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Distribution of phytoplankton in the southern Black Sea in summer 1996, spring and autumn 1998

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Abstract

The species composition, abundance, and biomass of micro- (>15 μm) and nano- (<15 μm) phytoplankton were studied along the southern Black Sea during June–July 1996 and March–April and September 1998. A total of 150 species were identified, ~ 50% of them being dinoflagellates. The average total phytoplankton abundance changed from 77×10^3 cells l^{-1} in spring to 110×10^3 cells l^{-1} in autumn and biomass from $250 \mu\text{g l}^{-1}$ in summer to $1370 \mu\text{g l}^{-1}$ in spring. Based on the extensive sampling grid from June–July 1996, phytoplankton seemed to have a rather homogeneous biomass distribution in the southern Black Sea. In all periods, the coccolithophorid *Emiliana huxleyi* was the most abundant species, its contribution to the total abundance ranging from 73% in autumn to 43% in spring. However, in terms of biomass, diatoms made up the bulk of phytoplankton in spring (97%, majority being *Proboscia alata*) and autumn (73%, majority being *Pseudosolenia calcar-avis*), and dinoflagellates in summer (74%, *Gymnodinium* sp.). There was a remarkable similarity in the dominant species between the western and eastern regions of the southern Black Sea, indicating transport of phytoplankton within the basin.

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1. Introduction

The Black Sea, which is an almost enclosed system, receives considerable amount of chemicals, organic matter, and nutrients from the countries around it (especially in the western Black Sea via the Danube River). The changes in the chemical structure of this presently highly eutrophic sea strongly affect the phytoplankton structure, composi-

tion, and distribution in the whole Black Sea by means of physical processes (Aubrey et al., 1996; Zaitsev and Alexandrov, 1997; Eker et al., 1999).

Intensive anthropogenic eutrophication took place in 1970s and 1980s in the western Black Sea coasts. However, after 1992, the level of anthropogenic pressure decreased due to economic transition in the central European countries (Shtereva et al., 1999; Moncheava et al., 1998).

Variations in abundance, biomass, and species composition of phytoplankton in the western Black Sea coasts were most considerable among the different regions of the Black Sea. Phytoplankton biomass changed from $495 \mu\text{g l}^{-1}$ during 1959–1963 to 4105

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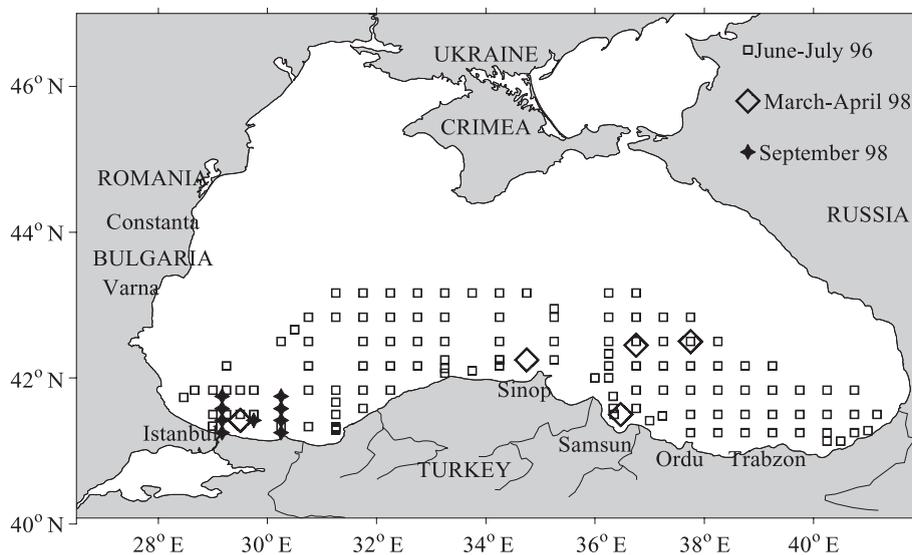


Fig. 1. Sampling stations in June–July 1996 and March–April and September 1998.

