO_2^--N, and cell density of dinoflagellates were strongly affected by temperature. A highly significant positive correlation (r= 0.763) existed between temperature and the cell density of dinoflagellates. There was also a highly significant positive correlation (r=0.878) between temperature and NH_4^+-N. However, there was a highly significant negative correlation (r=-0.901) between temperature and turbidity. Correlations between temperature and other physical-chemical parameters was not more significant except pH, conductivity and NO_2^--N. The very low negative correlation (r=-0.168) between temperature and diatom cell density was due to the quantitative abundance of some diatom species such as *Cylindrotheca closterium* Ehrenberg, *Rhizosolenia calcar-avis* Schultze, and Pseudonitzschia pungens (Grunow ex P. T. Cleve) Hasle in summer. Some diatoms seem to be able to stand fairly wide temperature ranges and maintain good growth rates, whereas other diatoms seem to have small ranges of temperature tolerance (Hay et al., 1990). Temperature may have indirect effects upon diatom

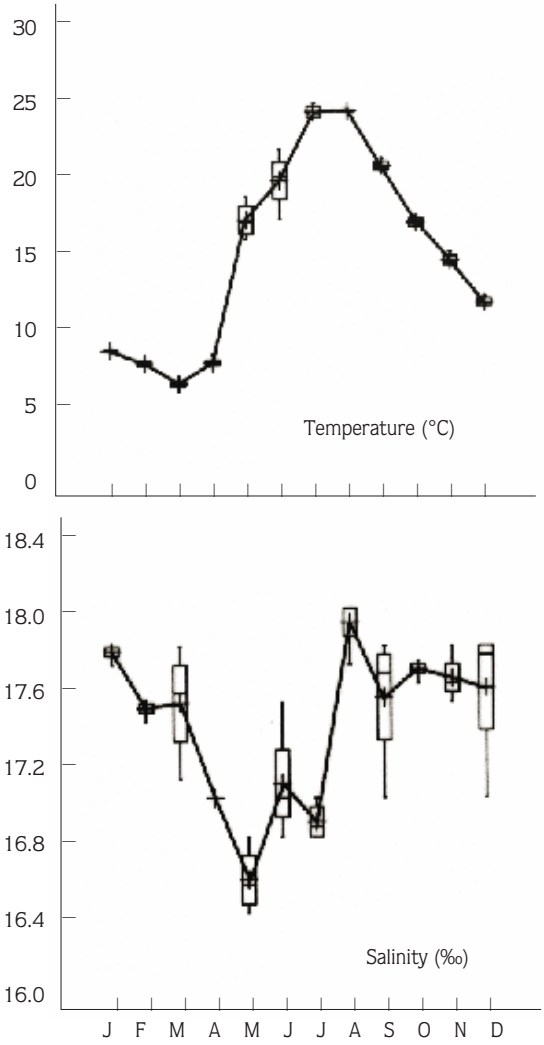


Fig. 2. Statistical results on the annual cycles of temperature (ºC) and salinity (‰) in the neritic waters of the Sinop peninsula in the southern Black Sea. Rectangles represent 95% confidence intervals of means (n = 80). Minima and maxima are shown with lines perpendicular to the rectangles.

Table 1. Correlation coefficients and evenness levels between physico-chemical parameters and numerical phytoplankton density in surface water (These indicate important correlation coefficients {◆: Significant; ◆◆: Highly significant} and evenness levels {♠: Significant; ♠♠: Highly significant}).

	T (ºC)	S (‰)	pH	Cond.	Turb.	NO_2^--N	NO_3^--N	NH_4^+-N	PO_4^{-3}-P	Dinop.	Bacil.	Prym.
T (ºC)		-0.194	0.637◆	-0.599◆	-0.901◆◆	-0.671◆	-0.024	0.878◆◆	-0.228	0.763◆◆	-0.168	0.073
S (‰)	0.591		-0.658◆	0.884◆◆	0.271	0.374	0.105	-0.311	0.572◆	0.145	-0.090	0.505◆
pH	0.048♠	0.039♠		-0.813◆◆	-0.515◆	-0.693◆	-0.073	0.776◆◆	-0.686◆	0.120	0.205	-0.550◆
Cond.	0.067♠	0.000♠♠	0.004♠♠		0.631◆	0.604◆	0.089	-0.693◆	0.560◆	-0.172	-0.048	0.428
Turb.	0.000♠♠	0.449	0.127♠	0.050♠		0.432	0.109	-0.770◆◆	0.113	-0.691◆	0.337	0.073
NO_2^- -N	0.033♠	0.287	0.026♠	0.065♠	0.213		0.241	-0.794◆◆	0.421	-0.408	-0.539◆	-0.073
NO_3^--N	0.947	0.773	0.842	0.807	0.765	0.512		-0.712◆◆	0.197	-0.075	-0.415	0.116
NH_4^+-N	0.000♠♠	0.382	0.008♠♠	0.026♠	0.009♠♠	0.006♠♠	0.009♠♠		-0.441	0.505◆	0.195	-0.212
PO_4^{-3}-P	0.527	0.084♠	0.029♠	0.092♠	0.756	0.226	0.586	0.203		-0.041	-0.194	0.413
Dinop.	0.010♠♠	0.691	0.740	0.636	0.027♠	0.242	0.836	0.135♠	0.910		-0.367	0.572◆
Bacil.	0.644	0.804	0.570	0.896	0.342	0.108♠	0.234	0.590	0.590	0.297		-0.102
Prym.	0.842	0.136♠	0.099♠	0.218	0.841	0.841	0.749	0.557	0.236	0.084◆	0.779	

communities. For instance, increased temperature decreases the viscosity of the water and thus increases the sinking rate of planktonic diatoms. It is well known that diatoms living in warm water often have less silica in their cell walls than those living in cold water (Hay et al., 1990). It is also known that increasing temperature increases the diffusion rates of solutes and reduces the solubility of oxygen and carbon dioxide. These fluctuations in the environmental conditions in which the diatoms live may affect their reproductive capacity and metabolic activities (Hay et al., 1990).

Salinity

The salinity varied between 16.4 and 18.0‰ in the surface waters at the Sinop peninsula during the sampling period. The salinity decreased from January (17.8‰) to May (16.6‰). Due to heavy spring rains and the effect of fresh water inputs, salinity remained lowest in late spring (especially in May) (16.4-16.8‰) (Fig. 2).

According to correlation results (Table 1), the cell density of *Emiliania huxlei* (Lohmann) Hay *et* Möller (*Prymnesiophyceae*) was affected by salinity. A significant positive correlation (r=0.505) existed among them. This means that the abundance of *Prymnesiophyceae* increased with increasing salinity. A highly significant positive correlation (r=0.884) was also found between salinity and conductivity, which was expected. However, there was a significant negative correlation (r=-0.658) between salinity and pH (Table 1).

Turbidity

The annual cycle of turbidity in the neritic waters of the Sinop peninsula showed a peak of 120 in March. After this peak, there was a sharp decrease in turbidity which lasted until July, and then it remained constant between May and December. After December, there were no marked monthly changes in turbidity between May and December (Fig. 3).

Turbidity is strongly affected by phytoplankton blooms, especially blooms of dinoflagellates, temperature and NH_4^+-N in summer. For instance, there was a highly significant positive correlation between turbidity and NH_4^+-N (r=-0.691) (Table 1). It is well known that increasing temperature makes phytoplankton populations grow. Therefore, it may increase the turbidity of the marine water in Sinop Bay. However, there were other environmental factors, such as strong waves and river inputs originated with Yeşilırmak, increasing the turbidity of the marine water in winter in Sinop Bay.

Conductivity

The surface conductivity of the neritic waters of the Sinop peninsula did not exhibit changes in August-March, varing between 28.6 and 29.5 mS cm^{-1}, but it decreased in April (26.1 mS cm^{-1}), due to the lowest salinity (Fig. 3). After the decrease, conductivity remained at low levels (27.1-27.3 mS cm^{-1}) during the summer period. Then conductivity increased sharply to the August value (28.9 mS cm^{-1}) (Fig. 3).

