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Algal Blooms in Surface Waters of the Sinop Bay in the Black Sea, Turkey

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Abstract: During the investigation period of August-1995 and July-1996, 22 algal species reached numerical densities exceeding 1.0×10^5 cells L^{-1} and it has been produced 17 mono-specific blooms by 11 of them reached values of the order of 1.0×10^6 cells L^{-1} (one of them exceeding 1.0×10^7 cells L^{-1}) in surface waters of the Sinop Bay. A monthly average of cell number has been estimated as 7.1×10^6 cells L^{-1} in the surface waters. In the diatom communities, subsequent blooms were dominated by *Nitzschia longissima* (5.2×10^6 cells L^{-1}) and *Cheatoceros danicum* (2.7×10^6 cells L^{-1}) in January, *Ditylum brightwelli* (7.6×10^5 cells L^{-1}) in March, *Pseudo-nitzschia delicatissima* (9.0×10^7 cells L^{-1}) in April, *Cylindrotheca closterium* (7.4×10^6 cells L^{-1}) in early July, *Rhizosolenia calcar-avis* (1.7×10^6 cells L^{-1}) and *Pseudo-nitzschia pungens* (1.2×10^6 cells L^{-1}) in late July and mid-August. Subsequent blooms in the dinoflagellate communities were dominated by *Heterocapsa triquedra* (1.0×10^6 cells L^{-1}) and *Protoperidinium depressum* (1.0×10^5 cells L^{-1}) in March, *Protoperidinium granii* (4.8×10^5 cells L^{-1}) and *Scripsiella trochoidea* (7.8×10^5 cells L^{-1}) in June, *Prorocentrum balticum* (9.0×10^6 cells L^{-1}) and *Prorocentrum compressum* (4.6×10^5 cells L^{-1}) in mid-July, *Gonyaulax polyedra* (1.4×10^5 cells L^{-1}) in June, *Prorocentrum micans* (7.2×10^5 cells L^{-1}), *Prorocentrum minimum*, *Protoceratium aerolatum*, *Protoperidinium longipes* (2.0×10^5 cells L^{-1}) in mid-August and *Prorocentrum aporum* (1.0×10^6 cells L^{-1}) in December. The highest cell numbers of prymnesiophyte *Emiliania huxleyi* (5.9×10^6 cells L^{-1}) was observed in mid-July. Results showed that the declines of diatoms were followed by increases of dinoflagellates. Dinoflagellates began to increase in late-March, reached a maximum in Mid-July and gradually declined towards October. In contrast to the diatom, dinoflagellates dominated mid-spring, late summer and mid-winter populations, dinoflagellate blooms showed more pronounced in late spring and mid-summer. The mean of cell numbers of total phytoplankton in surface waters was high in April (3.4×10^7 cells L^{-1}) and July (1.3×10^7 cells L^{-1}), while was low in February (9.0×10^5 cells L^{-1}), respectively. A list of excessive and potential excessive phytoplankton species together with numerical densities were prepared. Changes in number and density of algal blooms during the year were also discussed in relation to the physico-chemical features of the water column.

Key words: Algal blooms, species, succession, Southern Black Sea

INTRODUCTION

During the last two decades, the Black Sea ecosystem has been subject to dramatic fluctuations in the structure and function of biogeochemical regimes[1,2]. The strong growth in the early 1970s of nutrients carried by various rivers such as Danube, Dinyeper and Dinyester from the north-western part of the Black Sea[3,4] or as a result of industrial, harbour and tourism activities, created very important conditions for opportunistic phytoplankton species developments during the 1970s and 1980s[5].

The global increase of algal blooms (red tides) in coastal marine ecosystems has been documented over the last two decades[6-8]. This phenomenon involves two different aspects; the occurrence and the increased frequency of phytoplankton blooms and the spreading of toxic or potential toxic in new geographical areas[9]. The algal blooming phenomena formerly quite rare and produced by few species, have become chronic, common and frequent with a rapid succession of numerous species in the Black Sea[10]. Heavy algal outbursts usually end in mass mortalities which cause a partial or complete

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reduction of some animal populations due to oxygen deficiency[11]. The intensification of the frequency and abundance of blooms, the increase of the mass species number which produce algal blooms and the growth of mass species numerical densities induced high levels of global quantities of phytoplankton which continuously rise from one period to the other[12] .

