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Temporal Variations of Phytoplankton in Relation to Eutrophication in Samsun Bay, Southern Black Sea

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Abstract

The goal of this study was to determine the monthly variations of phytoplankton composition in the least studied southern shores of the Black Sea with respect to environmental factors. This region is known to be one of the most eutrophic seas in the world. During the course of this research, carried out between October 2002 and September 2003, various samples were collected monthly from a depth of 0.50 m at five stations. A total of 129 taxa belonging to 5 divisions and 14 potentially HAB species was recorded during this research. Three peaks were observed in the total phytoplankton in October 2002, May and July 2003. These findings were also supported by chlorophyll a (chl a) concentrations and the biodiversity index of Shannon-Wiener (H'). TRIX indices were computed in order to identify the trophic level of the region and the research area was determined to be highly eutrophic. Three groups of samples were described by Hierarchical agglomerative clustering and Multi-Dimensional Scaling (MDS) ordination. Species displaying a major role in discriminating the groups were *Dactyliosolen fragilissimus* (Bergon) G.R. Hassle, 1997, *Nitzschia longissima* (Brébisson) Ralfs in Pritchard, 1861, *Proboscia alata* (Brightwell) Sundström, 1986, *Pseudonitzchia pungens* (Grunow ex P.T. Cleve, 1897) Hasle, 1993 and *Skeletonema costatum* (Greville) P.T. Cleve, 1878 from diatoms, *Prorocentrum micans* Ehrenberg, 1833 from dinoflagellates and *Eutreptia lanowii* Steur 1904 from Euglenophyta.

Keywords: Black Sea, chlorophyll-a, eutrophication, phytoplankton, TRIX index.

Güney Karadeniz, Samsun Körfezi'nde Ötrofikasyona Bağlı Olarak Fitoplanktonun Zamansal Değişimi

Özet

Bu çalışmanın amacı, çok az araştırılmış olan güney Karadeniz kıyılarında aylık fitoplankton değişimleri ve çevresel faktörlerle olan ilişkilerini belirlemektir. Karadeniz dünyadaki en ötrofik denizlerden biri olarak bilinir. Örnekler, Ekim 2002 ve Eylül 2003 tarihleri arasında seçilen 5 istasyondan ve 0,50 metre derinlikten aylık olarak toplanmıştır. Bu araştırmada 5 divizyodan 14'ü potansiyel zararlı tür olmak üzere toplam 129 taksa tespit edilmiştir. Toplam fitoplankton bolluğunda Ekim 2002, Mayıs ve Temmuz 2003 tarihlerinde üç artış belirlenmiştir. Ayrıca bu bulgular klorofil *a* (chl *a*) ve Shannon-Wiener (H') biodiversite indeksi değerleri ile desteklenmiştir. Bölgenin trofik düzeyini belirlemek için TRIX indeksi kullanılmış ve bulgulara göre araştırma bölgesi yüksek oranda ötrofik olarak değerlendirilmiştir. Yapılan Hiyerarşik Kümeleme ve Çok Boyutlu Ölçeklendirme ordinasyon analizlerine göre üç örnek grubu tanımlanmıştır. Belirlenen bu örnek grupları arasındaki farklılıklara yol açan türler, diyatomelerden, *Dactyliosolen fragilissimus* (Bergon) G.R. Hassle, 1997, *Nitzschia longissima* (Brébisson) Ralfs in Pritchard, 1861, *Proboscia alata* (Brightwell) Sundström, 1986, *Pseudonitzchia pungens* (Grunow ex P.T. Cleve, 1897) Hasle, 1993 and *Skeletonema costatum* (Greville) P.T. Cleve, 1878, dinoflagellatlardan *Prorocentrum micans* Ehrenberg, 1833 ve euglenoidlerden *Eutreptia lanowii* Steur 1904 olarak belirlenmiştir.

Anahtar Kelimeler: Karadeniz, klorofil-a, ötrofikasyon, fitoplankton, TRIX indeksi.

Introduction

Degradation of coastal ecosystems is a worldwide issue resulting mainly from human activity, such as eutrophication (Zaitsev and Mamaev, 1997), climate change (Oğuz, 2005b), over-fishing (Gucu, 2002) and mechanical effects in physical structure such as constructions of harbours or roads. Perhaps, one of the most important factors, eutrophication results from the over-fertilization of the sea by nutrient input from agricultural, domestic and industrial wastes. This process starts deteriorating the ecosystem from the lowest trophic level. A major group of lower food web, plankton community, is

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initially altered in terms of species succession, intensity, frequency, and spatial extension of algal blooms. The deterioration then propagates towards higher trophic levels. Change of trophic state has been dramatically increasing especially in semi-enclosed marine systems e.g. the Baltic Sea, the Black Sea and the Mediterranean Sea.

A famous eutrophicated and semi-enclosed marine system, the Black Sea has been subjected to severe ecological degradation resulting from increased anthropogenic inputs of mineralized nutrients, organic and inorganic pollutants since 1970s (Mee, 2005). The Black Sea has a character that it presents a thin upper layer with high primary productivity and oxygen values, a strong main pycnocline where hypoxia increased and a deep layer where anoxic waters covered 87 percent of the water column (Oguz, 2005a). Excess nutrients have accumulated within the upper ~100 m above the pycnocline due to very limited water exchange laterally through the Bosporus Strait and vertically across the permanent pycnocline (Zaitsev and Mamaev, 1997).

Although it has been recently stated that social and economic collapse in the countries of northwestern region gave the Black Sea an opportunity for recovery (Mee, 2005), we now need to obtain more scientific knowledge of community structure of coastal marine ecosystem, especially for the southern Black Sea. The signs of recovery in the Black Sea and the effects of initial changes in the marine environment can specifically be evaluated and monitored in phytoplankton community as a major group of lower food web.