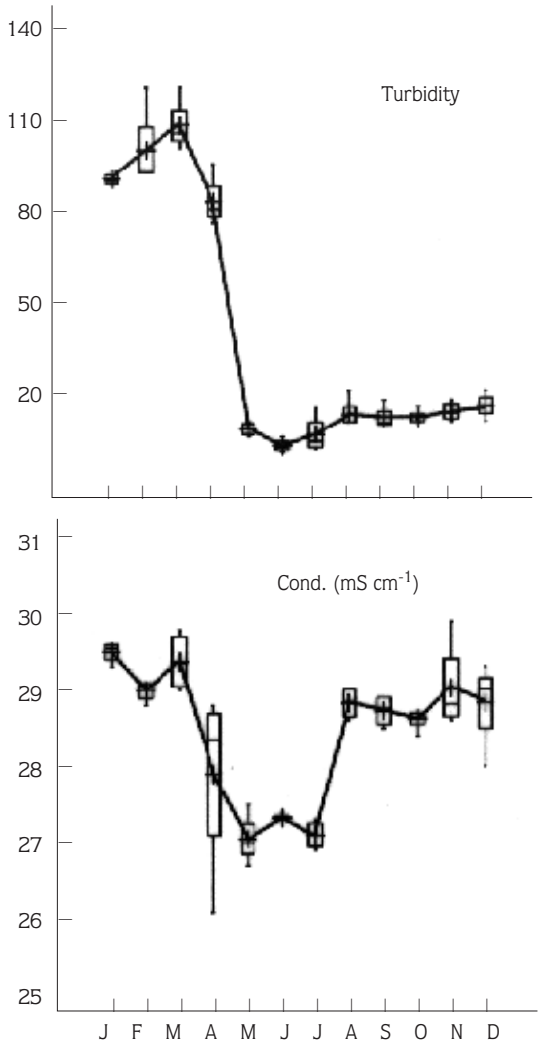


Fig. 3. Results of simple statistical analysis of the annual cycles of turbidity and conductivity (mS cm^{-1}) in the southern Black Sea. Rectangles represent 95% confidence intervals of means (n = 60). Minima and maxima are shown with lines perpendicular to the rectangles.

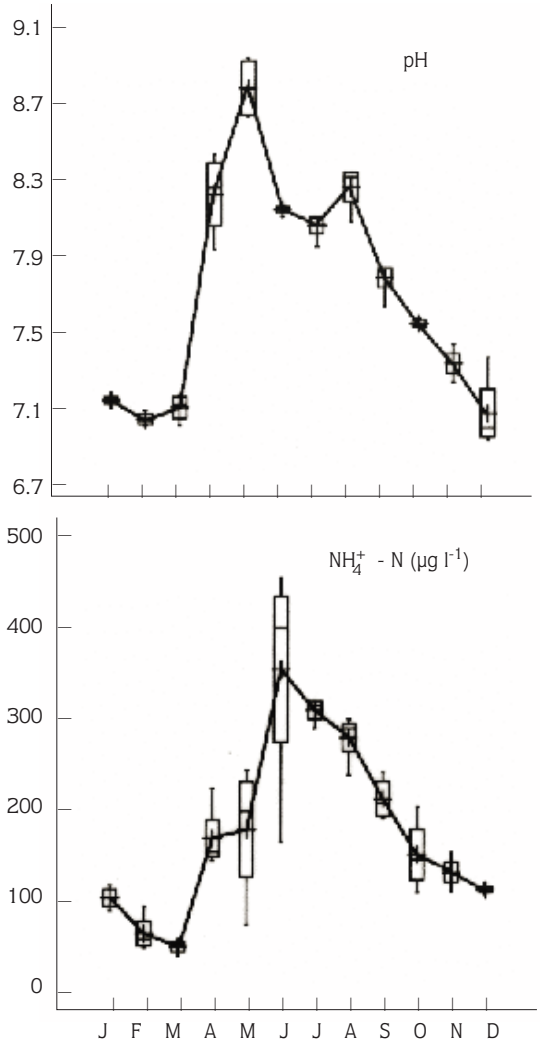


Fig. 4. Results of simple statistical analysis of the annual cycles of pH and NH^{+}_{4}-N (µg l^{-1}) in the southern Black Sea. Rectangles represent 95% confidence intervals of means (n = 60). Minima and maxima are shown with lines perpendicular to the rectangles.

According to the correlation coefficient and significance levels (Table 1), conductivity was strongly affected by salinity and pH. There was a highly significant positive correlation (r=0.884) between conductivity and salinity. However, the correlation between conductivity and pH was highly significantly negative (r=-0.813). This means that conductivity strongly depends on salinity, and so a highly significant correlation was found among them. No positive or negative correlations between conductivity and phytoplankton cell densities were found (Table 1).

pH

The seasonal cycle of pH in the neritic waters of the Sinop peninsula exhibited a major peak of pH 8.9 in May and a minor peak of pH 8.3 in August. Although variations were not evident, after the minor peak, pH decreased until February (mean: 7.0) and then increased from March until May (8.9). It was lowest during the winter period (mean: 7.0) (Fig. 4).

As seen in Table 1, there were very important correlations between pH and other physico-chemical

parameters such as conductivity, NH^{+}_{4}-N, PO^{-3}_{4}-P, NO^{-}_{2}-N and turbidity. However, in terms of cell density, between pH and the phytoplankton taxonomic groups there was only significant correlation with the *Prymnesiophyceae* (*Emiliania huxlei* (Lohmann) Hay *et* Möller) (r=-0.550). The cell densities of the diatoms and dinoflagellates were not affected by pH (Table 1).

Ammonia

The first detectable increase in ammonia in the research area was in April (means: 165 µg NH^{+}_{4}-N l^{-1}), and it continued to increase until June (means: 350 µg NH^{+}_{4}-N l^{-1}). Later, it decreased until March (means: 46.1 µg NH^{+}_{4}-N l^{-1}) (Fig. 4). The source of ammonia during early summer was probably from remineralization, probably related to tourism activities during the summer period in Sinop. On the other hand, the decrease in ammonia after July parallels the increase in nitrate and nitrite after June (Figs. 4 and 5).

The negative relationship between ammonia and nitrite-nitrate during the year is supported by correlation coefficients (r=-0.794 for nitrite and ammonia; r=-0. 712 for nitrate and ammonia) (Table 1). The relationships of nitrite and nitrate with ammonia were highly significant (p= 0.006 and p= 0.009, respectively). Not only was there a highly negative correlation between ammonia and nitrite-nitrate but there was also one between ammonia and turbidity (r=-0.770). On the other hand, not only were there negative correlations, but there were also very significant positive correlations between ammonia and other physico-chemical parameters such as temperature (r= 0.878) and pH (r= 0.776). According to the results of the correlation coefficient and significance levels (Table 1), a significant positive biological correlation with ammonia was only found between ammonia and dinoflagellate cell density (r=0.505). There was no significant correlation between ammonia and other taxonomic groups of phytoplankton. The dinoflagellate increase was affected more by ammonia than other inorganic nitrogen compounds.

Nitrite

Nitrite showed important variations during the sampling period (Fig. 5). The seasonal cycle of nitrite showed a major peak in February (mean: 7.81 µg NO^{-}_{2}-N l^{-1}) and a minor peak in June (mean: 3.20 µg NO^{-}_{2}-N l^{-1}). The maximum nitrite content in winter might be related to nitrogen regeneration but the minima in April and June might be due to nitrite consumption by phytoplankton blooms such as *Pseudonitzschia delicatissima* (P.T.Cleve) Heiden *in* Heiden and Kolbe (in April), *Cylindrotheca closterium* (Ehrenberg) Reimann *et* Lewin and *Prorocentrum balticum* (Lohmann) Loeblich III (in July), *Rhizosolenia calcar-avis* Schultze and *Pseudonitzschia pungens* (Grunow *ex* P. T. Cleve) Hasle (in August). This conjecture is supported by the correlation coefficient. According to the correlation coefficient between diatom cell density and nitrite (Table 1), diatom cell density was related to nitrite; there was a significant positive correlation between the abundance of diatoms and nitrite concentration (r=-0.539).