The present study focuses on the frequency and amplitude of algal blooms in the Sinop Bay of the Southern Black Sea, in order to identify species harmful or not to the ecosystem. This investigation is the first detailed study made on algal blooms growing on Turkish coastal area of the Black Sea.

Hydrography of the Black Sea: The Black Sea situated between 40° 54^l-46° 38^l N latitude and between 27° 27′-41°41′E longitude with a surface area of 413, 490 km^2, a maximum depth of 2258 m and a water volume of 537,000 km^3, constitutes one of the world's largest intra-continental seas exhibiting anoxic conditions below a thin layer (about 100 m) of oxygenated surface waters. The cyclonically meandering rim current which is driven by the wind stress and further modified by thermohaline fluxes and bathymetry is a unique basin-scale feature[13,14]. The whole deep basin is anoxic because a sharp halocline established below the Cold Intermediate Layer prevents ventilation of deep waters[15].

A well defined oxygen minimum zone is permanently formed in the pycnocline. This suboxic (oxygen poor) zone is relatively thin (few 10-15 m) and generally located between density surface of 15.4 and 16.2[15-17]. The distributions of pelagic fauna and flora are related to the boundaries of this oxygen minimum zone[18,19]. Vinogradov *et al.*[18] has separated pelagic ecosystem of the Black Sea into two parts; the aerobiotic and chermobiotic (suboxic and anaerobiotic zone). The aerobiotic waters of the Black Sea is biologically productive because of high run-off from rivers located on the north-western part of the basin. About 55% of the terrigenous matter is supplied by the Danube alone and about 25% is transported by the rivers in the south-eastern Black Sea. The terrigenous matter deposition is higher close to shore and reduces transparency and causes increases in phytoplankton crop particularly in the north-western part of the Black Sea[20]. Over the rest of the basin hydrological properties and phytoplankton crop are more stable and much smaller, respectively[21-26]. The depth of euphotic zone (1% light) in the anticyclonic regions and cyclonic region is around 35-40 m deep and 30-35 m in May in the Black Sea, respectively[27]. However, the depth of the photosynthetic layer in the Black Sea usually extends to 50-60 m with the optimum photosynthetic intensity being measured at a depth of 5-10 m[20]. The chemobiotic environment includes the suboxic (oxygen minimum) zone just above the H_2S-layer in depths between 80-150 m and the anaerobic or H_2S zone below the suboxic layer. Phytoplankton and fish are absent below the oxicline, where daytime mesozooplankton aggregation occurs. The principal components of the suboxic layer are some zooplankton species such as *Sagitta setosa*, *Pleurobrachia pileus*, *Pseudocalanus elongatus* and *Calanus euxinus*[18], which have maximum biomass among zooplankton species of the Black Sea[28].

MATERIALS AND METHODS

Five liter water samples were collected with a Hydro-bios universal series water sampler from surface water (0.5 m) in the Sinop Bay of Southern Black Sea (35°08′ and 35°09′ E, 41°59′ and 42°01′N) at monthly intervals between August-1995 and July-1996 (Fig. 1). Samples were fixed with lugol (for 5 L and 12.5 mL) preserved at 2-4°C in refrigerator pending microscopic examination.

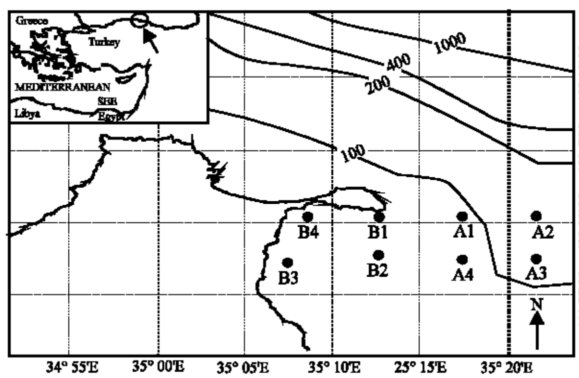

Fig. 1: The sampling stations in the Sinop Bay of the Southern Black Sea, Turkey

For enumeration of the phytoplankton species, Uterhmohl sedimentation chambers, Neauber and Sedgwick-Rafter counting slides were applied in combination according to organism dimension and the counting of cells was made using an inverted microscope[29-31]. The result of the counting was expressed by liter, thus establishing the numerical density by species, algal groups and total phytoplankton.

