Hydrobiologia **485:** 173–182, 2002.

On the formation of net phytoplankton patches in the southern Black Sea during the spring

Zahit Uysal
Middle East Technical University, Institute of Marine Sciences. P.O. Box 28, Erdemli, Icel, 33731, Turkey
Tel: 342-521-2406; Fax: 342-521-2327; E-mail: uysal@ims.metu.edu.tr

Received 2 July 2001; in revised form 26 July 2002; accepted 20 August 2002

Key words: net phytoplankton patches, abundance, diversity, ditribution, spring, southern Black Sea

Abstract

Species composition, community structure and spatial distribution of net phytoplankton in the southern Black Sea have been studied. In the fraction over 55 μm, diatoms were found to be predominant in cell abundance and followed by dinoflagellates. Net phytoplankters were found to be more abundant in the southwestern sector, especially near the Bosporus and near Sakarya River mouth. MDS (Multi-Dimensional Scaling) analysis has projected four distinct patches along the coast, two of which appear to occupy smaller regions compared to the main western and eastern patches which have lower species numbers and diversity. The diatom species *Pseudo-nitzschia seriata* and *Cerataulina pelagica* and the dinoflagellates *Noctiluca scintillans* and *Scrippsiella trochoidea* dominate the west, while diatom species *Synedra acus* and *Asterionella formosa* together with *Microspora* sp. and *Ankistrodesmus falcatus* from chlorophyceae dominate the east.

Introduction

The Black Sea is the World's largest meromictic semi-enclosed basin with a surface area of 4.23×10^5 km^2 (Sorokin, 2002). It is known to be a region of moderate to high productivity, as it receives a wealth of nutrients from the major rivers, Danube, Dniestr and Dniepr. Excess nutrient input via rivers has caused intense eutrophication, leading to hypoxia and occasional anoxia in the north-west shelf area, and has maintained a highly stable brackish surface layer separated from deep waters by a permanent halocline at depths of 80–200 m, which seriously prevents vertical exchanges in general, and convective mixing in particular. Hydrogen sulphide is present below the halocline.

Species composition, growth, and distribution of phytoplankton are controlled by environmental factors, such as range and time-dependent changes in temperature, salinity, density, light intensity, and nutrient supply. Since the intensity, scale and spatial pattern of plankton are strongly regulated by physical oceanographic processes (Mackas et al., 1985), the general features of the Black Sea circulation, river inputs, and productivity are expected to have effects. Results of recent investigations suggest that the selective redistribution of anthropogenic load from the Danube, affected by transport by currents, fronts, river plumes, coastal upwelling and mixing and meso-scale circulations provide opportunities for enhanced phytoplankton productivity adjacent to the continental shelf, thus contributing to the environmental changes in the Black Sea (Aubrey et al., 1995; Ozsoy & Unluata, 1997).

Among the unique hydrodynamic features of the Black Sea are the cyclonically meandering rim current together with two interior, western and eastern gyres, and several mesoscale anticyclonic eddies (see Fig. 1). This basin scale cyclonic boundary current (referred to as the "Rim Current" by Oguz et al., 1992, 1993a, b) is the main feature of the Black Sea general circulation. The two most persistent eddies are the Batumi and the Sevastopol eddies. In the south, three other quasi-permanent anticyclonic eddies (namely the

Bosporus, Sakarya and Kizilirmak eddies) are present. In addition to these, one or two more recurrent coastal anticyclonic eddies may occur in the region between Sakarya Canyon and Cape Sinop. Quasi-permanent Crimea and Caucasus eddies are located in the north-eastern coast. Finally, the Kali-Akra eddy from the Bulgarian coast is another apparently recurrent anticyclonic feature from the shallow west coast. The meandering nature of the boundary current is possibly responsible for these standing structures as well as transient features along the periphery. The strong boundary current limits the water and material transfer across the flow, while jet-like instabilities, mesoscale eddies, filaments, mushroom-like structures play important roles in the cross-shelf exchanges (Sur et al., 1994, 1996; Uysal & Sur, 1995).

To date, numerous studies on the planktonic flora of the Black Sea have primarily dealt with the following aspects; species composition (biodiversity and taxonomic structure), trophic relationships, primary and secondary production, spatio-temporal distribution, seasonal dynamics, long-term alterations in relation to variability of environmental factors, such as eutrophication and pollution, phytoplankton blooms with special emphasis on toxic ones, and the influence of water masses.

For a better understanding of the pelagic microscopic community, based not only on species composition and their quantitative dynamics, but also its scale dependent spatial pattern in relation to prevailing surface current regime, this study was performed at 88 stations along the entire Turkish Black Sea coast. To the best of our knowledge, information on aggregations (patchy assemblages) of planktonic flora at species level, other than abundance and biomass distribution at particular regions, is still lacking for the Black Sea. This preliminary study aimed to bring a different perspective on these aspects and to provide information on the distribution of plankters in the region.