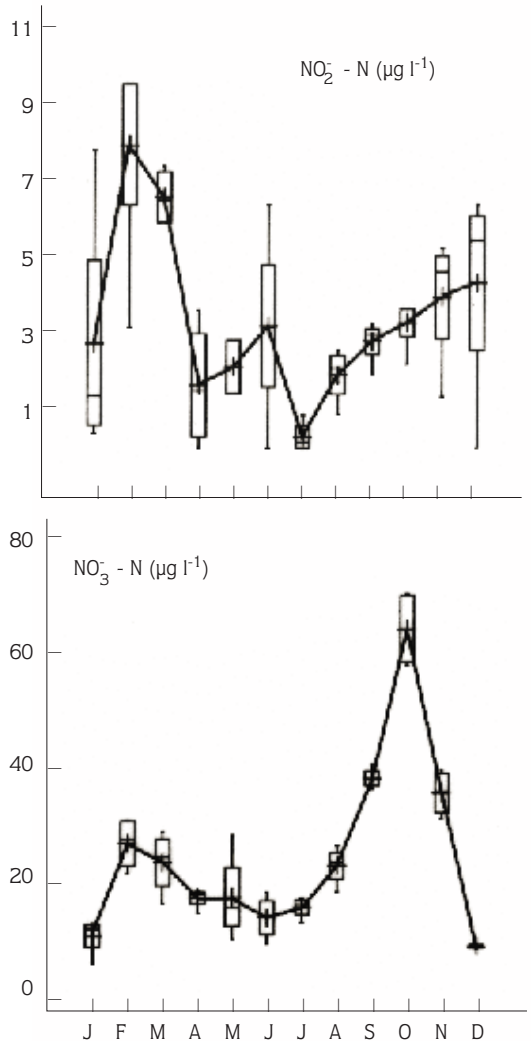


Fig. 5. Results of simple statistical analysis of the annual cycles of NO^{-}_{2}-N and NO^{-}_{3}-N (µg l^{-1}) in the southern Black Sea. Rectangles represent 95% confidence intervals of means (n=60). Minima and maxima are shown with lines perpendicular to the rectangles.

Nitrate

Nitrate concentration changes during the sampling period exhibited a major peak in October (means: 64.8 µg NO_3^--N l^{-1}) and a minor peak in February (means: 28.2 µg NO_3^--N l^{-1}). Although variations were not evident, after the minor peak, nitrate decreased until June (mean: 15.0 µg NO_3^--N l^{-1}) and then increased from June until October. After the maximum peak in October, nitrate decreased dramatically to the minimum concentration in December (mean: 10.8 µg NO_3^--N l^{-1} (Fig. 5).

The high nitrate concentration in October is perhaps mainly due to nitrogen regeneration in the Black Sea and increases in nitrogen by inputs from rivers. The other noteworthy feature of nitrate is that the low concentrations in winter (December and January) and from April to July were probably due to the gradual utilization of nitrate by phytoplankton blooms in winter and between April and July. Although we did not observe a good correlation between nitrate and phytoplankton cell density (Table 1), it is known that nitrate is a important nitrogen source for phytoplankton growth (Parsons et al., 1990).

Phosphorus

In the annual cycle of phosphorus in Sinop Bay (Fig. 6), there was a decrease between January (mean: 57.5 PO_4^{-3}-P µg l^{-1}) and April (mean: 20.5 µg PO_4^{-3}-P µg l^{-1}) and an increase between August (mean: 27.5 µg PO_4^{-3}-P µg l^{-1}) and October (mean: 66.9 µg PO_4^{-3}-P µg l^{-1}). After the maximum concentration in October, phosphate remained essentially constant between October and January (57.5-66.9 µg PO_4^{-3}-P µg l^{-1}). There were no important variations from early spring to late summer and the concentrations remained between 20.5 and 26.8 µg PO_4^{-3}-P µg l^{-1} (Fig. 6).

As stated by Parsons et al. (Parsons et al., 1990), like other inorganic major nutrient compounds, phosphorus is one of the major inorganic nutrients used in growth of the phytoplankton, and its concentration should always be considered first in determining possible limitations in primary production. Although we observed some significant correlations between nitrogen (except nitrate) and phytoplankton abundance, there was no significant negative or positive correlation between phosphorus and phytoplankton cell density (Table 1).

N:P ratio

N:P ratios with ammonia added as a nitrogen source in the southern Black Sea between April and August (from 17:1 to 37:1) were above the theoretical assimilation ratio of 16:1 for the world's oceans. However, N:P ratios varied from 7:1 to 13:2 between October and March. The theoretical assimilation ratio was only observed in September, while the highest N:P ratio was calculated to be 37:1 at the surface in June, and the lowest N:P ratios was calculated to be 4:1 and 5:1 at the surface in January and December, respectively (Fig. 6).

Species composition and community structure

According to the results of studies on the community structure and diversity of the phytoplankton during the

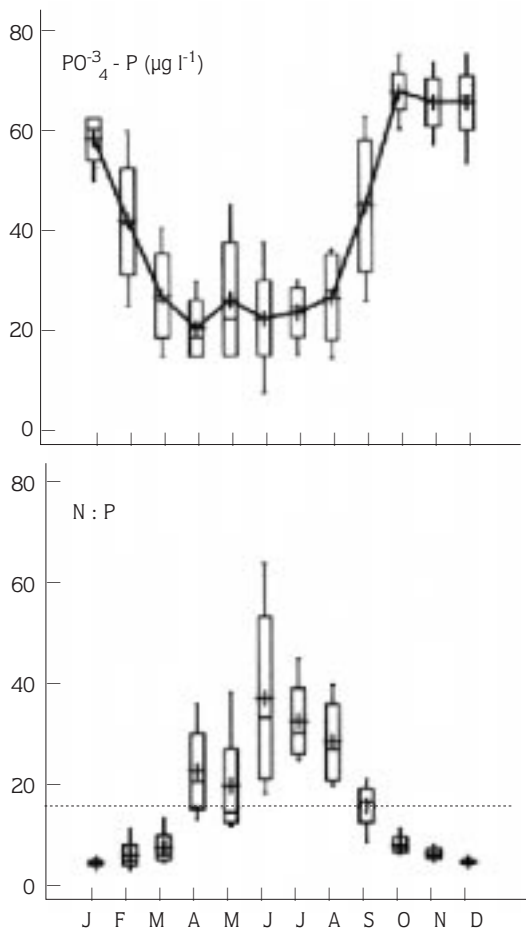


Fig 6. Results of simple statistical analysis of the annual cycles of PO_4^{-3}-P (µg l^{-1}) and N:P (µg at l^{-1}) in the southern Black Sea. Rectangles represent 95% confidence intervals of means (n=60). Minima and maxima are shown with lines perpendicular to the rectangles.

period of August 1995 to July 1996, a total of 179 taxa were distinguished (Table 2). Of these taxa, 1 species (0.56%) *Cyanophyceae* (1 genus and 1 species), 83 taxa (46.4%) *Dinophyceae* (15 genera, 67 species, 14 varieties and 2 forms), 1 species (0.56%) *Prymnesiophyceae* (1 genus and 1 species), 5 taxa (2.82%) *Dictyochophyceae* (2 genera, 3 species and 2 varieties), 88 taxa (49.2%) *Bacillariophyceae* (32 genera, 85 species, 2 varieties and 1 form) and 1 species (0.56%) *Euglenophyceae* (1 genus and 1 species) were distinguished in the neritic waters of the Sinop peninsula (Tables 2 and 3).

The following genera are richest in terms of species: among the dinoflagellates – *Ceratium* spp. (24 taxa), *Protoperidinium* spp. (20 taxa, 35.8% of total 179 taxa), *Prorocentrum* spp. and *Dinophysis* spp. (12 taxa, 21.5% of total 179 taxa) and *Gonyaulax* spp. (7 taxa, 12.5% of total 179 taxa); among the diatoms, *Chaetoceros* spp. (20 taxa, 35.8% of total 179 taxa), *Thalassiosira* spp. (8 taxa, 14.3% of total 179 taxa), *Coscinodiscus* spp. and *Rhizosolenia* spp. (7 taxa, 12.5% of total 179 taxa), *Pseudonitzschia* spp., *Licmophora* spp. and *Navicula* spp. (4 taxa, 7.2% of total 179 taxa) *Nitzschia* spp. and *Striatella* spp. (3 taxa, 5.4% of total 179 taxa) (Table 2).

Table 2. Species list and temporal variations of phytoplankton in the southern Black Sea (Sinop Bay) between August 1995 and July 1996 (1-20%: rare, 21-40%: common, 41-60%: abundant, 61-80%: very abundant, 81-100: continuous species, +: present, -: absent, q: quantitatively important).