Since this region has been impacted by a great many of anthropogenic effects, such as agricultural and industrial activities, domestic sewage water inputs, dumping areas, road and harbour constructions etc., we may use the information of phytoplankton community structure as a minimized model of an anthropogenically impacted coastal ecosystem. The aim of this study was to determine the lower trophic structure and to evaluate the phytoplankton assemblages and their controlling environmental factors in Samsun Bay.

Materials and Methods

Study Area

Samsun Bay is a coastal marine ecosystem located between the Kizilirmak and Yesilirmak river deltas of the southern Black Sea (41°15'-41°22' N and 36°22'-36°13' E). The bay has a shallow (average depth is 15 m), well-mixed, brackish and turbid water mass, which receives numerous freshwater inputs such as Mert, Kurtun, and İncesu creeks (Figure 1).

Sampling

Sampling was conducted monthly at five stations (approximately 1 km far from the shoreline) between October 2002 and September 2003. Sampling in December 2002 was not possible due to severe meteorological conditions. Water samples were collected horizontally with 55 µm plankton net and with a 2 L Hydro-Bios Water Sampler (Kiel, Germany) vertically at 0.50 m depth and they were analyzed both qualitatively and quantitatively. Water samples were stored in Plexiglas bottles and preserved with 2‰ final concentration of Lugol’s solution.

Environmental Data

In this study, the environmental variables were solar radiation, wind speed, atmospheric temperature, sea surface temperature, water transparency, irradiance (PAR: photosynthetically active radiation, 400-700 nm), pH, dissolved oxygen and inorganic nutrients. Total daily solar irradiance, atmospheric temperature and wind speed values were recorded at the Meteorological Station of Samsun city. Sea surface temperature was measured with a Consort 532 C water quality checker (Turnhout, Belgium). Water

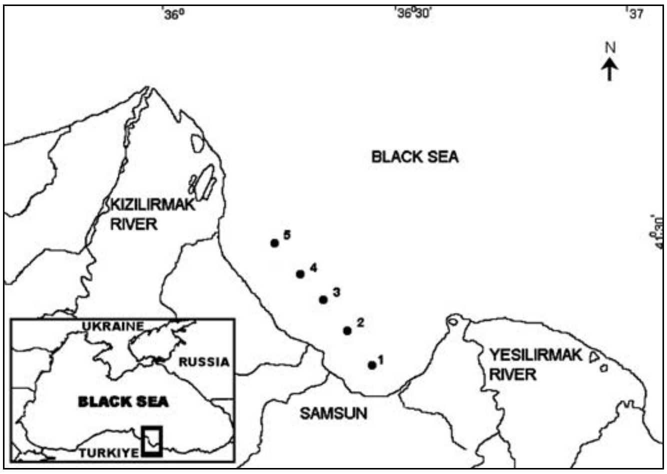

Figure 1. Location of the sampling stations in Samsun Bay, southern Black Sea.

transparency and percent irradiance profiles were determined with a secchi disk (Kirk, 1994). Incident solar irradiance was converted into downward irradiance assuming that PAR represents ca. 45% of total solar radiation (Kirk, 1994). Downward irradiance at z metre depth ($E_d(z)$) was estimated based on the equation of Beer-Lambert Law; $E_d(z) = E_d\ (0).e^{-kd.\ z}$, E_0 is the downward irradiance at the surface, k_d is the vertical attenuation coefficient for downward irradiance determined from Secchi disk depth and z is the depth in m. Dissolved oxygen and pH were determined by Consort model C534 water quality checker. Concentrations of nitrate (NO_3^-), nitrite (NO_2^-) ammonium (NH_4^+) and phosphate (PO_4^{-3}) were measured with a Hanna C200 analyzer (Sarmeola di Rubano, Italy). Furthermore, chl *a* concentrations were measured after correction for phaeophytin *a* by acidification with HCl (APHA, 1998).

Phytoplankton Data

Phytoplankton cells were identified and enumerated under a Prior microscope (Cambridge, United Kingdom), operating in phase contrast optics. Sea water samples were concentrated to 1 ml and then transferred to an improved Neubauer ruling haeomocytometer. After counting of the cells at x400 magnification, numbers of cells in liter were estimated according to the following formula;

Counts= (number of cells/ number of squares) x 10^4 x Dilution factor (Guillard, 1978).

The following references were used for the identification of phytoplankton: Cupp (1943), Tregouboff and Rose (1957), Rampi and Bernhard (1978), Hasle and Syvertsen (1996), Hasle *et al.* (1996), John *et al.* (2003), Steidinger and Tangen (1996), Throndsen (1996) and Trobajo (2007). Some uncertain HAB taxa were also identified by fluorescence microscopy (Fritz and Triemer, 1985) and transmitting electron microscope.

Statistical Analysis

A Bray-Curtis similarity matrix was performed on the overall square-root transformed data in order to downweight the effect of the most dominant phytoplankton taxa. A group-average linkage cluster analysis and multi-dimensional scaling (MDS) ordination were completed using PRIMER v5 software (Clark and Warwick, 2001). A one-way analysis of similarities (ANOSIM) was conducted on the same similarity matrix to test differences in the taxonomic composition between groups of samples.

Patterns in phytoplankton assemblage structure were linked to the environmental variables using the BIOENV procedure. BIOENV identifies which environmental variables are best explained the assemblage structure of the phytoplankton (Clarke and Warwick, 2001).

A Trophic index (TRIX) was calculated according to the equation below in order to determine the trophic level (i.e., mesotrophic or eutrophic) of Samsun Bay (Vollenweider *et al.*, 1998).

$$\text{TRIX (totN, } PO_4) = \log [\text{chl } a \text{ x DO\% x totN x } PO_4]$$

chl *a* : chlorophyll–*a* concentration, (mg m^{-3})
DO%: dissolved oxygen concentration, %
totN: Total concentration of nitrate, nitrite and ammonia nitrogen, (mg L^{-1}).