$\mu\text{g l}^{-1}$ between 1983–1990 in the open Romanian waters (mean values from 30 miles distance) as a result of increased nutrient concentrations (Bodeanu, 1993). Later on, between 1990 and 1994, this value was reported as $2100 \mu\text{g l}^{-1}$ in the same region (Petran, 1997). In the northwestern shelf, these values were around $1000 \mu\text{g l}^{-1}$ in the 1960s, $19,000 \mu\text{g l}^{-1}$ in the 1970s, and $30,000 \mu\text{g l}^{-1}$ in the 1980s (Zaitsev and Alexandrov, 1997).

The effects of the Danube River can extend towards the eastern Black Sea with cyclonic coastal rim current (Sur et al., 1996). Therefore, changes in the quantity of nutrient input of the Danube River can also affect the phytoplankton structure in the open waters as well as the southeastern Black Sea. Although the northwestern shelf, which is the central point of eutrophication, has been well studied (Petrova-Karadjova, 1973; Nesterova, 1986; Bodeanu, 1989; Bodeanu 1993; Moncheva and Krastev, 1997; Cociasu et al., 1997; Humborg et al. 1997; Bodeanu et al., 1998; Moncheva et al., 1998; Shtereva et al., 1999; Kideys, 2002), there is a limited number of investigations from the southeastern Black Sea (Karcam and Duzgunes, 1990; Feyzioglu, 1994; Uysal and Sur, 1995; Uysal et al., 1998; Yilmaz et al., 1998; Eker et al., 1999) in order to evaluate the long-term changes there. In this context, the scarcity of phytoplankton investigations undertaken from the south-

eastern Black Sea hampers efforts for understanding the whole Black Sea ecosystem. Because of this, it is also necessary to monitor the variations in the south-eastern Black Sea.

Thus, this investigation aims to evaluate the recent phytoplankton structure of the southern Black Sea by comparing it with previous investigations and with the western Black Sea.

2. Materials and methods

Sampling was performed from a total of 134 stations in June–July 1996 and March–April and September 1998 (Fig. 1). The stations were located

Table 1
Chemical parameters at the surface waters (2–5 m) of the Black Sea during the sampling periods (unpublished data of Yilmaz and Tuğrul, Institute of Marine Sciences) \pm confidence limits

Periods	PO ₄ (μM)	NO ₃ + NO ₂ (μM)	Si (μM)	Total chlorophyll ($\mu\text{g l}^{-1}$)
June–July 1996	0.09 ± 0.02	0.31 ± 0.08	3.30 ± 0.30	0.34 ± 0.13
March–April 1998	0.09 ± 0.15	0.11 ± 0.13	3.6 ± 3.14	0.42 ± 0.36
September 1998	0.04 ± 0.02	0.59 ± 0.36	2.35 ± 0.20	0.40 ± 0.22

in the whole southern Black Sea in June–July 1996, except one station (near Istanbul), in the southeastern Black Sea in March–April and in the southwestern Black Sea in September 1998 (Fig. 1). Samples were usually taken from the surface in June–July 1996 (a total of 161 samples, with 120 at the surface), from the light penetration depths of 95%, 75%, 50%, 25%, 10%, 5%, 1%, and 0.1% of surface light (a total of 43

samples, 5 of them from the surface) in April and usually from the surface in September 1998 (17 samples, 9 of them at the surface). Light penetration depths were determined by using a Li-Cor Model L1-192SA quantummeter. Samples were taken by using a General Oceanic Go-Flo Rosette bottles attached Sea-Bird Model 9 CTD probe. Phytoplankton samples were taken into 1-l dark bottles and preserved by