Materials and methods

Sampling

The sampling was done in an area between 28° E and 41° E along the Turkish Exclusive Economic Zone of the Black Sea. Plankton samples were collected from the surface, and at depths of the chlorophyll sub-maximum and minimum with 5 l capacity Nansen bottles on board the R/V BILIM in April 1989. Samples were collected with a rosette sampler coupled to a CTD probe. Total volumes of 5–10 l, depending on the phytoplankton density, were filtered on board through a net of 55 micrometre mesh size and preserved in a borax-buffered 4% seawater-formalin solution. Qualitative and quantitative analyses of plankters were performed separately for each depth under microscope (magnifications 400× and 1000×) and later, pooled data were utilized for further statistical computations. In a separate collection for qualitative analyses of diatoms, acid washing of the samples was done according to the method described in Baltic Sea Environment Proceedings (1988).

A total of 88 stations were surveyed (see Fig. 2) and these stations were grouped in 25 grid boxes. The mean abundance of each species at grid locations constituted the multispecies data which were analysed by multivariate techniques (Multi-Dimensional Scaling). Because some stations in grid #4 were influenced by Sakarya River input, a separate small grid #5 was constructed to contain these stations. Grouping the 88 stations in this fashion also reduces computational problems expected for large numbers of stations. Stations positioned on the longitude lines dividing grid boxes were included in the grids to the east of the boundary, as a matter of accounting.

Analytical methods

Plankton samples consisted mainly of diatoms, dinoflagellates, species from chlorophyta, cyanophyta, chrysophyta of phytoplankton, and frequently observed members of classis ciliata of zooplankton. Phytoplankton cell counts required root-root transformation to adjust the weight of abundant species. To calculate similarities between sites, the Bray-Curtis coefficient is used (Uysal & Sur, 1995). Then the similarity matrix was formed between every pair of samples in a lower triangular array for further clustering and ordination. For a graphic representation of relations among sites, a dendogram showing clustered groups at arbitrary cut-off level was constructed. Among the various hierarchical sorting strategies the group-average sorting was preferred to produce a dendogram from the similarity matrix. This joins 2 groups of samples together at the average level of similarity between all members of one group and all members of the other. In order to visualize sample (grid) relationships, ordination was done by

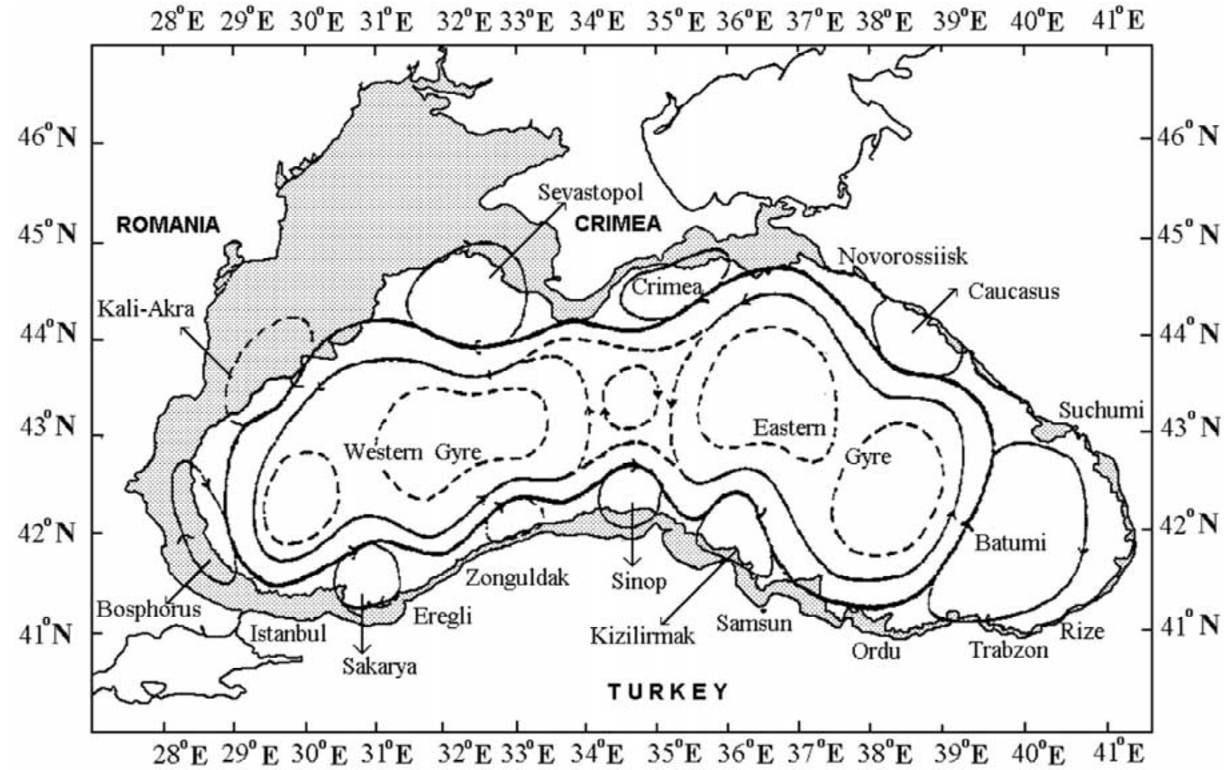

Figure 1. Main features of the upper layer general circulation of the Black Sea (redrawn from Oguz et al., 1993a). Solid (dashed) lines indicate quasipermanent (recurrent) features of the general circulation.

delineating dendogram classes on the corresponding ordination via Multi-Dimensional Scaling (MDS).