The water column was also sampled with Nansen bottles to determine physico-chemical parameters. Temperature and salinity were measured with water quality checker of a U-10 model Horiba. The major nutrient analyses, inorganic nitrate $(NO_3^- - N)$, nitrite $(NO_2^- - N)$ and ammonia nitrogen $(NH_4^+ - N)$; inorganic orthophosphate phosphorus $(PO_4^{-3} - P)$ were analysed according to the standard procedures of Strickland and Parsons[32].

RESULTS

Physico-chemical characteristics of the research area: During the sampling period, the first detectable increase in the temperature of the surface water was in April and it continued to increase until August. The temperatures in the surface water varied between 20 and 25°C in summer. However, the maximum temperature (25°C) observed in summer has continued in a short period (July and August). After a short period with a maximum of 24.1°C in August, temperature decreased sharply to the March value (6.2°C) (Fig. 2).

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

Nitrite showed different variations in the sampling period (Fig. 2). The seasonal cycle of nitrite showed a major peak in February (mean: 7.81 μg L^{-1}) and a minor peak in June (mean: 3.20 μg L^{-1}). The maximum nitrite content in winter might be related to nitrogen regeneration but the minimums in April and June might be due to nitrite consumption by phytoplankton blooms.

Nitrate concentration changes during the sampling period were showed a major peak in October (means: 64.8 μg L^{-1}) and a minor peak in February (means: 28.2 μg L^{-1}). Although variations were not evident, after the minor peak nitrate started to decrease until June (mean: 16.2 μg L^{-1}) and then to increase from June until October. After the maximum peak in October, nitrate dramatically fell down and subsided the lowest concentration in December (mean: 11.4 μg L^{-1}) (Fig. 2).

The first detectable increase of ammonia in the study area was in April (means: 170 μg L^{-1}) and ammonia continued to increase until June (means: 355 μg L^{-1}). After, it started to decrease until March (mean: 48.2 μg L^{-1}) (Fig. 2).

In the annual cycle of phosphorus in the Sinop Bay of the Southern Black Sea (Fig. 2), it decreased between January (mean: 57.5 μg L^{-1}) and April (mean: 21.3 μg L^{-1}) and increased between August (mean: 27.5 μg L^{-1}) and October (mean: 68.6 μg L^{-1}). After the maximum concentration in October, phosphate particularly remained constant in October and January (57.5-68.6 μg L^{-1}).

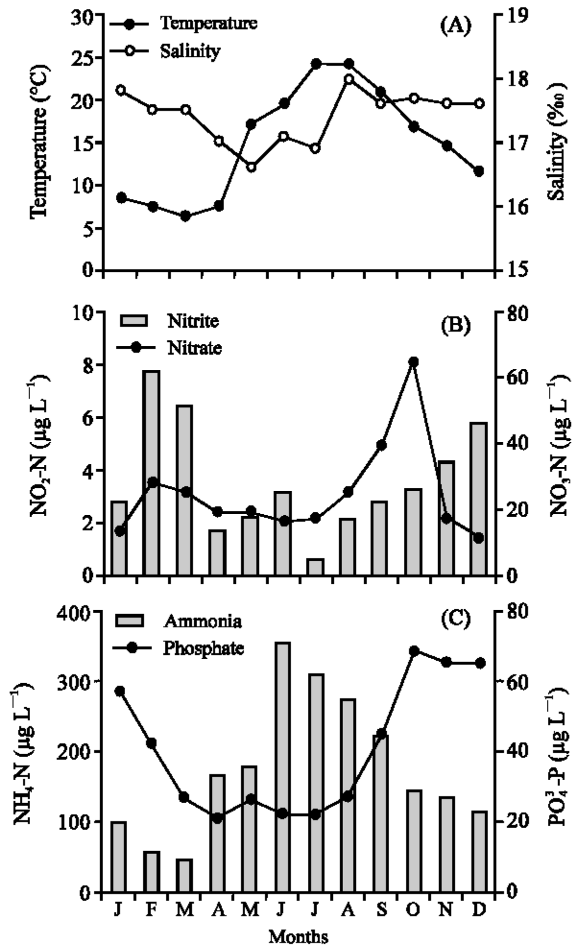

Fig. 2: Annual variations of temperature and salinity (A), nitrite and nitrate (B) and ammonia and phosphate (C) in the surface water of the Sinop Bay in the Southern Black Sea

Structure of algal blooms in the Sinop Bay: It presents maximum cell densities of species causing algal blooms and other species which will be potential excessive blooms in following years in the Sinop Bay (Table 1).