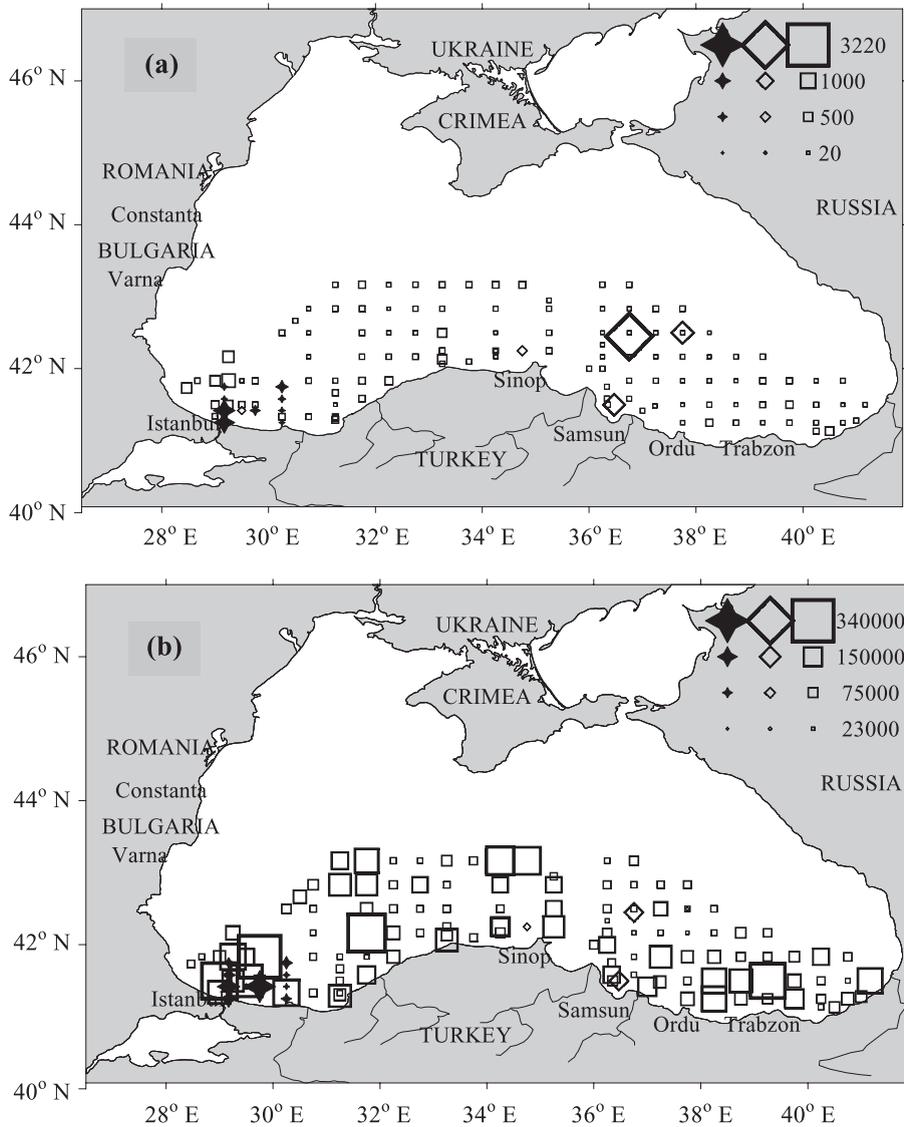


Fig. 2. (a) Total biomass ($\mu\text{g l}^{-1}$) (b) total abundance (cells l^{-1}) distribution in June–July 1996 (squares) and March–April (diamonds) and September (stars) 1998 (maximum and minimum values were shown on the scale).

buffered formaldehyde to obtain a final concentration of 2.5%. Samples were concentrated to ~ 20 ml by sedimentation method after keeping the samples immobile for at least 2 weeks (Eker et al., 1999). The microphytoplankton present in a subsample of 1 ml taken from the ~ 20-ml sample were counted using a Sedgewick-Rafter cell under a phase contrast binocular microscope. For nanoplankton analysis, 0.01-ml subsamples were scanned using a slide. The volume of each cell was calculated by measuring its appropriate morphometric characteristics (i.e., diameter, length, and width) (Senichkina, 1986a,b; Hill-ebbrand et al., 1999). Volume values were converted to biomass assuming $1 \mu\text{m}^3$ equals to 1 pg.