SPECIES	MONTHS												
	J	F	M	A	M	J	J	A	S	O	N	D	f (%)
CYANOPHYCEAE													
Oscillatoria sp.	-	+	+	+	+	+	-	+	+	+	-	-	67
DINOPHYCEAE													
Ceratium belone Cleve	-	-	-	-	+	+	-	-	-	-	-	-	17
Ceratium biceps Clap. & J.Lachm.	+	+	+	+	+	+	+	+	-	-	-	+	67
Ceratium carriense Gourret													
var. *volans* (Cleve) Sournia	-	-	+	-	-	-	-	-	-	-	-	-	8
Ceratium compressum Gran	-	+	+	-	+	-	-	-	-	-	-	-	25
Ceratium declinatum (G.Karst.) C.Jørg.													
f. *majus* C.Jørg.	+	-	-	-	-	-	-	-	-	+	+	+	33
f. *normale* C.Jørg.	+	-	-	-	-	-	-	-	+	+	+	+	42
Ceratium furca (Ehrenb.) Clap. & J.Lachm.													
var. *eugrammum* (Ehrenb.) J.Schiller	+	+	+	+	+	+	+	+	+	+	+	+	100
var. *furca* (Ehrenb.) Sournia	+	+	+	+	+	+	+	+	+	+	+	+	100
Ceratium fusus (Ehrenb.) Dujard.													
var. *fusus* (Ehrenb.) Dujard.	+	+	+	+	+	+	+	+	+	+	+	+	100
var. *schuetti* Lemmerm.	-	-	-	-	+	+	-	-	-	-	-	-	17
var. *seta* (Ehrenb.) J.Schiller	+	+	+	+	+	+	+	+	+	+	+	+	100
Ceratium hexacanthum (Rampi) Sournia													
var. *pavillardi* (Rampi) Sournia	-	-	-	-	+	-	-	-	-	-	-	-	8
Ceratium horridum (Cleve) Gran													
var. *denticulatum* C.Jørg.	-	+	-	-	-	-	-	-	-	-	-	-	8
var. *horridum* (Sournia) Grün	-	-	-	-	+	-	-	-	-	-	-	-	8
Ceratium incisum (G.Kars.) C.Jørg.	-	-	-	+	+	+	-	-	-	-	-	-	25
Ceratium inflatum (Kof.) C.Jørg.	+	+	+	+	+	+	+	-	-	-	-	+	67
Ceratium kofoidii C.Jørg.	-	-	-	-	+	+	-	-	-	-	-	-	17
Ceratium lineatum (Ehrenb.) Cleve	+	+	+	+	+	+	-	-	-	-	-	-	50
Ceratium longirostrum Gourret	-	-	-	-	-	+	-	-	-	-	-	-	8
Ceratium massiliense (G.Karst.) C.Jørg.													
var. *armatum* (G.Karst.) C.Jørg.	+	+	+	-	+	-	-	+	-	-	-	-	42

Table 2. (continued).

SPECIES		MONTHS												
		J	F	M	A	M	J	J	A	S	O	N	D	f (%)
Ceratium teres Kof.		-	-	-	-	-	+	-	-	-	-	-	-	8
Ceratium tripos (O.F. Müll.) Nitzsch														
var. *atlanticum* (Ostenf.) Paulsen		+	+	+	+	+	+	+	+	+	+	+	+	100
var. *pulchellum* f. pulchellum		-	+	+	+	+	+	+	-	+	+	+	+	92
Ceratium strictum (Okamura & Nishikawa) Kof.		+	+	+	+	+	+	-	-	-	-	-	-	50
Dinophysis acuminata Clap. & J.Lachm.		+	+	+	+	+	+	+	-	+	+	-	-	75
Dinophysis acuta Ehrenb.		-	+	-	-	-	-	-	-	-	-	-	-	8
Dinophysis caudata Kent		+	+	-	+	+	+	+	+	+	+	+	+	92
Dinophysis diegensis Kof.		-	-	-	-	-	+	+	-	-	-	-	-	17
Dinophysis fortii Pavill.		+	+	+	+	+	+	+	-	-	-	+	+	75
Dinophysis hastata J.R.Stein		+	+	-	-	-	+	-	-	-	-	-	+	33
Dinophysis infundibula J.Schiller		-	-	-	-	-	+	+	-	-	-	-	-	17
Dinophysis parvula (F.Schütt) Balech		-	-	-	-	-	-	-	-	-	-	+	-	8
Dinophysis punctata C.Jørg.		+	+	-	-	+	-	+	+	-	-	-	+	50
Dinophysis rotundata Clap. & J.Lachm.		+	+	+	+	+	+	+	+	+	+	+	+	100
Dinophysis rudgei (G.Murray & Whitting) T.H.Abé		+	+	-	+	+	+	+	-	-	-	+	+	67
Dinophysis sacculus J.R..Stein		+	+	-	+	+	+	+	+	+	+	+	+	92
Diplopsalis lenticula Bergh		+	+	+	+	+	+	+	+	+	+	+	+	100
Gonyaulax birostris F.Stein		-	-	-	-	-	-	+	+	+	+	-	-	33
Gonyaulax diacantha Meunier (J.Schiller)		-	-	-	-	-	+	+	+	+	+	-	-	42
Gonyaulax diegensis Kof.		-	-	-	-	-	-	+	+	-	-	-	-	17
Gonyaulax monocantha Pavill.		-	-	-	-	-	+	+	-	-	-	-	-	17
Gonyaulax polyedra F.Stein	q	-	-	-	-	+	+	+	+	-	-	-	-	33
Gonyaulax polygramma F.Stein		-	-	-	-	+	+	+	+	-	-	-	-	33
Gonyaulax spinifera (Clap. & J.Lachm.) Diesing	q	-	-	-	+	+	+	+	+	-	-	-	-	42
Gymnodinium sanguineum Hirasaka		+	-	-	-	-	-	-	-	-	-	+	+	25
Heterocapsa triquedra (Ehrenb.) J.R.Stein	q	-	+	+	+	+	+	+	-	-	-	-	-	50
Noctiluca scintillans (McCartney) Kof.		-	-	-	-	-	-	+	-	-	-	-	-	8
Oxytoxum sp.		+	+	+	+	-	+	+	-	-	-	-	+	50
Prorocentrum aporum (J.Schiller) T.H.Abé	q	+	-	-	-	-	+	+	-	-	-	+	+	25
Prorocentrum balticum (Lohmann) A.R.Loebl.	q	+	+	+	+	+	+	+	+	+	+	+	+	100
Prorocentrum compressum (Bailey) T.H.Abé	q	+	+	+	+	+	+	+	+	+	+	+	+	100
Prorocentrum cordatum (Ostenf.) J.D.Dodge		-	-	-	+	+	+	+	-	-	-	-	-	33
Prorocentrum dentatum J.R.Stein		-	-	-	+	-	-	-	+	+	-	-	-	25
Prorocentrum maximum (Gourret) J.Schiller		-	-	-	-	-	+	-	-	-	-	-	-	8
Prorocentrum micans Ehrenb.	q	+	+	+	+	+	+	+	+	+	+	+	+	100
Prorocentrum minimum J.Schiller	q	+	-	-	+	+	+	+	+	+	+	+	+	83
Prorocentrum pyriforme (J.Schiller) Hasle		-	-	-	-	-	-	+	-	-	-	-	-	8
Prorocentrum rotundatum J.Schiller		+	+	+	+	+	+	+	+	+	-	-	-	75
Prorocentrum scutellum J.Schiller		-	-	-	-	-	-	-	-	+	-	-	-	8
Prorocentrum triestinum J.Schiller	q	-	-	+	+	-	-	+	+	-	-	-	-	33
Protoceratium aerolatum Kof.		-	+	-	+	+	+	+	+	+	+	+	+	83
Protoperidinium brevipes Paulsen		+	+	-	-	-	-	-	-	-	-	-	+	25
Protoperidinium brochi (Kof. & Swezy) Balech		+	+	+	+	+	+	+	+	+	+	+	+	100
Protoperidinium claudicans (Paulsen) Balech		+	+	+	+	+	+	+	+	+	+	+	+	100
Protoperidinium conicoides Paulsen		-	-	-	-	+	-	+	+	+	+	+	+	58
Protoperidinium conicum (Gran) Balech														

Table 2. (continued).