During the investigation period of August-1995 and July-1996, algal blooms in the bay were so abundant that it was registered 17 mono-specific blooms produced by 11 algal species such as dinoflagellate *Prorocentrum balticum* (Lohmann) Loeblich III, coccolithophoride *Emiliania huxlei* (Lohmann) Hay et Möller, diatoms *Cylindrotheca closterium*, *Pseudo-nitzschia delicatissima* (P.T. Cleve) Heiden in Heiden and Kolbe, *Rhizosolenia calcar-avis* Schultze, in numerical densities of the species causing them exceeding 1.0×10^6-9.0×10^7 cells L^{-1} in surface water. However, there are 10 algal potential mass species such as *Prorocentrum micans*

Table 1: Species causing algal blooms and other potential mass species in Sinop Bay between August-1995 and July-1996

	Period, monthly maximum cell density (cells L^{-1}) and the percentage (‰) of the species compared to the whole community									
Bloom species	Aug.1995	Oct.1995	Dec.1995	Jan.1996	Feb.1996	Mar.1996	April 1996	May 1996	June 1996	July 1996
Gonyaulax polyedra Stein	$4.4x10^{4}$ %0.68	-	-	-	-	-	-	-	$1.4x10^{5}$ %7.0	$1.0x10^{4}$
Heterocapsa triquedra (Ehrenberg) Stein	-	-	-	-	$1.6x10^{5}$ % 17.8	$1.0x10^{6}$	-	$1.6x10^{5}$	$1.6x10^{5}$	$1.0x10^{4}$
Prorocentrum aporum (Schiller) Abe	$8.0x10^{4}$	$8.0x10^{4}$	$1.0x10^{6}$	$8.0x10^{4}$	-	$4.0x10^{4}$	-	-	$8.0x10^{4}$	$1.0x10^{4}$
Prorocentrum balticum (Lohmann) Loeblich III	$5.8x10^{6}$	$6.0x10^{5}$	$2.2x10^{5}$	$2.0x10^{5}$	$4.0x10^{4}$	$4.0x10^{5}$	-	$1.6x10^{5}$	$3.8x10^{5}$	$9.0x10^{6}$
Prorocentrum compressum (Bailey) Abe	$2.8x10^{5}$	$8.0x10^{4}$	$2.0x10^{5}$	$8.0x10^{4}$	$4.0x10^{4}$	-	-	$4.0x10^{4}$	$2.0x10^{4}$	$4.6x10^{5}$
Prorocentrum micans Ehrenberg	$7.2x10^{5}$	$1.6x10^{5}$	$1.1x10^{5}$	$4.0x10^{4}$	-	$2.0x10^{4}$	-	$2.0x10^{5}$	$1.8x10^{5}$	$6.0x10^{4}$
Prorocentrum minimum Schiller	$2.0x10^{5}$	$1.0x10^{5}$	$1.2x10^{5}$	$8.0x10^{4}$	-	-	-	$4.0x10^{4}$	$1.2x10^{5}$	$8.0x10^{4}$
Proroceratium aerolatum Kofoid	$2.0x10^{5}$	$1.0x10^{5}$	$1.2x10^{5}$	$8.0x10^{4}$	-	-	-	$4.0x10^{4}$	$1.2x10^{5}$	$8.0x10^{4}$
Protoperidinium depressum (Bailey) Balech	-	$8.0x10^{4}$	-	-	$4.0x10^{4}$	$1.0x10^{5}$	-	-	-	$2.0x10^{4}$
Protoperidinium granii (Ostenfeld in Paulsen) Balech	-	-	-	$4.0x10^{4}$	$4.0x10^{4}$	$8.0x10^{4}$	$2.5x10^{4}$	$2.0x10^{4}$	$4.8x10^{5}$	-
Protoperidinium longipes Balech	$2.0x10^{5}$	-	-	-	-	-	-	-	-	-
Scripsiella trochoidea (Stein) Loeblich III	$4.4x10^{4}$	$1.0x10^{6}$	$1.0x10^{5}$	$8.0x10^{5}$	$4.0x10^{4}$	-	$8.0x10^{4}$	$3.6x10^{5}$	-	$1.7x10^{5}$
Emiliania huxlei (Lohmann)Hay et Möller	$2.2x10^{4}$	$4.0x10^{4}$	$2.0x10^{4}$	$4.0x10^{4}$	$2.0x10^{4}$	$4.0x10^{4}$	-	-	-	$5.9x10^{6}$
Chaetoceros danicum Cleve	-	-	$1.0x10^{6}$	$2.7x10^{6}$	-	-	-	-	-	-
Cylindrotheca closterium	$1.6x10^{5}$	$4.0x10^{4}$	$4.4x10^{4}$	$2.4x10^{5}$	$1.2x10^{5}$	$6.0x10^{4}$	-	$1.2x10^{5}$	$6.0x10^{4}$	$7.4x10^{6}$
Ditylum brightwelli (T. West) Grunow in Van Heurck	-	-	$1.1x10^{5}$	$4.0x10^{4}$	$2.4x10^{5}$	$7.6x10^{5}$	$4.0x10^{4}$	-	-	-
Nitzschia longissima (Brebisson in Kützing) Ralfs in Pritchard	$4.0x10^{4}$	$4.0x10^{4}$	$1.7x10^{6}$	$5.2x10^{6}$	$1.0x10^{6}$	$1.2x10^{5}$	-	-	-	$5.0x10^{4}$
Pseudo-nitzschia delicatissima (P.T. Cleve) Heiden in Heiden and Kolbe	-	-	-	-	-	-	$9.0x10^{7}$	$1.2x10^{6}$	-	-
Pseudo-nitzschia pungens (Grunow ex P. T. Cleve) Hasle	$1.2x10^{6}$	$1.2x10^{5}$	$4.0x10^{5}$	$2.0x10^{5}$	$4.0x10^{4}$	-	-	$1.6x10^{5}$	$1.0x10^{6}$	$2.0x10^{4}$
Rhizosolenia calcar-avis Schultze	$1.7x10^{6}$	$6.4x10^{5}$	$1.6x10^{5}$	-	-	$4.0x10^{5}$	-	$2.0x10^{4}$	$2.0x10^{4}$	$6.3x10^{5}$
Thalassionema nitzschioides Hustedt	$4.0x10^{5}$	$1.0x10^{5}$	$6.4x10^{5}$	-	$4.0x10^{4}$	-	-	-	-	$1.0x10^{4}$
Thalassiosira spp.	$1.2x10^{5}$	-	$4.0x10^{4}$	$1.2x10^{5}$	$4.0x10^{4}$	$2.4x10^{5}$	$2.5x10^{4}$	-	-	$2.0x10^{4}$
Total blooms	3	1	3	2	1	1	1	1	1	3
Total phytoplankton	6.5×10^{6}	1.8×10^{6}	3.6×10^{6}	6.3×10^{6}	9.0×10^{5}	1.6×10^{6}	3.4×10^{7}	1.5×10^{6}	2.0×10^{6}	1.3×10^{7}