Usual physical (temperature, salinity, density, and Secchi disk depth, in situ fluorescence) and chemical (salinity, $\text{PO}_4\text{-P}$, $\text{NO}_3\text{-N}$, Si, and chlorophyll *a*) analyses of the seawater were done (unpublished data of the Chemistry Department of the Institute of Marine Sciences). Nutrient samples were taken into acid-cleaned polyethylene bottles and kept frozen for a few weeks until analysis by a Technicon Model two-channel Autoanalyzer (Strickland and Parsons, 1972). Chlorophyll *a* (Chl-*a*) samples were filtered through GF/F filters and extracted with 90% acetone solution. The fluorescence intensity of clear extracts was then measured (Strickland and Parsons, 1972; Holm-Han-

sen and Riemann, 1978) using a Hitachi F-3000 Model spectrofluorometer (see Yilmaz et al., 1998 for the methodology).

3. Results

A total of 150 species were identified in June–July 1996 and March–April and September 1998. About 50% of the total species number was formed by dinoflagellates in these three periods.

Nutrient and Chl-*a* concentrations during June–July 1996 and April and September 1998 were shown in Table 1. Their concentrations irregularly changed with the sampling regions, phytoplankton abundance, biomass, and composition. In June–July 1996, the very southwest as well as the coastal regions had generally higher phosphate and Chl-*a* concentrations. However, similar nutrient and Chl-*a* concentrations were observed in the coastal and open regions in April 1998, indicating spatial dynamism in these parameters for the different sampling periods. High nitrate concentrations did not always corresponded to high (or low) phytoplankton biomass and Chl-*a* values during the sampling periods.

Sampling regions (except one station near Istanbul) were different for the March–April and September

Table 2

Contribution of different phytoplankton groups to the average abundance and biomass in the surface waters of the southern Black Sea (numbers after \pm shows the confidence limits)

Periods	Abundance (%)					Average abundance (cells l^{-1})
	Dino. ^a	Diatoms	Cocco ^b	Flagel. ^c	Others	
March–April 1995 ^d	23	3	45	23	6	110,000 \pm 26,000
October 1995 ^d	7	9	69	11	5	364,000 \pm 161,000
June–July 1996	16	4	57	17	6	99,300 \pm 11,000
March–April 1998	2	42	43	6	7	77,300 \pm 67,400
September 1998	8	11	73	3	5	110,300 \pm 48,700
	Biomass (%)					Biomass ($\mu\text{g l}^{-1}$)
	Dino. ^a	Diatoms	Cocco ^b	Flagel. ^c	Others	
March–April 1995 ^d	83	5	7	3	2	170 \pm 90
October 1995 ^d	12	85	3	0.5	0.5	1790 \pm 520
June–July 1996	74	16	8	1	1	250 \pm 80
March–April 1998	3	97	0.4	0	0.1	1370 \pm 1420
September 1998	26	73	1	0.2	0.1	630 \pm 370

^a Dinoflagellates.

^b Coccolithophorids.

^c Small flagellates.

^d Eker et al., 1999.

1998 cruises. Because of this, it was difficult to compare spatial distribution of phytoplankton from these two periods. However, the well-dispersed sampling stations in June–July 1996 enabled us to evaluate spatial distribution of phytoplankton for this period. Thus, it was observed that except the rich areas in the very west, the phytoplankton biomass distributed rather homogeneously for the coastal and open waters in the entire southern Black Sea (Fig. 2a). However, generally higher abundances were noted along the coastal regions (Fig. 2b) mainly due to the coccolithophorid *Emiliania huxleyi* Lohmann in parallel to distribution of inorganic phosphate and Chl-*a* values.