To find out discriminating species responsible for groupings among the community, contribution to average dissimilarity ($\bar{\delta}$) or similarity ($\bar{S}$) from i^{th} species was calculated. Higher $\bar{\delta}_i$ and high ratio of $\bar{\delta}_i$/SD(δ_i) pointed out the discriminating species. Further, contribution of the *i*'th species ($\bar{S}_i$) to the average similarity within a group ($\bar{S}$) was computed similarly (FAO/IOC/UNEP, 1992). This indicates that species concerned is consistently prominent in that group.

Community diversity indices included Margalef's Index (d), Shannon-Wiener Index (H') for species richness and the Pielou's Evenness Index (J') for proportional representation (for details see Uysal & Sur, 1995). For the analysis of multispecies data and the associated environmental variables both STATGRAPHICS (Univariate Statistics Package) and PRIMER (Multivariate Analyses Package – Plymouth Routines in Multivariate Ecological Research), a number of PC programs written at the Plymouth Marine Laboratory, U.K. were used.

Results

Qualitative analysis of the spring net phytoplankton revealed that the majority (65%) of the total 86 phytoplankton species encountered were diatoms. Dinoflagellates formed the second major group (22%). In addition, seven species from Chlorophyta, two species from Cyanophyta, and 2 species from Chrysophyta were observed. Within the total content of the net material, classis Ciliata (tintinnids) of zooplankton had minor importance. Included in these groups also were the meroplanktonic bivalve larvae and gymnospermous bisaccate pollen as pseudoplankton. Due to filtering through 55 micrometre mesh, many mass Black Sea phytoplankton species (i.e., *Heterocapsa*, *Prorocentrum* and all species of coccolithophoridae) were not included in the samples.

Among the dominant phytoplankters, marine and brackish-marine water diatom species *Pseudo-nitzschia seriata*, *Thalassiosira decipiens* and *T. fallax* comprised about 70% of the total abundance of all species. These were followed by the other diatom species *Cerataulina pelagica*, *Chaetoceros decipiens*

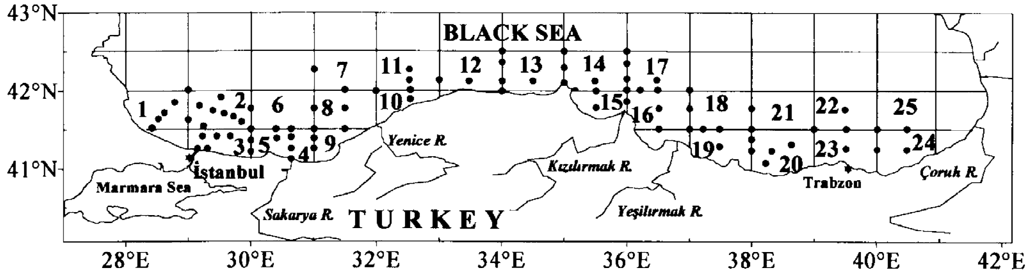

Figure 2. Location of the sampling stations and grid stations along the Turkish Black Sea coast in April 1989.

and *Nitzschia longissima* and by the dinoflagellate *Scrippsiella trochoidea*. Diatoms' contribution (94%) to total abundance was unusually much higher than dinoflagellates' (4%) for this period. Contribution from the rest of the groups was insignificant.

Abundance distribution of net phytoplankters within the euphotic zone has clearly revealed that the west coast, especially the Bosporus junction (grid #3) and Sakarya River vicinity (grid #4 in Fig. 2), formed the most productive regions (see Fig. 3). To the west of these productive regions, net phytoplankton abundance in the relatively colder grids #1 and #2 fell far behind these levels. Maximum cell counts (4.4×10^4 and 3.6×10^4 cells l^{-1}) were obtained near the Bosporus exit to the Black Sea and near the Sakarya River. Offshore stations generally had lesser figures (cell abundance) than the coastal regions in the west. To the east of this feature, plankters flourished considerably and maximum number of species were defined in grid #8 (see Fig. 4). Differences in total number of species present and abundances are more evident among the stations in the west than the east.

Contribution of the drifting flora via the cyclonic coastal flow from the west (Romanian and Bulgarian coasts) is most pronounced in the southwest coast, as there is significant differentiation in the quality and quantity of shelf and offshore plankton. Enhanced production around the Bosporus junction of the Black Sea and the Sakarya River front were induced primarily by species *Pseudo-nitzschia seriata*, *Cerataulina pelagica*, *Noctiluca scintillans*, *Scrippsiella trochoidea* and *Thalassiosira decipiens*. This high coastal biomass is further diluted towards east near the Yenice River. No significant changes in net phytoplankton abundance in the central and eastern part of the coast is observed except slightly higher numbers obtained near Sinop and Trabzon. It is interesting to note here that the regions of influence of major rivers (Kizilirmak and Yesilirmak) in the east were devoid of net phtoplankton.

Environmental stress is more apparent in the west than the east. More contrasting surface water temperatures (see Fig. 5) as well as slight cross-shelf changes in surface salinity (see Fig. 6) in the west caused for fluctuations in net phytoplankton abundance, species richness, diversity and proportional representation. Comparison of western community with the eastern community on the basis of species richness (see Fig. 7) resulted in higher diversity indice measures especially in the region to the east of the Sakarya River. This region had many but not abundant species as was the case in the eastern part.