Table 2: The monthly average values of the numerical densities of taxonomic groups and total phytoplankton in Sinop Bay in period of August-1995 and July-1996 (cells L^{-1})

	The monthly average densities (cells L^{-1}) of basic algal groups and total phytoplankton											
TG	Aug.1995	Oct. 1995	Dec.1995	Jan.1996	Feb. 1996	March 1996	April1996	May 1996	June 1996	July 1996	MM	%
DF	3.5×10^{6}	1.0×10^{6}	8.7×10^{5}	4.2×10^{5}	2.3×10^{5}	6.7×10^{5}	4.3×10^{4}	4.5×10^{5}	1.3×10^{6}	6.7×10^{6}	1.5×10^{6}	21.12
PR	5.5×10^{3}	1.5×10^{4}	1.0×10^{4}	1.0×10^{4}	5.0×10^{3}	1.0×10^{4}	-	-	-	2.2×10^{6}	2.3×10^{5}	3.20
DI	-	-	-	-	5.0×10^{3}	1.5×10^{4}	-	-	-	-	2.0×10^{3}	0.03
BA	3.0×10^{6}	8.0×10^{5}	2.7×10^{6}	5.9×10^{6}	6.6×10^{5}	8.8×10^{5}	3.4×10^{7}	1.1×10^{6}	6.9×10^{5}	3.8×10^{6}	5.3×10^{6}	74.65
TP	6.5×10^{6}	1.8×10^{6}	3.6×10^{6}	6.3×10^{6}	9.0×10^{5}	1.6×10^{6}	3.4×10^{7}	1.5×10^{6}	2.0×10^{6}	1.3×10^{7}	7.1×10^{6}	100