SPECIES		MONTHS												
		J	F	M	A	M	J	J	A	S	O	N	D	f (%)
var. *conicum* (Gran) Ostenf. & J.Schiller		-	+	-	+	-	+	+	-	-	-	-	-	33
var. *concavum* Matz.		-	+	+	+	+	+	+	+	-	-	-	-	58
Protoperidinium depressum (Bailey) Balech	q	+	+	+	+	+	+	+	+	+	+	+	+	100
Protoperidinium diabolus Cleve		-	-	-	-	-	-	-	-	-	-	-	+	8
Protoperidinium divergens (Ehrenb.) Balech		+	+	+	+	+	+	+	+	+	+	+	+	100
Protoperidinium globolus (J.R.Stein) Balech		+	-	-	-	+	+	+	+	+	+	+	+	75
Protoperidinium grande (Kof.) Balech		-	+	-	+	-	-	-	-	-	-	-	-	17
Protoperidinium granii (Ostenf.) Balech	q	+	+	+	+	+	+	+	-	+	+	+	+	92
Protoperidinium longipes Balech	q	+	+	-	-	-	+	+	+	+	+	+	+	75
Protoperidinium pellucidium (Bergh) Balech		+	-	-	-	+	-	+	-	-	-	-	+	33
Protoperidinium pentagonum Gran		+	+	+	+	-	+	-	-	+	+	+	+	75
Protoperidinium punctulatum (Paulsen) Balech		+	+	+	-	+	+	+	+	+	+	+	+	92
Protoperidinium pyriforme (Paulsen) Balech		+	+	-	+	+	-	-	-	-	-	-	-	33
Protoperidinium steinii (C.Jørg.) Balech		+	+	-	-	+	+	+	+	-	-	-	+	58
Protoperidinium subinerme (Paulsen) Balech		+	+	-	-	-	-	+	-	-	-	-	-	25
Pyrocystis elegans Pavill.		-	-	-	-	-	-	-	-	+	-	-	-	8
Pyrophacus horologium J.R.Stein		-	-	-	+	+	+	+	+	+	-	-	-	50
Scripsiella trochoidea (J.R.Stein) A.R.Loebl.	q	+	+	+	+	+	+	+	+	+	+	+	+	100
PRYMNESIOPHYCEAE														
Emiliania huxlei (Lohmann) W.W.Hay & Mölder	q	+	+	+	+	+	+	+	+	+	+	+	+	100
DICTYOCHOPHYCEAE														
Dictyocha fibula Ehrenb.														
var. *messanensis* (Haeckel) Lemmerm.		+	+	+	+	-	-	-	-	-	-	-	+	42
var. *pentagona* E.Schulz		+	+	+	+	-	-	-	-	-	+	42		
Dictyocha polyactis Ehrenb.		+	+	+	-	-	-	-	-	-	-	-	-	25
Dictyocha speculum Ehrenb.		+	+	+	+	-	-	-	-	-	-	-	+	42
Octactis octonaria (Ehrenb.) Hovasse	q	+	+	+	+	-	-	-	-	-	-	-	+	42
BACILLARIOPHYCEAE														
Achnanthes longipes J.Agardh		-	+	+	+	+	+	+	+	-	-	-	-	58
Asterionella japonica Cleve & O.F.Müll.		-	-	-	+	-	-	-	-	-	-	-	-	8
Bacillaria paradoxa G.F.Gmel.		-	-	-	+	+	+	+	-	-	-	-	-	33
Bacteriastrum delicatulum Cleve		-	-	-	-	-	-	+	-	-	-	-	-	8
Bacteriastrum hyalinum Lauder		-	-	-	-	+	-	+	-	-	-	-	-	17
Biddulphia sp.		-	-	-	-	-	-	-	-	+	-	-	-	8
Cerataulina pelagica (Cleve) Hendey	q	+	+	+	+	+	+	+	+	+	+	+	+	100
Chaetoceros affine Lauder		+	+	+	+	-	-	-	+	-	-	-	+	42
Chaetoceros breve F.Schütt		+	+	-	-	-	-	-	-	-	-	-	-	17
Chaetoceros compressum Lauder		+	+	+	+	-	-	-	-	-	-	-	+	42
Chaetoceros constrictum Gran		+	+	+	+	-	-	-	+	+	+	+	+	75
Chaetoceros curvisetum Cleve		+	+	+	-	-	-	-	+	-	-	-	+	42
Chaetoceros danicum Cleve	q	+	+	+	-	-	-	-	-	-	-	-	+	33
Chaetoceros debile Cleve		+	-	-	-	-	-	-	-	-	-	-	-	8
Chaetoceros decipiens Cleve		+	+	+	-	-	-	-	+	-	-	-	+	42
Chaetoceros didymum Ehrenb.														
var. *protuberans* (Lauder) Gran & yendo		-	+	-	-	-	-	-	-	-	-	-	-	8
Chaetoceros gracile F.Schütt		+	+	+	-	-	-	-	+	-	-	-	+	42

Table 2. (continued).

SPECIES		MONTHS												
		J	F	M	A	M	J	J	A	S	O	N	D	f (%)
Chaetoceros holtalicum F.Schütt		+	+	-	-	-	-	-	-	-	-	-	-	17
Chaetoceros laciniosum F.Schütt		+	+	-	-	-	-	-	-	-	-	-	-	17
Chaetoceros lorenzianum Grunow		-	-	-	-	-	-	-	+	-	-	-	-	8
Chaetoceros messanense Castrac.		-	+	-	-	-	-	-	-	-	-	-	-	8
Chaetoceros pseudocurvisetum L.Mangin		-	+	-	-	-	-	-	-	-	-	-	+	17
Chaetoceros sociale Lauder		-	+	-	-	-	-	-	-	-	-	-	-	8
Chaetoceros subsecundum (Grunow) Hust.		+	+	+	-	-	-	-	-	-	-	-	-	25
Chaetoceros tortissimum Gran		-	+	-	-	-	-	-	-	-	-	-	-	8
Chaetoceros vistulae Apstein		+	-	-	-	-	-	-	-	-	-	+	+	25
Chaetoceros wighami Brightw.		+	+	-	-	-	-	-	-	-	-	-	+	25
Climacosphenia elongata Bailey		-	+	-	+	+	-	+	-	-	-	-	-	33
Cocconeis scutellum Ehrenb.		+	+	-	-	+	+	+	+	-	-	-	+	58
Coscinodiscus centralis Ehrenb.		+	+	+	-	-	-	-	-	-	-	-	-	25
Coscinodiscus concinnus W.Sm.		+	+	+	+	+	+	+	+	+	+	+	+	100
Coscinodiscus granii Gough		+	+	+	-	+	+	-	+	+	+	+	+	83
Coscinodiscus lineatus Ehrenb.		+	+	+	-	-	-	-	-	-	-	-	-	25
Coscinodiscus marginatus Ehrenb.		+	+	-	-	-	+	-	-	-	-	-	-	25
Coscinodiscus perforatus Ehrenb. var. *pavillardi* (Forti) Hust.		+	+	+	+	+	+	+	+	+	+	+	+	100
Coscinodiscus radiatus Ehrenb.		+	+	+	+	+	+	+	+	+	+	+	+	100
Cylindrotheca closterium (Ehrenb.) Reimann & Lewin	q	+	+	+	-	+	+	+	+	+	+	+	+	92
Ditylum brightwelli (T.West) Grunow	q	+	+	+	+	+	+	+	+	-	-	-	+	75
Grammatophora marina (Lyngb.) Kütz.		+	+	+	+	+	+	+	+	+	+	+	+	100
Guinardia flaccida (Castrac.) H.Perag.		-	-	-	-	+	+	-	-	-	-	-	-	17
Gyrosigma spenceri (Quekett) J.F.Griff. & Henfr.		+	+	-	-	+	+	+	-	-	-	-	-	42
Hemiaulus hauckii Grunow		-	-	-	-	-	-	-	-	+	-	-	-	8
Lauderia sp.		+	-	-	-	-	-	-	-	-	-	-	-	8
Leptocylindrus danicus Cleve		+	-	-	+	+	+	+	-	+	+	+	+	75
Leptocylindrus minimus Gran		+	-	-	+	+	+	+	-	+	+	+	+	75
Licmophora abbreviata J.Agardh		-	-	+	+	+	+	+	-	+	-	-	-	50
Licmophora gracilis (Ehrenb.) Grunow		-	+	-	-	-	-	-	-	-	-	-	-	8
Licmophora flabellata J.Agardh		-	+	+	+	+	+	-	-	-	-	-	-	42
Licmophora paradoxa (Lyngb.) J.Agardh		-	-	+	+	-	-	-	-	-	-	-	-	17
Melosira borreri Grev.		-	+	+	+	+	+	-	+	+	+	+	+	83
Navicula crabro Ehrenb.		-	-	+	+	-	-	-	-	-	-	-	-	17
Navicula lanceolata J.Agardh (Kütz.)		-	-	-	-	+	-	-	-	-	-	-	-	8
Navicula pennata G.W.Schmidt		-	-	-	+	+	+	-	-	-	-	-	-	25
Navicula zostereti Grunow		-	-	-	-	+	+	+	+	-	-	-	-	33
Nitzschia longissima (Breb.) Ralfs	q	+	+	+	+	+	+	+	+	+	+	+	+	100
Nitzschia paradoxa Grunow		-	+	+	+	+	+	+	-	-	-	-	-	50
Nitzschia sigma (Kütz.) G.Sm.		+	+	+	+	+	+	+	+	-	-	-	-	67
Pleurosigma angulatum (E.J.Quekett) G.Sm.		-	-	+	-	-	-	-	-	-	-	-	-	8
Pseudonitzschia delicatissima (Cleve) Heiden	q	+	+	+	+	+	+	+	+	+	+	+	+	100
Pseudonitzschia pseudodelicatissima (Hasle) Hasle		+	+	+	+	+	-	-	-	-	-	+	+	58
Pseudonitzschia pungens (Grunow ex Cleve) Hasle	q	+	+	+	+	+	+	+	+	+	+	+	+	100