When the regional differences were disregarded, the overall mean abundance in September 1998 ($110 \pm 49 \times 10^3$ cells l^{-1}) was higher than in March–April 1998 ($77 \pm 67 \times 10^3$ cells l^{-1}) and June–July 1996 ($99 \pm 11 \times 10^3$ cells l^{-1}). However, biomass in March–April 1998 (1370 ± 1420 μg l^{-1}) was higher than in September 1998 (630 ± 370 μg l^{-1}) and June–July 1996 (250 ± 80 μg l^{-1}) (Table 2). The high biomass values in March–April 1998 were due to the dominance of big-sized diatoms.

The coccolithophorid *E. huxleyi* was the most abundant species in all three periods, reaching a maximum in September 1998 (average 75×10^3 cells l^{-1}) (Table 2), denoting a contribution of about 73% to the total phytoplankton abundance. The very notable dominance of *E. huxleyi* in September was not due to the regional but due to the seasonal difference, because when the analysis was limited to the southwestern Black Sea in order to eliminate regional differences, a lower coccolithophorid contribution to the total abundance was still apparent for the June–July 1996 and March–April 1998 surveys (46% and 55%, respectively).

In March–April 1998, diatoms constituted the most important group in all the sampling stations both in the southwestern and southeastern Black Sea in terms of biomass due to mainly a single species, *Proboscia alata* (Brightwell) Sundsröm. The average biomass of this species was $\sim 1,200$ μg l^{-1} , it constituted 91% of the total biomass at the surface in this period. It must be noted that *P. alata* was also observed at high quantities at greater depths (at 85.5 and 56 m in two nearshore stations near Sinop and Samsun, respectively). These depths were far below the euphotic zone ($< 0.1\%$ of the

surface light). Similarly, in situ fluorometer values were also high at these depths.

In June–July 1996, *Gymnodinium* sp. was the dominant species again both in the southwestern and southeastern Black Sea. The diatoms formed the majority of biomass in September 1998 similar to March–April 1998. However, the dominating diatom species was *Pseudosolenia calcar-avis* (Schultz) Sundström rather than *P. alata* in this period. Other important species and average abundance and biomass values were given in Table 3.

Table 3

Important species and average abundance (cells l^{-1}) and biomasses (μg l^{-1}) for the surface waters in June–July 1996 and March–April and September 1998

Species	June–July 1996	Mar–April 1998	Sep 1998
<i>Average abundance</i>			
<i>Emiliania huxleyi</i> Lohmann	56,290	29,740	75,210
Small flagellates	17,160	6720	3220
<i>Proboscia alata</i> (Brightwell) Sundsröm	180	10,710	560
<i>Chaetoceros curvisetus</i> Evensen and Hasle	5	10,360	0
<i>Hillea fusiformis</i> Schiller	3080	5220	25
<i>Glenodinium paululum</i> Lindemann	1910	10	3890
<i>Thalassionema nitzschioides</i> Grunow	0	210	3430
<i>Gymnodinium</i> sp.	2570	0	0
<i>Pseudonitzschia</i> <i>pseudodelicatissima</i> Hasle	2210	0	2440
<i>Pseudosolenia calcar-avis</i> (Schultz) Sundström	90	90	1590
<i>Prorocentrum cordatum</i> (Ostenfeld) Dodge	590	25	1590
<i>Average biomass</i>			
<i>Proboscia alata</i> (Brightwell) Sundsröm	7	1085	20
<i>Pseudosolenia calcar-avis</i> (Schultz) Sundström	10	20	420
<i>Polykrikos schwartzii</i> Bütschli	1	5	40
<i>Gymnodinium</i> sp.	20	0	0
<i>Ceratium tripos</i> (O.F. Müller) Nitzsch	15	10	25
<i>Gyrodinium fusiforme</i> Koifoid and Swezy	20	1	15
<i>Ceratium fusus</i> Ehrenberg	10	10	15
<i>Dactyliosolen fragilissimus</i> (Bergon) Hasle	10	5	5