Community diversity indices included Shannon-Wiener Index (H') for species richness and the Pielou's Evenness Index (*J*) for proportional representation (Clarke and Warwick, 2001).

Results

Physical Variations

The physical variables of the sea water recorded during the sampling period from October 2002 to September 2003 in Samsun Bay of the southern Black Sea are presented in Figure 2. Sea surface temperature followed a seasonal cycle varying from minimum (4.40°C) in March 2003 to maximum (24.40°C) in July 2003, with lower values mainly recorded during the winter months and the higher values during summer (Figure 2A). Atmospheric temperature showed a similar trend with the sea surface temperature. The water transparency measured with the Secchi disk varied between 1.30 and 2.40 m during sampling period (Figure 2B). Similar to the sea surface temperature, the PAR showed a seasonal trend with the lowest value of $6.10x10^3$ $kJ.d^{-1}$ in March and the highest value of $51.20x10^3$ $kJ.d^{-1}$ in May (Figure 2C). The wind stress fluctuated between 0.80 and 3.30 $m.sec^{-1}$ during the sampling period (Figure 2D).

Chemical Variations

Chemical variables are presented in Table 1 with fairly constant pH values, while dissolved oxygen varied from 4.33 mg L^{-1} in January 2003 to 6.89 mg L^{-1} in April 2003.

Surface water nutrients showed some variations during the sampling period (Table 1). Ammonium concentrations ranged from the lowest 2.57 µM in April to the highest 19.57 µM in September 2002. Nitrite concentrations were lower than 0.50 µM during the year sampling, while nitrate concentrations varied from 1.15 µM in March to 5.14 µM in October 2002. Phosphate concentrations varied from 0.03 µM in April 2003 to 1.84 µM in November 2002.

Chlorophyll *a* and TRIX Index Variations

Chlorophyll *a* concentrations varied from a

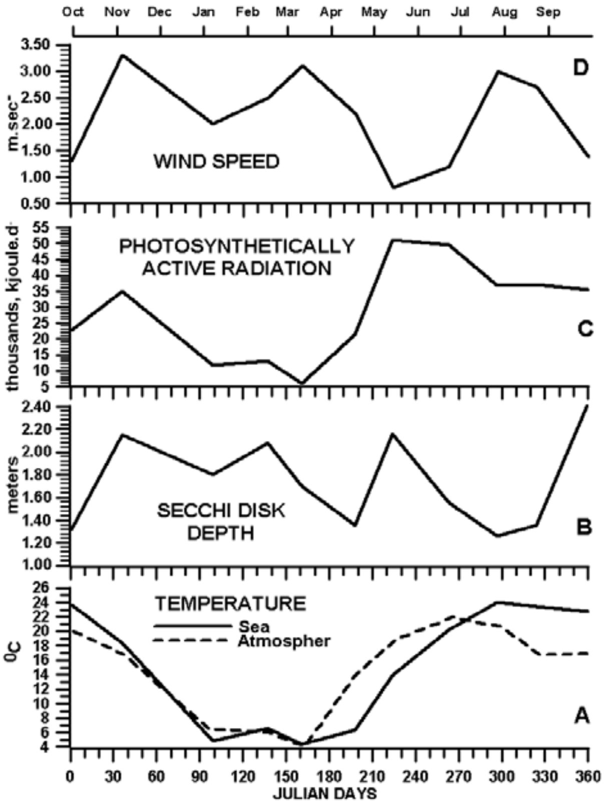

Figure 2. Temporal variations of (A) sea surface temperatures and atmospheric temperatures, (B) Secchi Disk depths, (C) PAR values, (D) wind speed in Samsun Bay from October 2002 to September 2003.

Table 1. Nutrient concentrations (shown as µM) and nitrogen to phosphate ratio of the Samsun Bay sea water. Dissolved oxygen concentrations and pH are also shown for each sampling period

Sampling date	pH	DO (mg L^{-1})	NO_2 (µM)	NO_3 (µM)	NH_4 (µM)	PO_4 (µM)	N/P Ratio
October 02	8.47	5.27	0.28	1.89	5.71	1.71	5.30
November 02	8.49	5.90	0.44	1.91	9.28	1.84	6.32
January 03	8.35	4.33	0.24	3.47	4.00	1.26	6.12
February 03	8.25	4.48	0.46	3.14	10.86	1.42	10.18
March 03	8.10	6.88	0.27	1.15	3.92	0.97	5.51
April 03	8.39	6.89	0.06	2.20	2.57	0.03	24.15
May 03	8.19	5.33	0.27	4.18	4.78	0.29	31.76
June 03	8.42	4.90	0.11	2.97	2.28	0.48	11.07
July 03	8.26	5.00	0.36	3.88	9.79	0.71	19.75
August 03	8.30	5.27	0.43	4.71	17.00	0.84	26.37
September 03	8.32	5.53	0.47	5.11	19.57	1.29	19.47

minimum of 0.15 mg m^{-3} in February 2003 to a maximum of 2.40 mg m^{-3} in May (Figure 3B). The trophic index given by TRIX varied between 6.90 and 7.70 throughout the sampling period with, however, an index value below 6 in April (Figure 3C).

Phytoplankton Variations

Phytoplankton abundances were lower than $0.01x10^6$ cells L^{-1} in February 2003 and reached a maximum value of $1.20x10^6$ cells L^{-1} in July. Abundances were parallel to the seasonal trend in chl *a* over the entire sampling period (Figure 3A).