Table 2. (continued).

SPECIES		MONTHS												
		J	F	M	A	M	J	J	A	S	O	N	D	f (%)
Rhabdonema adriaticum Kütz.		-	-	+	-	+	-	-	+	-	-	-	-	25
Rhizosolenia alata Brightw. f. *gracillima* (Cleve) Gran		+	+	+	+	+	+	+	+	+	+	+	+	100
Rhizosolenia calcar-avis M.Schultze	q	+	+	+	+	+	+	+	+	+	+	+	+	100
Rhizosolenia delicatula Cleve		-	-	-	-	+	-	-	+	+	-	-	-	25
Rhizosolenia fragilissima Bergon		+	+	+	+	+	+	+	+	+	+	+	+	100
Rhizosolenia imbricata Brightw. var. *shrubsolei* (Cleve) Schröd.		-	-	-	-	-	-	-	-	+	+	+	+	33
Rhizosolenia setigera Brightw.		-	+	-	-	-	-	-	-	-	-	-	-	8
Rhizosolenia stolterfothii H.Perag.		-	-	-	-	-	-	+	-	-	-	-	-	8
Skeletonema costatum (Grev.) Cleve		+	+	+	+	+	+	-	+	-	-	-	-	58
Stephanopyxis palmeriana (Grev.) Grunow		-	+	-	+	+	-	-	-	-	-	-	-	25
Stephanopyxis turris (Grev.) Ralfs		-	-	-	+	-	-	-	-	-	-	-	-	8
Striatella delicatula Kütz.		-	+	+	-	+	+	+	-	-	-	-	-	42
Striatella interrupta (Ehrenb.) Heib.		-	+	-	-	-	+	+	-	-	-	-	-	25
Striatella unipunctata (Lyngb.) J.Agardh		-	+	+	+	+	+	+	-	-	-	-	-	50
Synedra undulata (Bailey) W.Greg.		-	+	-	+	+	+	+	-	-	-	-	-	42
Thalassionema nitzschioides Hust.	q	+	+	+	+	+	+	+	+	+	+	+	+	100
Thalassiosira allenii Takano		+	+	-	+	-	-	-	-	-	-	-	-	25
Thalassiosira anguste-lineata (G.W.Schmidt) G.A.Fryxel & Hasle		+	+	+	-	+	+	+	+	-	-	-	+	67
Thalassiosira decipiens (Grunow) C.Jørg.		+	+	+	-	+	+	-	-	-	-	-	+	50
Thalassiosira ccentrica (Ehrenb.) Cleve		+	+	+	+	+	+	+	+	-	-	-	+	75
Thalassiosira gravida Cleve		+	+	+	+	+	+	+	+	-	-	-	+	75
Thalassiosira nordenskioeldii Cleve		+	+	+	+	-	-	-	-	-	-	-	+	42
Thalassiosira rotula Meunier	q	+	+	+	+	-	+	-	-	-	-	-	+	50
Thalassiosira subtilis (Ostenf.) Gran		+	+	+	-	-	+	-	-	-	-	-	+	42
Thalassiothrix frauenfeldii Grunow		+	+	+	+	+	+	+	-	+	+	+	+	92
Thalassiothrix longissima Cleve & Grunow		+	+	-	+	+	+	+	-	-	-	+	-	58
Thalassiothrix mediterranea Pavill.		-	+	+	+	+	+	+	-	-	-	-	-	50
EUGLENOPHYCEAE														
Eutreptiella sp.		+	-	-	+	-	-	-	+	-	-	-	-	25

Table 3. Taxonomic composition and proportional representation of the phytoplankton species in the southern Black Sea, between August 1995 and July 1996.

Taxonomic Group	Genus	Sp.	Var.	For.	Taxa	f (%)	Cell l^{-1} x103	f (%)
Cyanophyceae	1	1	-	-	1	0.56	960.000.	
Dinophyceae	15	67	14	2	83	46.4	1.500	21.12
Prymnesiophyceae	1	1	-	-	1	0.56	230.	3.20
Dictyochophyceae	2	3	2	-	5	2.82	2.	0.03
Bacillariophyceae	32	85	2	1	88	49.1	5.300.	74.65
Euglenophyceae	1	1	-	-	1	0.56	0.	0.00
Total	52	158	18	3	179	100	$7.1x10^6$	100

According to the results of frequency coefficients in the community structure of the phytoplankton species, 49 taxa (27.4% of total 179 taxa) are rare (frequency group of 1-20%), 36 taxa (20.1% of total 179 taxa) are common (frequency group of 21-40%), 29 taxa (16.2% of total 179 taxa) are abundant (frequency group of 41-60%), 25 taxa (14.0% of total 179 taxa) are very abundant (frequency group of 61-80%), and 40 taxa (22.3% of total 179 taxa) are continuous species (existent throughout the year) (frequency group of 81-100%) (Fig. 7).

Diatoms and dinoflagellates were more abundant both qualitatively (95.5%) and quantitatively (95.8%) than the other taxonomic groups. Diatoms and dinoflagellates were conspicuous as the two most diverse groups with 49.1% and 46.4% in total species number, respectively. Although diatoms and dinoflagellates were almost equally diverse groups in terms of species number, the quantitative proportion of diatoms (74.65%) in the total community was higher than the quantitative proportion of dinoflagellates (21.12%) (Table 3).

In terms of species number, the diatoms were more abundant in winter (January and February) and early spring (March) than in other periods. However, dinoflagellates were more abundant in summer (May, June and July). Maximum and minimum species numbers were recorded in February (116 taxon) and October (67 taxon), respectively (Table 4). While the species number decreased in autumn due to fluctuations in the hydrological structure, it increased in February and June, due to the constant hydrological structure of the water column.

The declines in diatoms were followed by increases in dinoflagellates. Dinoflagellates began to increase in late March; they reached a maximum in mid July and gradually declined towards October (Fig. 8). In contrast to the diatoms, they dominated in summer and early-autumn populations. Dinoflagellate blooms were more pronounced in late spring and mid-summer.

The results showed that the mean cell numbers of diatoms and dinoflagellates in surface waters were high in April (3.4 x 10^7 cells l^{-1}) and July (1.3 x 10^7 cells l^{-1}), and low in February (9.0 x 10^5 cells l^{-1}) (Fig. 8). The monthly average cell number was estimated to be 7.1 x 10^6 cells l^{-1} in surface waters (Table 3). Maximum phytoplankton abundance in April was only represented by the diatom *P. delicatissima*. The maximum cell density of this species reached 9.0 x10^7 cells l^{-1}.

For diatoms, subsequent blooms were dominated by *Nitzschia longissima* (Brebisson *in* Kützing) Ralfs *in* Pritchard (5.2 x 10^6 cells l^{-1}) and *Chaetoceros danicum* Cleve (2.7 x 10^6 cells l^{-1}) *in* January, *Ditylum brightwelli* (T.West) Grunow in Van Heurck (7.6 x 10^5 cells l^{-1}) in March, *P. delicatissima* (9.0 x 10^7 cells l^{-1}) in April, *C. closterium* (7.4 x 10^6 cells l^{-1}) in July, *R. calcar-avis* (1.7 x 10^6 cells l^{-1}) and *P. pungens* (1.2 x 10^6 cells l^{-1}) in late July and mid-August, respectively and *Thalassionema nitzschioides* Hustedt (6.4 x 10^5) in December (Figs. 9 and 10).