All the community diversity measures (d, H′ and J) (see Figs 7–9) were found relatively higher in the central region (grids #11, 12, 13 and 14). Species richness (**d**) was highest at grid #13 with a good apportionment among species. In contrast, the lowest levels were attained in the offshore Trabzon region (grid #23) represented by the least number of species. Diversity (H′) was higher where the proportional representation of species was well established.

MDS (Multi-Dimensional Scaling) plots of gridded stations (see Fig. 10) have distinguished 4 main grid station groups at an arbitrary similarity level of 35% (see Fig. 11). Group I is composed of grids #1, 2, 3, 4, 5, and 6, group II of grid #9, group III of grid #23 only, and finally the largest of all, group IV composed of the rest of the grids up to grid #25. The average dissimilarity between groups I and III was 97.9%, II and III was 87.6%, and III and IV was 70.5%.

Diatom species *Pseudo-nitzschia seriata*, *Cerataulina pelagica* and *Thalassiosira angulata* and the dinoflagellates *Noctiluca scintillans* and *Scrippsiella trochoidea* contributed much to average similarities within the western grid stations (as shown in Table 1). Contribution of these five species to total abundance was about 50%. It should be stressed here that het-

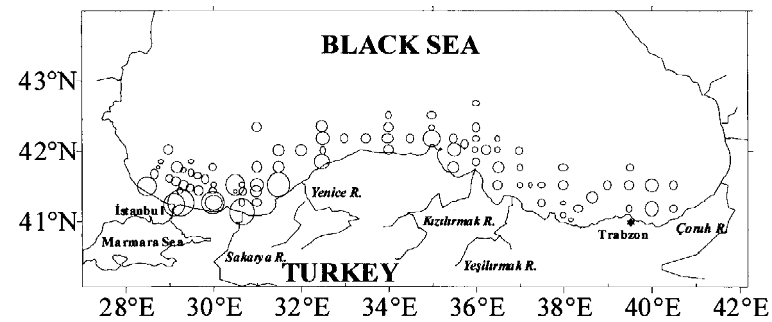

Figure 3. Changes in spatial distribution of net plankton abundance (log cells l^{-1}) in the water column along the coast in April 1989 (min: 1.46; max: 4.64).

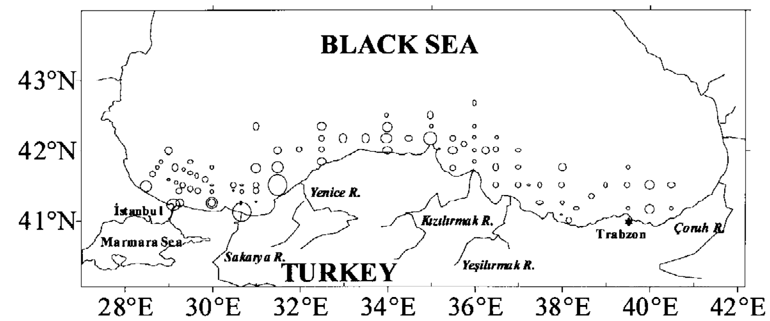

Figure 4. Changes in species frequency distribution superimposed to the water column in April 1989 (min: 2; max: 29 species).

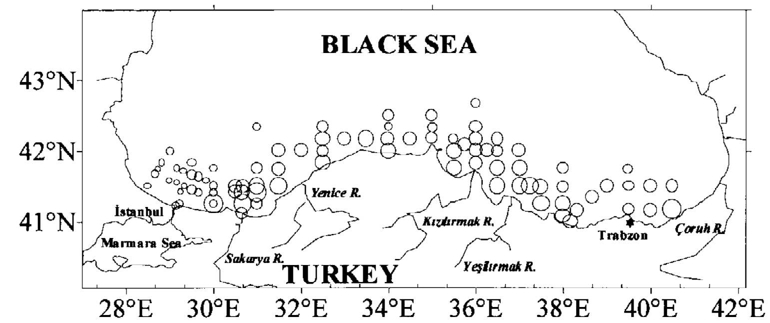

Figure 5. Changes in surface temperature distribution along the coast in April 1989 (min: 8.6; max: 12.13 °C).

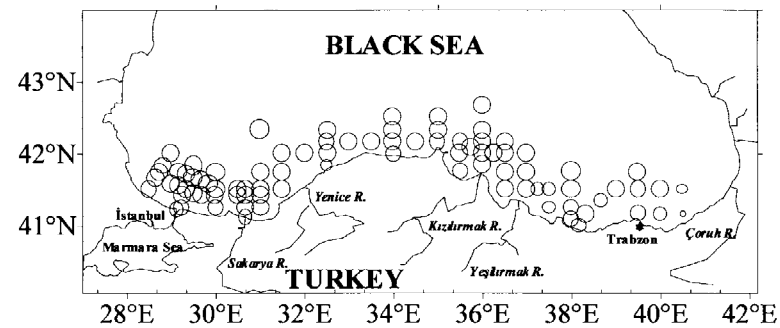

Figure 6. Changes in surface salinity distribution along the coast in April 1989 (min: 17.12; max: 18.29)

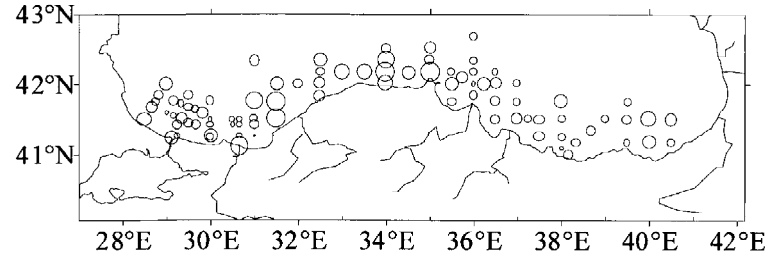

Figure 7. Differences in Margalef's Index (d) in the water column in April 1989 (min: 0.21; max: 2.79).