A total of 129 taxa were recorded from the neritic waters in Samsun Bay during the sampling period (Table 2). The phytoplankton assemblage was composed of 76 Bacillariophyta, 43 Myzozoa, 5 Heterokontophyta, 2 Cyanobacteria, 1 Chlorophyta, 1 Haptophyta and 1 Euuglenophyta. Diatoms numerically dominated among taxonomic groups of the phytoplankton during the sampling period, except in November 2002 and June 2003 when the euglenophyte *E. lanowii*, and several dinoflagellate taxa were dominant, respectively. The other groups occupied only 6% of the assemblage in Samsun Bay.

D. fragilissimus, *P. alata* and *P. pungens* were the most numerous diatom taxa of the phytoplankton communities with 5.26 x 10^5 cells L^{-},

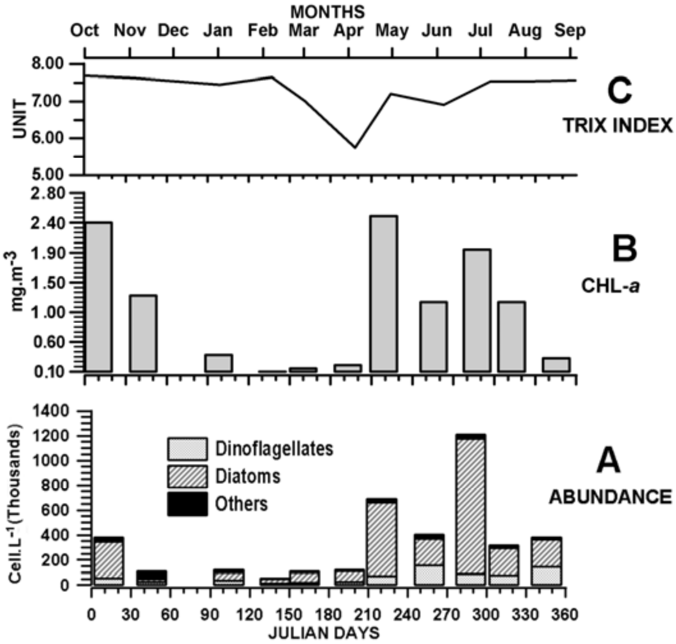

Figure 3. Temporal variations of (A) abundance of major phytoplanktonic groups, (B) chl *a* concentrations and (C) TRIX.

3.08×10^5 cells L$^-$ and 2.34×10^5 cells L$^-$, respectively recorded in July 2003, May 2003 and October 2002 (Figure 4). In June dinoflagellates contributed significantly to the phytoplankton community both in terms of abundance and diversity.

We identified 14 potentially harmful taxa in Table 2. Among them, dinoflagellates were numerically dominant in respect of causing HABs. Potentially harmful diatoms, *P. pungens* (2.34×10^5 cells L$^-$) and *S. costatum*, reached higher abundances than dinoflagellates throughout the sampling period. However, toxic species of *Akashiwo sanguinea* (Hirasaka) Hansen and Moestrup, 2000, *Alexandrium* spp., *Dinophysis* spp., *Lingolidinium polyedrum* (F. Stein) J.D. Dodge, 1989 Dodge may have harmful effects on the higher levels of the food chain even if they show lower abundance. Figure 4 represents common species and some of HAB organisms. Maximum cell abundance of species which are not shown in Figure 4 were determined as the following: *A. sanguinea* 12×10^3 cell L^{-1} (August), *Alexandrium minutum* Halim, 1960 6×10^3 cell L^{-1} (June), and *Dinophysis* spp. 24×10^3 cell L^{-1} (September 2003), *Noctiluca scintillans* (Macartney) Kofoid and Swezy, 1921 6×10^3 cell L^{-1} (July) and *Prorocentrum balticum* (Lohmann, 1908) Loeblich, 1970 90×10^3 cell L^{-1} (September).

Statistical Analysis

The results of Shannon-Wiener's diversity index (Figure 5) have shown that the index decreased in the bloom periods of the species mentioned above. The highest value (H'=3.49) of diversity was detected in September 2003. Also it was recorded with the lowest diversity value (H'=1.43) in October 2002 (H'=1.43). Pielou's evenness index varied from 0.36 to 0.86.

Analyses of clustering and MDS ordination were then carried out on 57 taxa comprising more than 0.10% of total abundance in order to prevent confusing of patterns in cluster and MDS analysis. Group average clustering from Bray-Curtis similarities divided the samples into three groups (1-3) at a similarity level of 52.77% (Figure 7A). Group 1 included the fall samples collected in October and November 2002 and group 2 comprised winter-early spring samples from January to April 2003. Group 3 contained late spring and summer samples covering May to September. The graphic representation of the clusters on a two-dimensional MDS plot showed the relative distances between the three groups (Figure 6B). Results with both February and August samples produced high MDS stress 0.23, so these data were removed from data matrix and ordination run again producing a MDS stress of 0.14.

Differences between discrete groupings were tested by means of the analysis of similarities (One-way ANOSIM), global R value (R=0.82) implied the rejection of null hypothesis H_0: "no difference between groupings" at the significance level of 0.10%.

Patterns in community structure identified by cluster and MDS analyses were linked to environmental variables using the BIOENV and BVSTEP procedure of PRIMER. Correlations and stepwise algorithms resulted between species-sample similarity and environmental dissimilarity matrices identified that the best matching environmental variables were N:PO_4 ratio, SST, AT and wind stress, r: 0.75 at the significance level of 0.10% (Figure 7).