4. Discussion

Several improvements in eutrophication were noted after 1992 in the coastal waters of the north-western shelf (Shtereva et al., 1999; Moncheva et al., 2001). Decrease in phytoplankton quantity (i.e., biomass and abundance) and bloom frequency and shifts in the bloom period, as well as lower contribution of dinoflagellates to the total phytoplankton abundance and biomass, are among the indications for these improvements.

Although the long-term changes were well determined in the northwestern Black Sea shelf (see the Introduction), it is difficult to report the mentioned changes above for the entire open and coastal Black Sea due to the scarcity of the data. Variable abundance and biomass values of phytoplankton found in three different periods in this study seem insufficient to speak about the annual and seasonal changes in the southern Black Sea, even if one considers a previous limited number of investigations from the region. However, the long-term Chl-*a* distribution during the more stable period of warm months showed the presence of three different periods in the open waters (>1000 m) of the Black Sea: These are low Chl-*a* concentration period in 1964–1986 (average $0.15 \pm 0.04 \mu\text{g l}^{-1}$), increased period in 1988–1992 (maximum $0.99 \pm 0.7 \mu\text{g l}^{-1}$), and decreasing period in 1993–1996 ($< 0.26 \pm 0.08 \mu\text{g l}^{-1}$) (Yunev et al., 2002).

Before the anthropogenic eutrophication becomes a problem, an intense spring and a less-intense autumn bloom, which is a characteristic of the typical temperate waters, were present in the Black Sea. Later, intense summer blooms were reported (Sorokin, 1983). However, it is worth noting that maximum values in Chl-*a* measurements from long-term data set (1978–1992) were still reported for the winter–early spring (i.e., January, February, and March) period throughout the year (Vedernikov and Demidov, 1997; Yunev et al., 2002). Recently, however, positive changes in the frequency and timing of phytoplankton blooms have been reported for the northwestern shelf. Related to this, more than a sixfold increase in autumn and winter, whilst a two-fold decrease in summer in the average biomass of phytoplankton, were reported from 1987–1992 to 1993–1997 in Varna Bay, Bulgaria (Table 4) (Velikova et al., 1999).

Table 4

Phytoplankton biomass at the surface water of Varna Bay, Bulgaria in different time periods as micrograms per liter

Reference	Shtereva et al., 1999	Velikova et al., 1999	Velikova et al., 1999
Periods	1983–1988	1987–1992	1993–1997
Winter	24,000	3790	27,480
Spring	57,000	5380	3210
Summer	40,000	33,470	16,100

There were also changes in the phytoplankton groups forming the blooms. Previously (in the 1970s), there were two major peaks in primary production in the Black Sea, the first one was the diatom bloom in spring, and the second one was the coccolithophorid bloom in autumn (Sorokin, 1983). Later, as it was often reported, occasional summer blooms of dinoflagellates and coccolithophorids were observed (Bologa, 1986; Benli, 1987). In this study, dinoflagellate abundance and biomass in summer 1996 were higher than in other periods (i.e., March–April and September 1998), while the coccolithophorid abundance (mainly *E. huxleyi*) was maximum in September 1998 (Table 2). Similar to the present study, phytoplankton abundance in autumn 1995 was higher than in spring 1995 due to the presence of coccolithophorid *E. huxleyi* (Table 2). Thus, high coccolithophorid abundance in autumn in both 1995 and 1998 in the southern Black Sea conforms to the typical structure of the 1970s.