Subsequent blooms in the dinoflagellate communities were dominated by Heterocapsa triquedra (Ehrenberg) Stein (6.2 x 10^5 cells l^{-1}) and *Protoperidinium depressum* (Bailey) Balech (4.0 x 10^4 cells l^{-1}) in March, *Protoperidinium granii* (Ostenfeld *in* Paulsen) Balech (4.8 x 10^5 cells l^{-1}) and *Scripsiella trochoidea* (Stein) Loeblich III (7.8 x 10^5 cells l^{-1}) in June, *P. balticum* (9.0 x 10^6 cells l^{-1}) and *Prorocentrum compressum* (Bailey) Abe (4.6 x 10^5 cells l^{-1}) in mid-July, *Gonyaulax polyedra* Stein (4.4 x 10^4 cells l^{-1}) in late July and August, *Prorocentrum micans* Ehrenberg (7.2 x 10^5 cells l^{-1}), *Prorocentrum minimum* Schiller, *Protoceratium aerolatum* Kofoid, *Protoperidinium longipes* Balech (2.0 x 10^5 cells l^{-1}) in mid-August and *Prorocentrum aporum* (Schiller) Abe

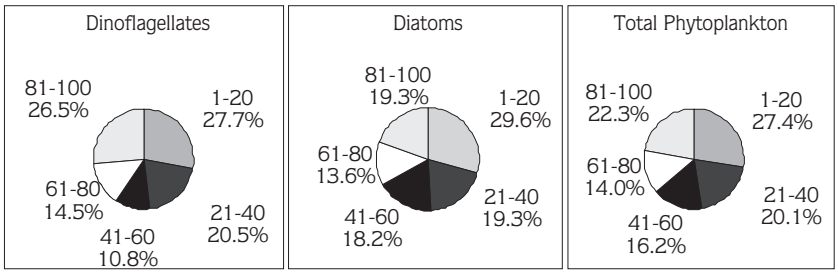


Fig. 7. Grouping of phytoplankton species in the littoral waters of the Sinop peninsula in the southern Black Sea in terms of frequency coefficient.

Table 4. Percentage composition of the taxonomic groups in phytoplankton in the southern Black Sea.

Taxonomic Group	S ampling P eriod													
	August 1995		September 1995		October 1995		November 1995		December 1995		January 1996		February 1996	
	no	%	no	%	no	%	no	%	no	%	no	%	no	%
Cyanophyceae	1	1.3	1	1.6	1	1.5	-	-	-	-	-	-	1	0.9
Dinophyceae	39	52.0	35	57.5	39	58.2	33	49.2	42	48.8	44	43.6	46	39.6
Prymnesiophyceae	1	1.3	1	1.6	1	1.5	1	1.5	1	1.2	1	1.0	1	0.9
Dictyochophyceae	1	1.3	-	-	-	-	-	-	4	4.7	5	4.9	5	4.3
Bacillariophyceae	32	42.7	24	39.3	26	38.8	23	34.3	39	45.3	50	49.5	63	54.3
Euglenophyceae	1	1.3	-	-	-	-	-	-	-	-	1	1.0	-	-
Total	75	100	61	100	67	100	67	100	86	100	101	100	116	100

Table 4. (continued)

Taxonomic Group	S ampling P eriod											
	March 1996		April 1996		May 1996		June 1996		July 1996		Total 1996	
	no	%	no	%	no	%	no	%	no	%	no	%
Cyanophyceae	1	1.1	1	1.1	1	1.0	1	1.0	-	-	1	0.56
Dinophyceae	33	37.1	42	45.2	51	51.0	58	55.7	55	59.1	83	46.4
Prymnesiophyceae	1	1.1	1	1.1	1	1.0	1	1.0	1	1.1	1	0.56
Dictyochophyceae	5	5.7	4	4.3	-	-	-	-	-	-	5	2.8
Bacillariophyceae	48	53.9	44	47.3	47	47.0	44	42.3	37	39.8	88	49.2
Euglenophyceae	-	-	1	1.0	-	-	-	-	-	-	1	0.56
Total	88	100	93	100	100	100	104	100	93	100	179	100

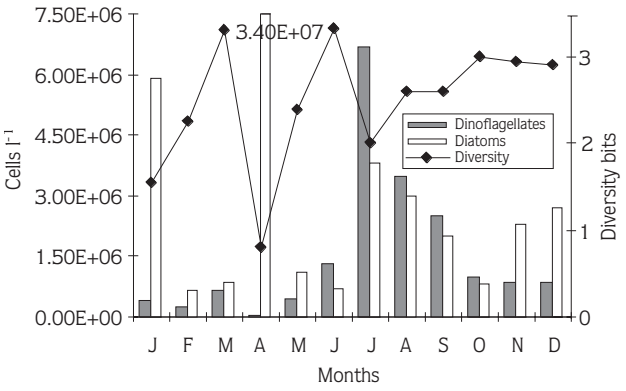


Fig. 8. Annual variations in abundance of the major algal groups and species diversity in the southern Black Sea.

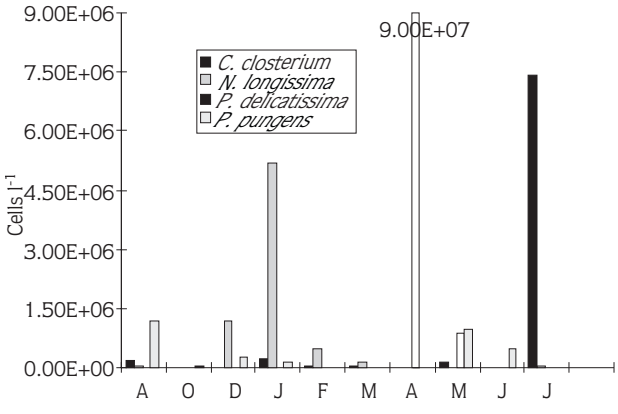


Fig. 9. The annual variations in abundance of some small diatoms in the southern Black Sea.

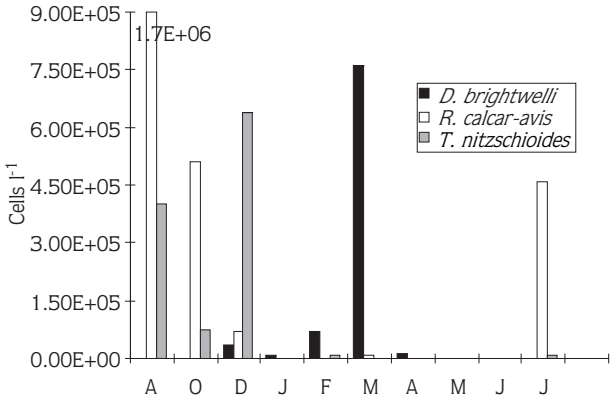


Fig. 10. The annual variations in abundance of some large diatoms in the southern Black Sea.

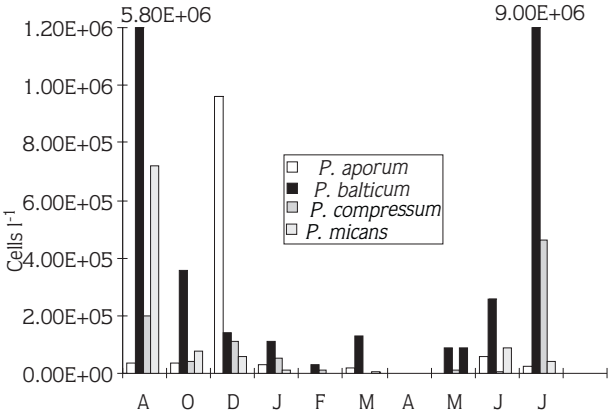


Fig. 11. The annual variations in abundance of *Prorocentrum* spp. in the southern Black Sea.