Table 2. List and frequency of phytoplanktonic taxa in Samsun Bay

Species	%	Species	%
CYANOBACTERIA		*Skeletonema costatum* (Greville)P.T. Cleve, 1878	74
Phormidium limoum (Dillwyn) Silva, 1996	31	*Striatella delicatula* (Kützing) Grunow ex Van Heurck, 1881	37
Trichormus variabilis (Kützing) Komárek & Anagnostidis, 1989	20	*Striatella unipunctata* (Lyngbye) Agardh, 1830	60
BACILLARIOPHYTA		*Thalassionema frauenfeldii* (Grunow) Hallegraeff, 1986	40
Achnanthes brevipes C.A. Agardh, 1824	28	*Thalassionema nitzschioides* (Grunow, 1862) Mereschkowsky, 1902	69
Achnanthes longipes C.A. Agardh, 1824	40	*Thalassiosira angulata* (Gregory) G.R. Hasle,1978	35
Asterionellopsis glacialis (F. Castracane) Round, 1990	50	*Thalassiosira gravida* P.T. Cleve, 1896	44
Bacillaria pradoxa Gmelin in L., 1788	43	*Thalassiosira nordenskioeldii* P.T. Cleve, 1873	40
Campylodiscus decorus de Brébisson, 1854	27	*Thalassiosira rotula* Meunier, 1910	52
Cerataulina pelagica (Cleve) Hendey, 1937	38	*Thalassiosira subtilis* (Ostenfeld) Gran, 1900	40
Chaetoceros affinis Lauder, 1864	90	*Thalassiothrix mediterranea* Pavillard, 1916	60
Chaetoceros anastomosans Grunow in Van Heurck, 1882	24	*Ulnaria ulna* (Nitzsch) Compére in Jahn *et al*., 2001	20
Chaetoceros atlanticus P.T. Cleve,1873	47	**CHLOROPHYTA**	
Chaetoceros compressus Lauder, 1864	62	*Halosphaera viridis* Schmitz, 1878	72
Chaetoceros constrictus Gran, 1897	54	**HAPTOPHYTA**	
Chaetoceros costatus Pavillard, 1911	20	*Emiliania huxleyi* (Lohmann) Hay & Mohler, 1967	20
Chaetoceros curvisetus Cleve	75	**HETEROKONTOPHYTA**	
Chaetoceros danicus P.T. Cleve, 1889	30	*Bicosoeca mediterranea* Pavillard, 1916	20
Chaetoceros debilis P.T. Cleve, 1889	56	*Dictyocha fibula* Ehrenberg, 1837	40
Chaetoceros decipiens P.T. Cleve, 1894	48	*Dictyocha speculum* Ehrenberg, 1837	48
Chaetoceros diadema (Ehrenberg) Gran, 1897	54	*Dinobryon balticum* (Schütt) Lemmermann, 1900	33
Chaetoceros didymus Ehrenberg 1845	20	*Octactis octonaria* (Ehrenberg) Hovasse, 1946	21
Chaetoceros diversus P.T. Cleve, 1873	45	**MYZOZOA**	
Chaetoceros neogracilis VanLand., 1968	44	*Akashiwo sanguinea* (Hirasaka, 1924) G. Hansen &Moestrup, 2000	39
Chaetoceros lauderi Ralfs in Lauder, 1864	41	*Alexandrium minutum* Halim, 1960	20
Chaetoceros lorenzianus Grunow, 1863	33	*Amylax triacantha* (Jörgensen, 1899) Sournia, 1984	20
Chaetoceros peruvianus Brightwell, 1856	87	*Ceratium declinatum* (Karsten, 1907) Jörgensen, 1911	20
Chaetoceros perpusillus P.T Cleve, 1897	30	*Ceratium furca* (Ehrenberg, 1834) Claparéde & Lachmann, 1859	60
Chaetoceros pseudocurvisetus Mangin, 1910	35	*Ceratium furca* var. *eugrammum* (Ehrenberg)) Jörgensen, 2002	31
Chaetoceros similis P.T. Cleve, 1896	46	*Ceratium fusus* (Ehrenberg, 1834) Dujardin, 1841	58
Chaetoceros socialis Lauder, 1864	43	*Ceratium hirundinella* (O.F. Müller) Dujardin, 1841	45
Chaetoceros teres P.T. Cleve, 1896	30	*Ceratium inflatum* (Kofoid, 1907) Jorgensen, 1911	33
Chaetoceros tortissimus Gran, 1900	28	*Dinophysis acuminata* Claperede & Lachmann, 1859	39
Chaetoceros wighamii Brightwell, 1856	76	*Dinophysis caudata* Saville-Kent, 1881	73
Cocconeis scutellum Ehrenberg, 1838	20	*Diplopsalis lenticula* Bergh, 1882	46
Coscinodiscus centralis Ehrenberg, 1844	20	*Gonyaulax digitale* (Pouchet, 1883) Kofoid, 1911	62
Coscinodiscus concinnus W. Smith, 1856	30	*Gonyaulax polygramma* Stein, 1883	50
Coscinodiscus perforatus var. *pavillardi* (Forti) Hustedt in Hendey, 1974	43	*Gonyaulax scrippsae* Kofoid, 1911	50
Coscinodiscus radiatus Ehrenberg, 1840	43	*Gymnodinium simplex* (Lohmann, 1911) Kofoid & Swezy, 1921	73
Cyclotella meneghiniana Kützing, 1844	35	*Heterocapsa triquetra* (Ehrenberg, 1840) Stein, 1883	84
Ceratoneis closterium Ehrenberg 1841	20	*Kofoidinium velelloides* Pavillard, 1928	20
Cymbella cymbiformis C.A. Agardh, 1830	22	*Lingulidinium polyedrum* (F. Stein) J.D. Dodge, 1989	55
Dactyliosolen fragilissimus (Bergon) G.R. Hasle, 1997	64	*Neoceratium tripos* (O.F. Müller) Gomez *et al*., 2010	63
Diatoma vulgare Bory de Saint-Vincent, 1824	33	*Noctiluca scintillans* (Macartney) Kofoid & Swezy, 1921	45
Ditylum brightwellii (T.West) Grunow in Van Heurck, 1885	80	*Phalacroma rotundatum* (Claperede & Lachmann) Kofoid & Michener, 1911	33
Eucampia zoodiacus Ehrenberg, 1840	42	*Podolampas palmipes* Stein, 1883	53
Fragilaria crotonensis Kitton, 1869	23	*Podolampas spinifera* Okamura, 1912	20
Grammatophora marina (Lyngbye) Kützing, 1844	20	*Polykrikos kofoidi* Chatton, 1914	40
Guinardia delicatula (Cleve) G.R. Hassle, 1996	33	*Prorocentrum balticum* (Lohmann,190) Loeblich, 1970	54
Gyrosigma spenceri J.W.Bailey exQuekett, Griffith & Henfrey,1856	42	*Prorocentrum compressum* (Bailey, 1850) Abé ex Dodge, 1975	54
Hantzschia amphioxys (Ehrenberg)Grunowin Cleve&Grunow, 1880	33	*Prorocentrum micans* Ehrenberg, 1833	81
Hemiaulus hauckii Grunow in Van Heurck, 1882	87	*Protoperidinium brevipes* (Paulsen, 1908) Balech, 1974	37
Hemiaulus sinensis Greville, 1865	51	*Protoperidinium conicum* (Gran, 1900) Balech, 1974	53
Leptocylindrus danicus P.T. Cleve, 1889	55	*Protoperidinium depressum* (Bailey, 1850) Balech 1974	66
Leptocylindrus minimus Gran, 1915	37	*Protoperidinium divergens* (Ehrenberg, 1841) Balech, 1974	57
Licmophora lyngbyei (Kützing) Grunow ex Van Heurck 1867	26	*Protoperidinium globolus* (Stein) Balech, 2005	29
Licmophora ehrenbergii (Kützing) Grunow, 1867	33	*Protoperidinium granii* (Ostenfeld, 1906) Balech, 1974	20
Melosira moniliformis (Müller) Agardh, 1824	44	*Protoperidinium oceanicum* (Vanhöffen, 1897) Balech, 1974	66
Navicula gregaria Donkin 1861	26	*Protoperidinium pallidum* (Ostenfeld, 1899) Balech, 1973	57
Nitzschia longissima (Brébisson in Kützing) Ralfs in Pritchard, 1861	70	*Protoperidinium pellucidum* Bergh ex Loeblich Jr.&Loeblich III 1966	72
Nitzschia sicula (Castracane) Hustedt in Hallegraeff *et al*., 2003	48	*Protoperidinium pentagonum* (Gran, 1902) Balech, 1974	25
Odontella mobiliensis (J.W. Bailey) Grunow, 1884	64	*Protoperidinium steinii* (Jörgensen, 1899) Balech, 1974	56
Pleurosigma delicatulum W.Smith, 1852	30	*Pyrophacus steinii* (Schiller, 1935) Wall & Dale, 1971	30
Proboscia alata (Brightwell) Sundström, 1986	82	*Pyrophacus horologicum* Stein, 1883	20
Pseudo-nitzschia delicatissima (P.T. Cleve1897) Heiden, 1928	50	*Pyrocystis elegans* Pavillard, 1931	27
Pseudo-nitzschia pseudodelicatissima (Hasle) Hasle, 1993	46	*Scrippsiella trochoidea* (Stein) Balech ex Loeblich III, 1965	52
Pseudo-nitzschia pungens (Grunow ex Cleve, 1897) Hasle, 1965	63	**EUGLENOPHYTA**	
Pseudosolenia calcar-avis (Schultze) Sundström, 1986	69	*Eutreptia lanowii* Steur, 1904	59