TG: Taxonomic group, DF: Dinophyceae, PR: Prymnesiophyceae, DI: Dictyochophyceae, BA: Bacillariophyceae, TP: Total phytoplankton, MM : monthly average density

Table 3: Maximum densities (cells L^{-1}) of the main micro-algal species in the Sinop Bay between August-1995 and July-1996 compared to the maximum of the same species in Romanian and Central Black Sea waters

Bloom species	Turkish littoral waters (Sinop Bay) 1995-1996	Romanian littoral waters[12,13] 1986-1990	Central Black Sea waters[38]
Heterocapsa triquedra (Ehrenberg) Stein	1.0x10^6	1.3x10^7	
Prorocentrum aporum (Schiller) Abe	1.0x10^6	-	
Prorocentrum balticum (Lohmann) Loeblich III	9.0x10^6	-	
Scripsiella trochoidea (Stein) Loeblich III	1.0x10^6	2.6x10^7	
Emiliania huxlei (Lohmann) Hay *et* Möller	5.9x10^6	2.9x10^8	
Cheatoceros danicum Cleve	2.7x10^6	-	
Cylindrotheca closterium	7.4x10^6	1.3x10^7	
Nitzschia longissima (Brebisson *in* Kützing) Ralfs *in* Pritchard	5.2x10^6	-	
Pseudo-nitzschia delicatissima (P.T. Cleve) Heiden *in* Heiden and Kolbe	9.0x10^7	1.7x10^7	6.0x10^9
Pseudo-nitzschia pungens (Grunow *ex* P. T. Cleve) Hasle	1.2x10^6	4.8x10^5	
Rhizosolenia calcar-avis Schultze	1.7x10^6	3.2x10^6	
Other mass species			
Gonyaulax polyedra Stein	1.4x10^5	-	
Prorocentrum compressum (Bailey) Abe	4.6x10^5	1.2x10^5	
Prorocentrum micans Ehrenberg	7.2x10^5	4.0x10^5	
Prorocentrum minimum Schiller	2.0x10^5	4.6x10^8	
Protoperidinium depressum (Bailey) Balech	1.0x10^5	-	
Protoperidinium granii (Ostenfeld in Paulsen) Balech	4.8x10^5	-	
Protoperidinium longipes Balech	2.0x10^5	-	
Ditylum brightwelli (T. West) Grunow in Van Heurck	7.6x10^5	1.0x10^5	
Skeletonema costatum (Greville) Cleve	1.0x10^5	1.4x10^8	
Thalassionema nitzschioides Hustedt	6.4x10^5	1.2x10^6	
Thalassiosira spp.	2.4x10^5	-	

Table 4: Number of phytoplankton species with massive developments in the Sinop Bay in period of August-1995 and July-1996

	Numerical density classes of cells (cells L^{-1})			
Months	10^5-10^6	10^6-10^7	10^7-10^8	Total species
August	7	3	-	10
October	6	1	-	7
December	9	3	-	12
January	5	2	-	7
February	3	1	-	4
March	6	1	-	7
April	-	-	1	1
May	6	1	-	7
June	6	1	-	7
July	3	3	-	6
Total species	11	10	1	22

Ehrenberg, *Prorocentrum compressum* (Bailey) Abe, *Protoperidinium granii* (Ostenfeld *in* Paulsen) Balech, *Ditylum brightwelli* (T. West) Grunow *in* Van Heurck, *Thalassionema nitzschioides* Hustedt in density of 1.0×10^5-1.0×10^6 cells L^{-1} in the Bay (Table 1).

In the diatom communities, subsequent blooms were dominated by *Nitzschia longissima* (Brebisson in Kützing) Ralfs in Pritchard (5.2×10^6 cells L^{-1}) and *Cheatoceros danicum* Cleve (2.7×10^6 cells L^{-1}) in January, *D. brightwelli* (7.6×10^5 cells L^{-1}) in March, *P. delicatissima* (9.0 × 10^7 cells L^{-1}) in April, *C. closterium* (7.4×10^6 cells L^{-1}) in early July, *R. calcar-avis* (1.7×10^6 cells L^{-1}) and *Pseudo-nitzschia pungens* (Grunow ex P. T. Cleve) Hasle (1.2×10^6 cells L^{-1}) in late July and mid-August. Among the diatom species, although *P. delicatissima* is an oceanic species, it was so abundant in April (9.0×10^7 cells L^{-1}) that not only diatom community, but whole phytoplankton community in this month was also occurred by this species (Table 1). It seems that the species can possibly go on producing similar heavy blooms in following years. Therefore, it is followed blooms like this in the Bay.