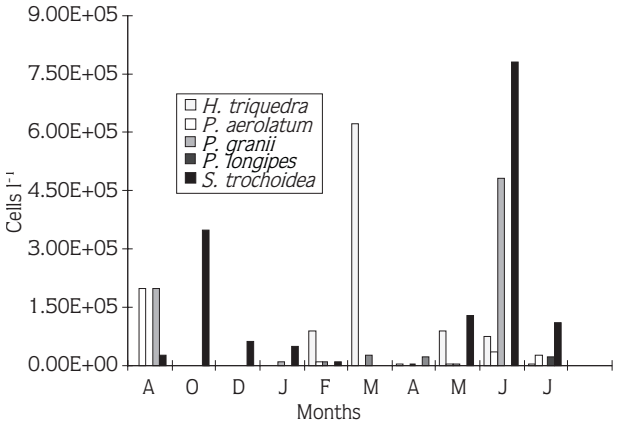


Fig. 12. The annual variations in abundance of some dinoflagellates in the southern Black Sea.

(9.6 x 10^5 cells l^{-1}) in December (Figs. 11 and 12). The highest cell numbers of prymnesiophyte *E. huxlei* (5.9 x 10^6 cells l^{-1}) and silicoflagellate *Octactis octonaria* (Ehrenberg) Hovasse (6.0 x 10^4 cells l^{-1}) were observed in mid-July and in March, respectively.

The monthly changes in diversity indices are shown in Fig. 8. The Shannon-Weaver diversity index (I_{SHW}) in surface waters was found to be between 0.69 and 3.49. Evenness indices were calculated to be a minimum of 0.25 in April and a maximum of 0.85 in March, June and December in surface waters. According to the results of studies on community structure and diversity, the phytoplankton community diversity indices indicate that the variation during March reflects a transition to a community with lower diversity (Fig. 8). Between April and May, the community structure changed from a higher diversity toward a lower one. The rate of community change was generally high between late summer and early autumn. While the lowest index of diversity coefficient (I_{SHW}) was 0.69 bits in April, the highest peak was 3.49 bits in June. However, the community change in phytoplankton species was evident between October and December. The diversity index of 0.69 in April indicates a weak community structure and low diversity of species in the community. However, the diversity index of 3.49 in June indicates a strong community structure and high diversity during this period. The lowest diversity (0.69 bits) and Pielou evenness index (EP) (0.25) in April was due to the excessive bloom of *P. delicatissima* (9.0 x 10^7 cells l^{-1}).

Discussion

Phytoplanktonic species of 6 classes (*Cyanophyceae*, *Dinophyceae*, *Prymnesiophyceae*, *Dictyochophyceae*, *Bacillariophyceae* and *Euglenophyceae*) were distinguished. Among them, the diatom (*Bacillariophyceae*) species were generally dominant during the research period except between July and October. When cell density is taken into consideration, the diatoms were abundant, especially in April and January (Fig. 9). However, diatoms were more abundant in terms of species number in winter (January and February) and early spring (in March) than in the other periods (Table 4).

The declines in diatoms were followed by increases in dinoflagellates. Dinoflagellates began to increase in late March; they reached a maximum in mid-July and

gradually declined towards October (Fig. 8). In contrast to the diatoms, they dominated in summer and early autumn populations. Dinoflagellate blooms were more pronounced in late spring and mid-summer. The Black Sea is known to be a region of moderate to high productivity since it is fed by a rich supply of nutrients compared with most other marine ecosystems in the world (Koblentz-Mishke et al., 1970). Sorokin (1983) indicated that peaks in the primary productivity of the Black Sea were known to occur twice a year, with a major bloom generally composed of diatoms in early spring, followed by a secondary bloom mainly comprising coccolithophorids in autumn. Extensive blooms of coccolithophorids and dinoflagellates occurred mainly in coastal areas of the Black Sea. Additional summer blooms with a predominance of dinoflagellates and coccolithophorids have been increasingly observed in the region in recent years (Benli, 1987; Hay et al., 1990; Uysal & Sur, 1995; Türkoğlu 1999, 2000).

The two most diverse groups, diatoms and dinoflagellates, were more abundant in terms of both number of species (95.5%) and individual number (95.77%) than the other taxonomic groups. Although diatoms and dinoflagellates were almost equally diverse (49.1% and 46.4%, respectively) in terms of species number, the quantitative proportion of diatoms (74.65%) in the total community was higher than that of dinoflagellates (21.12%) (Table 3). We have already drawn attention to the fact that the phytoplankton community structure of the southern Black Sea (Sinop Bay) is rather variant relative to that of the north-western Black Sea. As stated by many investigators studying the Black Sea (Bologa, 1986; Gomoiu, 1992; Bodeanu, 1995), especially in the last three or four decades, there have been proportional fluctuations between major taxa in the north-western part of the Black Sea.

Despite the abundance of diatoms and dinoflagellates, in terms of species number the variations in phytoplankton diversity basically depended on 8.5% diatoms and 11 percent dinoflagellates. Thus, community diversity was usually controlled by 8-10 species, and other taxa have been considered as accessory species that have not caused significant fluctuations in the phytoplankton biomass. As shown by many researchers (Pielou, 1977; Hasle, 1978; Lukatelich and McComb, 1986), and also in the present study, cell density is inversely proportional to diversity.

If the species list is examined in terms of the geographical distribution of the species, then, generally, most of the species are boreal (boreal, arcto-boreal and boreal-tropical species) and cosmopolitan. Most of the blooming species are generally boreal-tropical and arcto-boreal among the dinoflagellates, and cosmopolitan forms among the diatoms. According to the results of comparisons of the species compositions of Sinop peninsula with those of Turkish seas (Kıdeyş et al., 1989; Koray, 1995; Polat et al., 2000, Türkoğlu, 2000), 36.0% of the identified taxa were found to differ from those of other Turkish seas in terms of qualitative distribution. However, due to low salinity, the size spectra of phytoplankton species in the southern Black Sea were larger than those of the same species in other Turkish seas. In Sinop Bay, there were not only neritic species but also oceanic species, such as *P. delicatissima*, which occur as algal bloom in spring.

The increasing particulate and dissolved organic matter, such as POC (particulate organic carbon) and DOC (dissolved organic carbon) stocks, favoured excessive development of phytoplankton species with mixotrophic affinity, such as dinoflagellates, during the warm period of the year (Bleijswick et al., 1994). This status of the phytoplankton species which are mixotrophic represents one more piece of evidence for increasing eutrophication in the research area. This fact determined the modifications between the algal group proportions in terms of qualitative and quantitative phytoplankton composition.

As stated by Gomoiu (1992) and Bodeanu (1989), the proportion of diatoms in the total community progressively decreased, while the dinoflagellates and other non-diatom groups increased. As in early studies in the southern Black Sea (Benli, 1987; Uysal & Sur, 1995), changes were also found in the correlation between different taxonomic groups of algae in our study. For instance, while the percentage of dinoflagellates in the total species number was as low as 20.65% in April 1989 (Feyzioğlu & Tuncer, 1994), it was shown in our study that it was 46.1% in 1996.

We have already drawn attention to the fact that the process of eutrophication is accompanied by a shift in the existing qualitative and quantitative relations between major taxa. In more general terms, this signifies a relative decrease in the number of diatoms and a relative increase in dinoflagellates, and green and blue-green algae. A large

number of these are mixotrophic, i.e., capable of using not only mineral substances but also organic matter as nutrients. The relative numbers of different phytoplankton taxa may fluctuate slightly in the Black Sea region, but a general trend can still be seen. For example, to the north of a line connecting Cape Tarkhankut and Zmeiny Island, dinoflagellates accounted for 18.8% of the total phytoplankton biomass in the 1950s and 1960s (Ivanov, 1967), but 55% in the 1980s (Nesterova, 1987).

Another general change that has affected the phytoplankton since the onset of eutrophication has been the growth in small species. Species with small-sized cells, such as *Prorocentrum balticum*, *P. micans, P. compressum, Emiliania huxle*i and *P. delicatissima*, have now become the dominant species, while populations of large species such as *R. calcar-avis*, D*. brightwelli, Leptocylindrus danicus* Cleve, *P. pungens* and others have fallen compared with the period before eutrophication.

At the moment, as stated by Zahitsev and Mamaev (1997), there is no suspicion that all the recent changes in the Black Sea phytoplankton were originally caused by anthropogenic eutrophication, and this premise was accepted as a studying hypothesis for future investigations. The main manifestations of these changes in the phytoplankton include more extensive and more irregular water blooms, an increase in total biomass, an increase in the number of mass species, a decline in populations of previously abundant species, a growth in the number of species of brackish water and freshwater origin, and changes in the correlation between different taxa of algae.

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