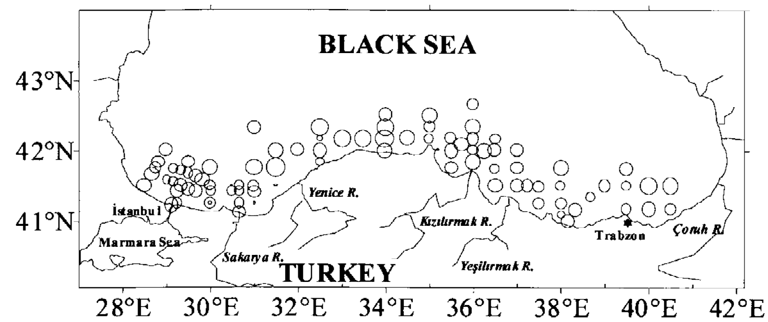

Figure 8. Differences in Shannon–Wiener Index (H') in the water column in April 1989 (min: 0.17; max: 2.57).

erotrophic non-thecate form *Noctiluca scintillans* has almost invaded the entire Turkish Black Sea coast and contributed much to the pelagic flora especially in the west. However, in the largest group IV representing the central and eastern net phytoplankton flora, diatom species *Synedra acus*, *Asterionella formosa* and *Fragilaria capucina* together with species *Microspora* sp. and *Ankistrodesmus falcatus* from chlorophyceae were consistently prominent.

Species displaying a major role in discriminating the sites (groups) are listed in Table 2. Diatom species *Pseudo-nitzschia seriata*, *Thalassiosira angulata*, *Cerataulina pelagica* and *Chaetoceros decipiens* dominating the first group and *Synedra acus* dominating the largest fourth group were the cause for the discrepancy between the larger groups I and IV.

Discussion

Of the total 86 phytoplankton species encountered, 56 species belonged to diatoms and 19 species belonged to dinoflagellates. Similar ratios were also observed for the winter period (Uysal & Sur, 1995). Both groups were also regarded as the major constituents of the phytoplankton in the Black Sea (Ivanov & Beverton, 1985).

Among the few dominant diatom species observed during this period, *Thalassiosira decipiens* is known as a widely distributed species in all temperate seas but, according to Skolka (1969), it is rarely present in the Black Sea. This species has been previously recorded by the author in the near Bosporus region of the Black Sea in January 1986 (Uysal, 1987). Except *Chaetoceros decipiens*, the rest have made significant contribution to the planktonic flora offshore Constantza along the Romanian Black Sea coast, especially *Cerataulina pelagica*, reaching a density in between 10^5 and 10^6 cells l^{-1} (Bologa et al., 1981). Among other dominant species, the dinoflagellate *Scrippsiella trochoidea* was also found as the major constituent of the spring phytoplankton by Eker et al. (1999). Although the contribution of dinoflagellates to bulk was rather low, it is also alarming that a considerable part was composed of heterotrophic non-thecate form *Noctiluca scintillans* which impacts the production of other plankters in the food web through phagotrophic nutrition. Having a wide range of living capability under undesirable conditions, this species made significant contributions to the plankton biomass in recent years in the Black Sea (Porumb, 1989) and Bosporus junction of the Sea of Marmara (Uysal, 1987). According to Vinogradov (1979) *Noctiluca scintillans* on average accounted for 43% of

Table 1. Species contributions ($\bar{S}_i$) to average similarities ($\bar{S}$) within site groups

Group	Species	$\bar{S}_i$	SD(S_i)	$\bar{S}_i$/SD(S_i)	$\Sigma\ \bar{S}_i$%
*47.6	*Pseudo-nitzschia seriata*	8.0	2.9	2.7	16.8
	Cerataulina pelagica	4.1	1.6	2.6	25.5
I	*Noctiluca scintillans*	3.7	1.3	2.8	33.3
	Scrippsiella trochoidea	3.7	1.0	3.8	41.0
	Thalassiosira angulata	3.6	3.2	1.1	48.6
*49.0	*Synedra acus*	8.4	2.5	3.4	17.2
	Asterionella formosa	6.3	1.9	3.2	30.0
IV	*Microspora* sp.	5.9	3.2	1.8	42.1
	Ankistrodesmus falcatus	5.4	2.6	2.1	53.0
	Fragilaria capucina	4.8	3.8	1.2	62.7

*Average similarity ($\bar{S}$) within the group. Groups II and III are missing because they were the only grid stations forming these groups.