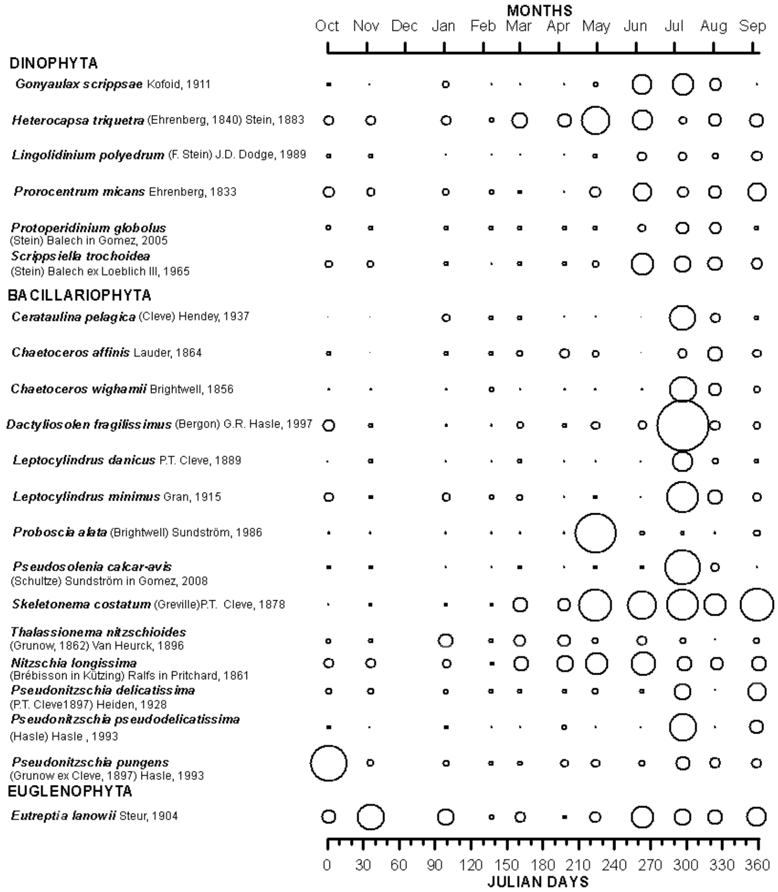

Figure 4. Temporal variations of the abundances abundant taxa in Samsun Bay from October 2002 to September 2003. Bubble size is proportional to cell, corresponding to $25x10^5$ cells L^{-1}.