Subsequent blooms in the dinoflagellate communities were dominated by *Heterocapsa triquedra* (Ehrenberg) Stein (1.0×10^6 cells L^{-1}) and *Protoperidinium depressum* (Bailey) Balech (1.0×10^5 cells L^{-1}) in March , *P. granii* (4.8×10^5 cells L^{-1}) and *Scripsiella trochoidea* (Stein) Loeblich III (7.8×10^5 cells L^{-1}) in June, *P.balticum* (9.0×10^6 cells L^{-1}) and *P. compressum* (4.6×10^5 cells L^{-1}) in mid-July, *Gonyaulax polyedra* Stein (1.4×10^5 cells L^{-1}) in June, *P. micans* (7.2×10^5 cells L^{-1}), *Prorocentrum minimum* Schiller, *Protoceratium aerolatum* Kofoid, *Protoperidinium longipes* Balech (2.0×10^5 cells L^{-1}) in mid-August and *Prorocentrum aporum* (Schiller) Abe (1.0×10^6 cells L^{-1}) in December. The highest cell numbers of *E. huxlei* (5.9×10^6 cells L^{-1}) was observed in mid-July (Table 1).

Results showed that the mean of cell numbers of total phytoplankton in surface waters was high in April (3.4×10^7 cells L^{-1}) and July (1.3×10^7 cells L^{-1}), while was low in February (9.0×10^5 cells L^{-1}). A monthly average of cell number has been estimated as 7.1×10^6 cells L^{-1} in surface waters (Table 2).

The declines of diatoms were followed by increases of dinoflagellates. Dinoflagellates began to increase in late-March, reached a maximum in mid-July and gradually declined towards October. In contrast to the diatom, they dominated in summer and early-autumn populations. Dinoflagellate blooms were more pronounced in late spring and mid summer. Monthly average numerical density of diatoms and dinoflagellates were more abundant (%74.65 and 21.12, respectively) than the other groups (%3.23) (Table 2).

When the maximum densities of the main micro-algal species in the Sinop Bay between August-1995 and July-1996 compared with the maximums of the same species in Romanian littoral and central Black Sea waters (Table 3), maximum cell densities of Romanian littoral waters[33] are more amplitude than in the Sinop Bay of the Southern Black Sea. However, biomass and composition of phytoplankton species in Sinop Bay are more high and different than the other polluted Mediterranean coastal lagoon such as Izmir Bay in Aegean Sea[34,35], Iskenderun Bay in East Mediteranean[36], respectively.

The most important ecological consequence of the nutrient increase in north-western Black Sea has been that algal blooms have been increasing in density over the last two decades, while before 1970 they were exceptional phenomena[37]. Although nutritive contribution of the Bay is not as high as Romanian littoral waters[23-25], owing to the enough nutritive contribution coming from various resources such as harbour and tourism activities during the summer-1995 and 1996[23, 26], some other mass species such as *G. polyedra*, *P. compressum*, *P. micans*, *P. granii* among the dinoflagellates and diatom *D. brightwelli* have been more abundant than Romanian littoral waters (Table 3).

Owing to the nutritive contribution in recent years, some other micro-algae with remarkable amplitude occurred simultaneously with the red water species, although they did not change water colour. In period of August-1995 and July-1996, 22 algal species reached numerical densities exceeding $1.0\text{x}10^5$ cells L^{-1} in the Sinop Bay and 11 of them reached values of the order of $1.0\text{x}10^6$ cells L^{-1} (one of them exceeding $1.0\text{x}10^7$ cells L^{-1}) (Table 4).

DISCUSSION

In this study, maximum cell densities of species causing algal blooms were carried out and to be potential mass species in the Sinop Bay (Table 1). During the research period (August-1995 and July-1996), 22 algal species reached numerical densities exceeding $1.0\text{x}10^5$ cells L^{-1} in the Sinop Bay and 11 species reached values of the order of $1.0\text{ x}10^6$ cells L^{-1} (one of them exceeding $1.0\text{ x}10^6$ cells L^{-1}). Owing to main ecological consequences of hydrological structure and the important nutritive contribution during the investigation period, algal blooms in the Bay were so amplitude that it was registered 17 mono specific blooms produced by 11 algal species.