In the present study, species number of dinoflagellates was always higher than that of diatoms along the southern Black Sea (Table 5). Generally, nitrogen and phosphorus are the nutrients increasing with eutrophication, and this increase often leads to excessive phytoplankton growth. However, diatoms require silica for their shells in addition to these nutrients. Because of this, other phytoplankton groups like dinoflagellates and coccolithophores increase in number and biomass in the areas of eutrophication (Escaravage et al., 1999). Related to this, it was reported that in years prior to the observed eutrophication, the number of dinoflagellate species was usually lower than that of diatoms (Ivanov, 1965; Bologa, 1986; Zaitsev and Alexandrov, 1997), but with proceeding eutrophication, contribution of dinoflagellates into total species number as well as into total numerical abundance increased. The results obtained here for

Table 5
Species number percentages of dinoflagellates and diatoms within the total species number

	Total species number	Dinoflagellates (%)	Diatoms (%)	Reference
March–April 1995	121	41	26	Eker et al. (1999)
October 1995	108	44	26	Eker et al. (1999)
April 1996	73	45	36	Uysal et al. (1998)
June–July 1996	119	60	20	present study
April 1998	65	48	30	present study
September 1998	50	48	24	present study

three different periods still show the dominance of dinoflagellates in species diversity (Table 5).

The contribution of dinoflagellates to the total biomass was never higher than 40% for any season between 1995 and 1997 in the Bulgarian Black Sea waters (Bodeanu et al., 1998), which was rarely the case before 1992. As seen in Table 2, the contribution of dinoflagellates to the total biomass was high in March–April 1995 (83%) and June–July 1996 (74%), but low in March–April 1998 (3%) and in September 1998 (26%) in the southern Black Sea. However, the limitations in our data hamper us to speak about improvements in the ecosystem by merely looking at percentage contribution of dinoflagellates in the southern Black Sea.

P. alata and *P. calcar-avis* were the reason for high biomass values observed in both April and September 1998, respectively. Similarly, *P. calcar-avis* was also the predominating species in autumn 1995 (it constituted 78% of the total biomass at the surface in the eastern Black Sea, Eker et al., 1999). This result agrees well with the investigation of Kustenko (1983) who reported that *P. calcar-avis* started to form auxospores in autumn with the beginning of the first large cell occurrence (40–44 µm diameter). In addition, Karacam and Duzgunes (1990) also reported that *Rhizosolenia* and *Ceratium* genera were the most abundant during the months between November 1987 and October 1988 along the Trabzon coasts (the eastern Black Sea).

Dominant (in terms of both abundance and biomass) phytoplankton species did not change between the southwestern and southeastern Black Sea in March–April 1995 [*Heterocapsa triquetra* (Ehrenberg) Stein and *Scrippsiella trochoidea* (Stein) Balech, Eker et al., 1999], October 1995 [*P. calcar-avis*, Eker et al., 1999 and *Velikova et al.*, 1999], March–April 1998 (*P. alata*), and June–July 1996 (*Gymnodinium* sp.). This indicates high dynamism in the Black Sea basin and a rather rapid horizontal transport of phytoplankton possibly via the prominent rim current (Sur et al., 1996). The biomass of phytoplankton in the coastal and open waters was also quite similar (Fig. 2a). This was also supported with the homogeneous distribution of the major nutrients in the open waters (TU-Black Sea Data Base). Moreover, there was no statistically significant spatial difference in terms of Chl-*a* for the open waters (>1000 m) of the whole Black Sea (Yunev et al., 2002). Because of this, the entire open Black Sea can be considered as a single water mass for the analysis of long-term and seasonal variability in Chl-*a* and phytoplankton species composition. However, in terms of abundance, there was no homogeneity as observed for the biomass values. This difference is partly caused by phytoplankton composition. For example, results from our June–July 1996 survey confirm the preferential distribution of the coccolithophorids (which have low individual biomass) for the coastal regions (Fig. 2b).

In the present study the southern Black Sea phytoplankton abundance, biomass, and species composition were estimated in three different periods and compared with limited previous data from the same region. This data may be helpful for future investigations to understand the changes in the structure of the ecosystem and validation of the satellite images.

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