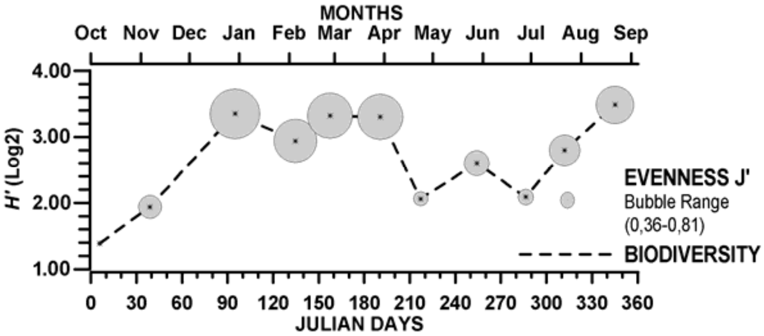

Figure 5. Monthly changes in diversity index of Shannon Wiener (broken line) and evenness index of Pielou (bubbles) during the sampling period.

Discussion

The sea surface temperature was highly correlated with air temperature in Samsun Bay and showed a clear seasonality during the sampling period. We may therefore consider that the sea surface temperature was strongly affected by the meteorological conditions existing in the neritic waters of Samsun Bay. The variations in the taxonomic composition of phytoplankton community were therefore correlated by sea surface temperature, air temperature, wind stress, PAR and N:P ratio (r=0.75, P<0.01). Accordingly, phytoplankton production showed an upward trend with increased sea surface temperature and air temperature. Furthermore, the abundance of flagellates increased during low wind speed while autotrophic diatoms began to increase at higher PAR levels.

Since biogeochemical characteristics of the Black Sea show structural differences in contrast to a great many seas of the world (Konovalov *et al.*, 2005), these concentrations are more comparable to the northwestern part. In the northwestern (Romanian) Black Sea, it was shown that yearly averaged

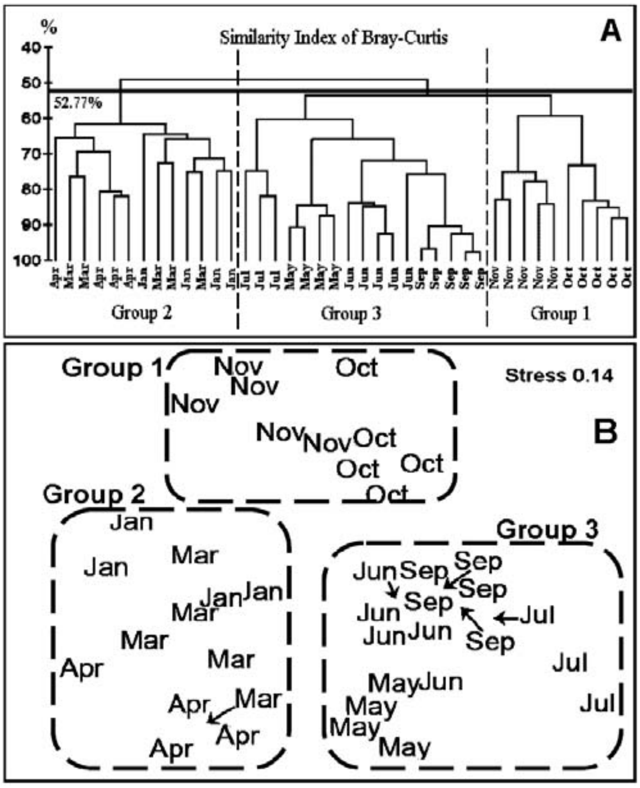

Figure 6. A) Hierrarchical cluster dendogram of the abundance data for 5 sampling stations, using group average clustering from Bray-Curtis similarities on square root transformed abundances. B) 2-dimensional MDS configuration (dashed lines contours the groupings at 15% similarity level).

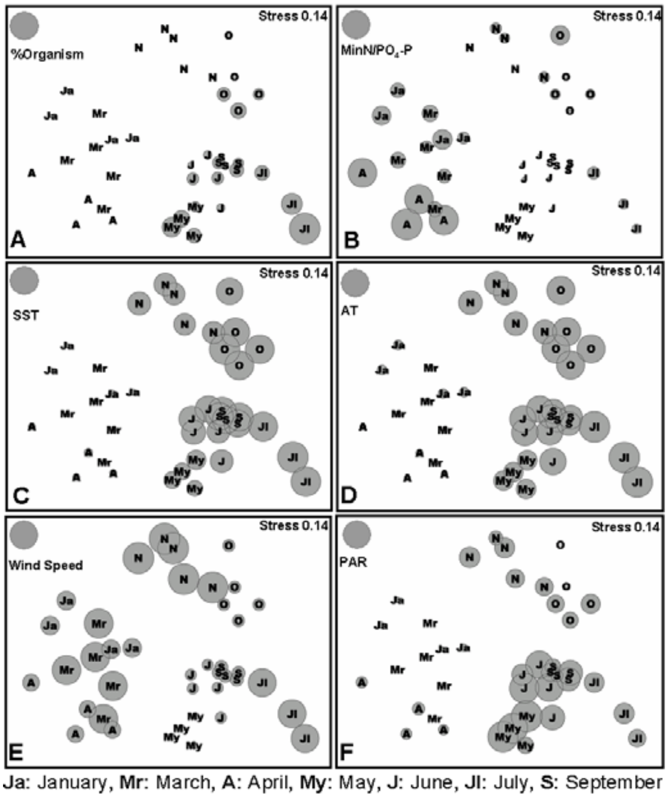

Figure 7. The same MDS plot as in figure 6 but with superimposed circles which represent, %organisms (A), nitrogen to phosphate ratios (B), sea surface temperatures (C), atmospheric temperatures (D), wind stress (E) and photosynthetically active radiation (F), stress = 0.14.