Although nutrient inputs coming from several local rivers such as Kizilirmak and global rivers such as Danube to the Bay is undoubtedly the reason of extensive blooms during the research period, the simple presence of the nutrients, as expected as their levels might be no sufficient to disclose blooms of one or few species exceeding $1.0\text{x}10^7$ cells L^{-1} and to lead water discoloration. An essential role in activation of blooms is played by hydrological peculiarities changing year to year and local variabilities in the physico-chemical processes, in addition to the biological processes.

Moreover, the initiation of the spring bloom is shown to be critically depended on the water column stability as stated by Oguz *et al.*[39]. It starts as soon as the convective mixing process weakens and before the seasonal stratification of surface waters begins to develop. During the establishment of the seasonal thermocline in April, it is followed by a lower phytoplankton production. However, although diatom *P. delicatissima* is a cold water and oceanic species, its extensive bloom in the Bay in April is undoubtedly due to sufficient light, depth and nutrient, especially ammonium nitrogen (mean: 165 NH_4^+-N μg L^{-1}). According to results of the correlation coefficient and significance levels between nitrogen concentration and phytoplankton abundance in the Southern Black Sea[23-26], a significant positive correlation 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. It is difficult to say that the abundance of dinoflagellates have been more affected by ammonia than other inorganic nitrogen compounds. But also, it is known that other inorganic nitrogen compounds such as nitrite, nitrate and phosphate are important to growth of dinoflagellates[25,26,35].

When summer nutrient concentrations in the mixed layer are low enough to limit production, the layer between the thermocline and the base of the euphotic zone provides sufficient light and nutrient to support subsurface phytoplankton development. The autumn bloom takes place some time between October and December depending on environmental conditions. In the case of weaker grazing pressure to control the growth rate, the autumn bloom shifts to December-January and emerges as the winter bloom or, in some cases, is connected with the spring bloom to form one unified continuous bloom structure during the January-March period[39]. As a matter of fact, two algal blooms constructed by *P. aporum* (1.0×10^6 cells L^{-1}) in December and *S. trochoidea* (8.0×10^5 cells L^{-1}) in January are essentially autumn outbreaks. Probably, it can say that these outbreaks could be delayed due to seasonal construction and complex of hydrological structure in autumn in the Sinop Bay.

The declines of diatoms were followed by increases of pico-nanoplankton and dinoflagellates. Dinoflagellates began to increase in late-March, reached a maximum in mid-July and gradually declined towards October. In contrast to the diatom, 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 temperate to high productivity since it is fed by a rich supply of nutrients compared with other marine ecosystems in the world[40]. Sorokin[41] 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 coccoliths in autumn. Extensive blooms of coccoliths and dinoflagellates occurred, mainly in coastal areas of the Black Sea. Additional summer blooms with a predominance of dinoflagellates and coccoliths (*E. huxleyi*) have been increasingly observed in the region in recent years[20,21,42,43].

Algal blooms in the Black Sea were formerly quite rare and produced by a few species, but they have become chronic, common and frequent with a rapid succession of numerous species[10]. Proportions among the taxonomic groups of phytoplankton have changed as a result of the rapid succession of mixotrophic forms such as *E. huxleyi*, *P. balticum*, *S. trochoidea* in the Black Sea. For instance, diatoms have decreased in importance to the advantage of blue-green algae, coccolitophorids and dinoflagellates. Likewise, as stated by various researchers[11,12], modifications have been registered in the biological cycles of some species (extension of life cycles, increase or decrease in frequency of division rates, etc.) mostly in connection with the fact that the nutritional factors are no more limiting. The intensification of the frequency and abundance of blooms, the increase of the mass species number which produce algal blooms and the growth of mass species numerical densities induced high levels of global quantities of phytoplankton which continuously rise from one period to the other in the Black Sea.

The maximum nitrite content in winter might be related to nitrogen regeneration but the minimums in April and June might be due to nitrite consumption by phytoplankton blooms which are *P. delicatissima* (in April), *C. closterium* and *P. balticum* (in July), *R. calcar-avis* and *P. pungens* (in August). The high nitrate concentration in October may be mainly due to the nitrogen regeneration and the increase of nitrogen by river sourced inputs. The other noteworthy feature of nitrate is that the low concentrations in winter (December and January) and from April to July have been probably due to quickly utilization of nitrate by phytoplankton blooms in winter and between April and July.

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