Table 2. Species contribution ($\bar{\delta}_i$) to total average dissimilarity ($\bar{\delta}_i = \Sigma\ \bar{\delta}_{ii}$) between all four site groups

Group	Species	$\bar{\delta}_i$	SD($\bar{\delta}_i$)	$\bar{\delta}_i$/SD(δ_i)	$\Sigma\bar{\delta}_i$%
*69.1	*Pseudo-nitzschia seriata*	8.4	3.1	2.7	12.2
	Thalassiosira angulata	5.4	3.2	1.7	20.0
I & II	*Cerataulina pelagica*	4.9	1.6	3.1	27.1
	Chaetoceros decipiens	4.1	2.1	1.9	33.0
	Nitzschia longissima	3.9	2.3	1.7	38.6
*97.9	*Pseudo-nitzschia seriata*	9.3	3.7	2.5	9.5
	Thalassiosira angulata	5.9	3.4	1.7	15.4
I & III	*Cerataulina pelagica*	5.4	1.6	3.3	20.9
	Melosira granulata	5.3	2.8	1.9	26.3
	Chaetoceros decipiens	4.4	2.2	2.0	30.8
*77.3	*Pseudo-nitzschia seriata*	6.2	3.2	1.9	7.9
	Thalassiosira angulata	4.7	2.8	1.7	14.1
I & IV	*Cerataulina pelagica*	4.1	1.7	2.5	19.4
	Chaetoceros decipiens	3.4	2.0	1.7	23.7
	Synedra acus	3.2	1.4	2.4	27.8
*74.9	*Lithodesmium undulatum*	6.2	2.7	2.3	8.3
	Synedra acus	5.7	1.5	3.8	15.9
II & IV	*Scrippsiella trochoidea*	5.3	3.4	1.5	23.0
	Microspora sp.	4.8	2.5	1.9	29.4
	Fragilaria capucina	4.4	2.6	1.7	35.3
*70.5	*Microspora* sp.	5.6	3.0	1.9	8.0
	Melosira granulata	5.4	4.4	1.2	15.6
III & IV	*Fragilaria capucina*	5.1	3.0	1.7	22.8
	Ankistrodesmus falcatus	4.5	1.8	2.6	29.2
	Tintinnopsis nucula	4.2	1.2	3.5	35.3

*Average dissimilarity ($\bar{\delta}$) within the groups.

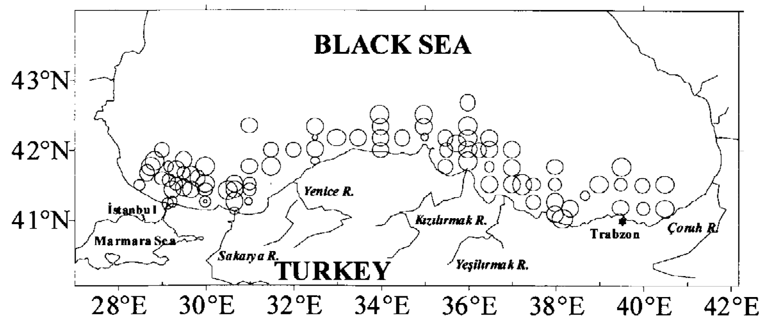

Figure 9. Differences in Pielou's Evenness Index (J′) in the water column in April 1989 (min: 0.08; max: 0.99).

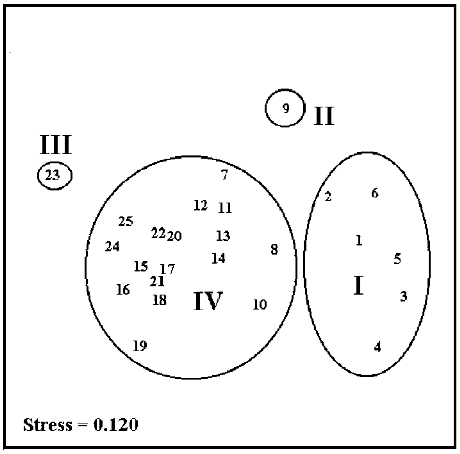

Figure 10. Two-dimensional non-metric MDS (Multi-Dimensional Scaling) ordination of the 25 grid stations.

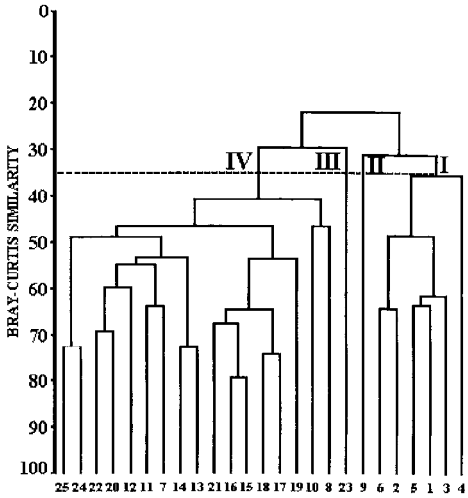

Figure 11. Dendogram showing classification of 25 grid stations with four major groups distinguished at an arbitrary similarity level of 35%.

the fresh weight of all plankton biomass, disregarding macroplanktonic jelly-fish.