phosphate concentrations varied from 0.2 to 1.5 µM between 1968 and 1982 (Oguz, 2005a). Nitrate concentrations also varied from the values around 15 µM during the first half of the 1980s to 7-8 µM during the early 1990 (Oğuz, 2005a). Our nutrient measurements (Table 1) were low compared to those previous studies conducted in different sectors of the Black Sea (Konovalov *et al*., 2005; Konovalov and Murray, 2001). Nevertheless, these nutrient concentrations were found to be higher than the other marine regions of Turkey such as the Aegean, the Mediterranean and the Marmara Seas (Yilmaz, 2002) because of agricultural fertilizers coming from the deltas of Kizilirmak and Yesilirmak rivers (Pinarli *et al*., 1991). If we consider temporal variations, nutrient concentrations of Samsun Bay exhibited fluctuations between October 2002 and March 2003 and then sharply decreased in early spring. It is noteworthy that the cell density of the phytoplankton began to increase during this period and the assimilation of these nutrients by phytoplankton may account for this decline. Besides, the N:P ratio above 11 during this period is indicative of a phosphorus limitation and corresponded to spring phytoplankton bloom in the study area.

It was suggested that trophic index TRIX, representing a numerical expression of the trophic level, provides the quality characteristics of a water body (Giovanardi and Wollenweider, 2004). Only the April value was lower than the value of 6 units, which means that the water body of the research area showed higher levels of trophic status throughout the sampling period (except April).

Chl *a* concentrations ranged between 0.15 and 1.30 mg m^{-3}, except three peaks (2.40, 2.00and 2.00 mg m^{-3} in October 2002, May 2003 and July 2003, respectively). The biodiversity index of Shannon-Wiener conversely decreased during these peaks. Although two of these peaks which were formed in late spring and autumn were comparable to the production structure of seasonal cycling in the Black Sea (Sorokin, 2002), a peak during mid-summer was unusual and had a monotonous character. These findings about Chl *a* concentrations in summer reinforce an investigation reported by Oğuz *et al.* (2002). They suggested an evidence for a close link between biological production along the southern coasts and SeaWiFS images of the northwestern shelf of the Black Sea in mid summer.

The Black Sea is known to be mainly characterized by a high primary production potential (Sorokin, 2002). Nevertheless, the contribution of the phytoplankton taxa to the primary productivity has dramatically changed in the western part of the Black Sea over the last 50 years since the quasi-pristine period due to an enhanced nutrient riverine input. In Romanian waters the proportion of dinoflagellates has gradually increased from 19% to 24% since 1960s, while a reverse situation occured for diatoms which have decreased from 67% to 46% of the phytoplankton community (Bodeanu, 1984). A similar trend was reported in a review study for the southern parts of the Black Sea; despite of decreasing level of diatoms from 60% to 41%, dinoflagellates increased from 20% to 60% between 1989 and 1999 (Bat *et al*., 2007). In Samsun Bay, the actual proportion of diatoms and dinoflagellates are represented by 61% and 33% of the phytoplankton community, respectively. Comparing to the diatom percentages of Romanian coasts (Bodeanu, 1984), contributions of diatoms to total phytoplankton were more or less similar to the percentages found in the southern Black Sea. Dinoflagellates, however, occupied more space than Romanian coasts in respect of species number.

According to the hierarchical clustering and MDS analyses, the samples were divided into three groupings which were represented by three periods of sampling. Group 1 indicated a community character of low diversity but high dominance of the heterotrophic flagellate *E. lanowii* and chainforming diatoms, *Pseudonitzschia* spp from October to November 2002. However, Group 2 consisted generally of cold water species such as *Thalassiosira* spp. And it was represented by lower chl *a* concentration and moderate values of diversity index between 2.94 and 3.35 from January to April 2003. Group 3 showed the highest production from May to September 2003 (Figure 7A). During this period, phytoplankton community was stressed two times in May and July, respectively. Common species (abundance>1%) of the phytoplankton were also observed in this group and maximum abundance (1.20×10^6 cells L^{-1}) during the research period was determined in July. Besides, phytoplankton community from May to September included several HAB species. For instance, *S. costatum* (one of the common taxa in this study) is an indicator species of the eutrophic level. Exceeding up to million cells L^{-1}, it depletes the oxygen in water column. Fish and mussel mortality may thus occur due to hypoxia (Stonik and Selina, 1995). The other important HAB taxa, *Dinophysis* spp. showed rather weak abundances ($6\text{-}24 \times 10^3$ cells L^{-1}) in group3. However, these mixotrophs were reported as the agents of DSP intoxication, leading to closure of bivalve harvest (Shumway, 1990), although these were recorded at lower cell densities (>500 cell L^{-1}).

In conclusion, a large part of the phytoplankton production in Anatolian coastal waters seems to be supported as long as they received sufficient nutrient supply from the northwestern shelf through the counter clockwise coastal current system. If we, however, consider that the eutrophication in the northwestern shelf has weakened over the years, we need to know why the production in Samsun Bay elevated with a mid-summer peak in addition to normal spring and autumn blooms. During this peak, nutrient tolerant taxa including potential HAB species were dominant group of the phytoplankton community. The findings of this study are indicating a highly eutrophic ecosystem and the reason for this may be the agricultural fertilizers and domestic wastes discharged from various sources such as Kizilirmak and Yesilirmak to the region. In the light of the foregoing, the southern Black Sea may encounter with continuing eutrophication problems and degradation of the coastal ecosystem. Furthermore, economic activities committed to fisheries such as bivalve and seasnail harvesting may thus cease due to enhanced oxygen depletion and propagation of harmful algal blooms which can be triggered by continued anthropogenic eutrophication.

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