Along the study area the coastal regions in the west, especially the Bosporus junction (grid #3 in Fig. 2) and Sakarya River vicinity (grid #4) formed the most productive regions (Fig. 3). This coastal region was also found most productive during the winter of 1990 (Uysal & Sur, 1995). Grid #3 corresponds to the upwelling region associated with the bifurcation of the MBSC (Main Black Sea Current) as described previously off the Bosporus entrance (Oguz et al., 1992) and #4 is much affected by the Sakarya river, being the most numerous in cell density among all regions. Net phytoplankton abundance is slightly diluted towards east near the Yenice River and except relatively higher abundances observed at grids 15, 24 and 25, almost no significant changes in abundance in the central and eastern part of the coast is observed. It is known from earlier studies that the cyclonic boundary current reaches the concave coastline east of the Sakarya Canyon, veers north and expands near Cape Baba where the narrow shelf topography is terminated (Uysal & Sur, 1995). Both the total number of species identified and the abundance were found high around Cape Baba. Zenkevich (1947) has also shown that in a narrowly limited area off the Bosporus the plankton content may rise to 300 mg m^{-3}. Greater chl-*a* ($\sim$1.5 μg l^{-1}) and TOC (Total Organic Carbon) values ranging from 2.0 to 2.8 ppm (Oguz et al., 1990) also confirm the productivity of the region. It was also stated by Malone (1980) that net plankton fraction increases in relative abundance in continental shelf and coastal upwelling waters where chain-forming diatoms and large, solitary diatoms and dinoflagellates dominate the phytoplankton.

Increasing levels of environmental stress are generally considered to yield decrease in species richness (d), diversity (H') and in proportional representation

(J). Contrasting surface water temperatures in the west would possibly cause heterogeneity on such parameters (see Fig. 5). This may also, to a certain extent, due to slight cross-shelf changes in surface salinity (see Fig. 6). All the community diversity measures (d, H′ and J) (see Figs 7–9) were relatively higher in the central region (grids #11, 12, 13 and 14) where a strong meandering jet up to ~34° E and a strong elongated anticyclonic feature to the east prevails. Lower measures were obtained at productive sites due to rigorous outburst of a few species, although maximum number of species were identified also in coastal regions in the western part (see Fig. 4). From this point of view, there seems to be much homogeneity in the eastern part.

Although plankters are known to be free drifting organisms, and despite the presence of a well-defined cyclonic flow parallel to the coast, patchy assemblages of plankters at varying scales were observed in the southern Black Sea coast during this study. Similar phytoplankton patches of varying size are observed during winter (Uysal & Sur, 1995), spring and summer (Uysal et al., 1998) as well. An overall look at MDS plots of grid stations 1 through 25 from west to east in an alternating manner implies the influence of cyclonic flow, although some adjacent grids fall into categories apart from each other. Besides the two western and the larger eastern patches, grids #9 and #23 formed two small distinct sub-aggregations. Within the western patch (see Fig. 10, group I) grids fall apart from each other indicating varying community assamblages. Net phytoplankton community of much colder offshore grids #2 and #6 were located in closer proximity compared to the community of relatively warmer coastal grids #3 and 5 (see Figs 10 and 11). As the grid #1 includes both the coastal and offshore stations it is situated in between these two communities. Similar close affinities in the community structure are also observed in the largest patch (group IV). MDS plot of grids in the largest patch implies the existence of slightly distinct subcommunities. In the central region grids #7, 8, 10, 11, 12, 13 and 14 seem to form a slightly distinct cluster within the main patch. Similarly alternating grids #15, 16, 17, 18, 19, 20, 21 and 22 seem to form another group in the east. In the far east grids #24 and 25 also seem to form another small subentity.

Clearly visible from the MDS plots is the fact that groups II and III were separated from the rest, having the least number of species and lower diversity measures. Lacking species *Pseudo-nitzschia seriata*, *Thalassiosira decipiens*, *Cerataulina pelagica* and *Synedra acus* resulted in grid #9 to be placed between the two main groups as a separate group. Among the species thriving in offshore Trabzon (grid #23), the rarely found diatom species *Gomphonema angustatum* of fresh-water origin could possibly have drifted from local rivers near Trabzon. This species has been also reported by Skolka (1969) as a seldom found species in the Black Sea in March. *Gomphonema* is a genus with many more freshwater than marine species. Besides this, the presence of *Melosira granulata* of fresh and brackish-fresh water origin in the region also implies the intrusion of fresh water from local creeks. It is also reported by Honjo et al. (1987) that besides the biogenic products of the surface layer, detritus from rivers and shelf sediments are major components of the flux in the Black Sea. Lastly, it could be concluded that the general features of the Black Sea circulation, river plume dynamics, coastal upwelling, mixing and downwelling over the shelf break and slope, as well as the presence of quasi-permanent eddies along the coast could also result in heterogeneous spatial distribution of net phytoplankters along the entire southern Black Sea coast.

Acknowledgements

This work is a part of a Ph.D. thesis carried out within the framework of the project "Stock Assessment Studies for the Turkish Black Sea Coast" supported by NATO through the Science for Stability Programme, the State Planning Organization of Turkey (DPT) and Turkish Scientific and Technical Research Council (TUBITAK). The generous help of Dr. Erhan Mutlu in statistics is greatly acknowledged. I am also grateful to Dr. Emin Ozsoy for his comments and corrections on the manuscript, and to my sister-in-law Kimberly Davis Uysal for editing the manuscript. I wish to thank officers and crew of R/V BILIM for their help on board.

References

Aubrey, D., S. Moncheva, E. Demirov, V. Diaconu & A. Dimitrov, 1995. Environmental changes in the western Black Sea related to anthropogenic and natural conditions. J. mar. Syst. 7: 411–425.

Baltic Sea Environment Proceedings, 1988. Guideliness for the Baltic Monitoring Programme for the Third Stage. No.27 Part D., Biological Determinands: 161 pp.

Bologa, A. S., M. Usurelu & P. T. Frangopol, 1981. Planktonic primary productivity of the Romanian surface coastal waters (Black Sea) in 1979. Oceanol. Acta 4/3: 343–350.

Eker, E., L. Georgieva, L. Senichkina & A. E. Kideys, 1999. Phytoplankton distribution in the western and eastern Black Sea in spring and autumn 1995. ICES J. mar. Sci. 56: 15–22.

FAO/IOC/UNEP, 1992. Report of the FAO/IOC/UNEP Training Workshop on the Statistical Treatment and Interpretation of Marine Community Data. In cooperation with IOC/UNEP. Athens, February 1992: 212 pp.

Honjo, S., B. J. Hay, S. J. Manganini, E. T. Degens, S. Kempe, V. Ittekkot, E. Izdar, Y. T. Konuk & H. A. Benli, 1987. Seasonal cyclicity of lithogenic particle fluxes at a southern Black Sea sediment trap station. In Degens, E. T., E. Izdar & S. Honjo (eds), Particle Flux in the Ocean. Mitt. Geol. Palaont. Inst. Univ. Hamburg, 62: 1–18.

Ivanov, L. & R. J. H. Beverton, 1985. The fisheries resources of the Mediterranean. Part two: Black Sea. Etud. Rev. CGPM / Stud. Rev. GFCM, 60: 1–135.

Mackas, D. L., L. D. Kenneth & M. R. Abbott, 1985. Plankton patchiness: biology in the physical vernacular. Bull. mar. Sci. 57/2: 652–674.

Malone, T. C., 1980. Algal size in the physiological ecology of phytoplankton, In Morris, I. (ed.), The Physiological Ecology of Phytoplankton. Blackwell Sci. Publ. Oxford 7: 433–463.

Oguz, T., S. Tugrul, F. Bingel & M. Unsal, 1990. Stock assessment studies for the Turkish Black Sea coast. NATO-TU Fisheries. First technical report. METU- Institute of Marine Sciences. Erdemli, Turkey: 1–122.

Oguz, T., P. E. La Violette & U. Unluata, 1992. The upper layer circulation of the Black Sea: its variability as inferred from hydrographic and satellite observations. J. Geophys. Res. 97/C8: 12 569–12 584.

Oguz, T., V. S. Latun, M. A. Latif, V. V. Vladimirov, H. I. Sur, A. A. Markov, E. Ozsoy, B. B. Kotovshchikov, V. V. Eremeev & U. Unluata, 1993a. Circulation in the surface and intermediate layers of the Black Sea. Deep-Sea Res. 40/8: 1597–1612.

Oguz, T., D. G. Aubrey, V. S. Latun, E. Demirov, L. Koveshnikov, H. I. Sur, V. Diaconu, S. Besiktepe, M. Duman, R. Limeburner & V. Eremeev, 1993b. Mesoscale circulation and thermohaline structure of the Black Sea observed during HydroBlack 1991. Deep Sea Res. 41/4: 603–628.

Ozsoy, E. & U. Unluata, 1997. Oceanography of the Black Sea: a review of some recent results. Earth Sci. Rev. 42/4: 231–272.

Porumb, F., 1989. On the development of *Noctiluca scintillans* (Macartney) Kofoid and Swezy, under the eutrophication of the Romanian Black Sea waters. Cercet. Mar. 22: 247–262.

Skolka, H., 1969. The most frequent species found into the Black Sea water. Ecol. Mar. 4: 149–226.

Sorokin, Y. I., 2002. The Black Sea. Ecology and Oceanography. Backhuys Publ., Leiden. Chapter 6: 391–468.

Sur, H. I., E. Ozsoy & U. Unluata, 1994. Boundary current instabilities, upwelling, shelf mixing and eutrophication processes in the Black Sea. Prog. Oceanogr. 33: 249–302.

Sur, H. I., Y. P. Ilyin, E. Ozsoy & U. Unluata, 1996. The impacts of continental shelf/deep water interactions in the Black Sea. J. mar. Sys. 7: 293–320.

Uysal, Z., 1987. Fate and distribution of plankton around the Bosporus – south-western Black Sea, Bosporus, Golden Horn, north-eastern Marmara and the bay of Izmit -. Master Thesis. METU-IMS. Erdemli, Turkey: 1–151.

Uysal, Z. & H. I. Sur, 1995. Net phytoplankton discriminating patches along the southern Black Sea coast in winter 1990. Oceanol. Acta 18/6: 639–647.

Uysal Z., A. E. Kideys, L. Senichkina, L. Georgieva, D. Altukhov, L. Kuzmenko, L. Manjos, E. Mutlu & E. Eker, 1998. Phytoplankton patches formed along the southern Black Sea coast in spring and summer 1996. In Ivanov, L. & T. Oguz (eds), Ecosystem Modeling as a Management Tool for the Black Sea. Kluwer Acad. Pub.: 151–162.

Vinogradov, M. Ye. & V. M. Grinberg, 1979. 64th cruise of the R/V Vityaz – A study of pelagic ecosystems of the Black Sea. Oceanology 19/2: 225–228.

Zenkevitch, L., 1963. Biology of the Seas of the USSR. Allen & Unwin, London: 955 pp.