Major shifts in the phytoplankton community (1980-1994) in the Romanian Black Sea

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ABSTRACT

Between 1980 and 1994, thirteen marine transects off the Romanian coast were sampled at monthly intervals from February to October at 5, 10 and 20 m depths, together with control sites situated 10, 20 and 30 miles from the coast. The present paper is based on 2,864 phytoplankton and 1,588 pigment samples. In this long data set, consistent patterns of phytoplanktonic community structure were identified: 1) The community maintained the capacity to produce huge biomasses (max. 20,163-205,084 or even $422,140 \times 10^3$ cell l^{-1}), but an increased tendency to develop in "patches" became much more evident; 2) The frequency and cell density of nannoplanktonic species increased up to bloom phenomena: *Apedinella* (21.5), *Mantoniella* (5.97), *Hyalobrion* (13.25), and *Coccolithus* (30.72), all Figures in cell no $\times 10^6$ l^{-1}; 3) Ultraplanktonic organisms represented by phytoplanktonic bacteria bloomed between 1990-1994 (103.68 and 63.57×10^6 cell l^{-1}); 4) Chlorophyll *a* had maximum values of 35-427 and phaeophytin 37.73-65.82 μg l^{-1}. Correlations with nutrients and light are discussed.

RÉSUMÉ

Évolution de la communauté phytoplanctonique devant les côtes roumaines de la mer Noire

Les eaux de la mer Noire ont été étudiées au large des côtes roumaines sur 13 radiales parcourues chaque mois, de février à octobre, entre 1980 et 1994, sur des fonds de 5, 10 et 20 m, ainsi qu'en des stations de référence situées à 10, 20 et 30 milles de la côte. Portant sur 2 864 échantillons de phytoplancton et 1 588 échantillons de pigments, le présent travail met en évidence la structure de la communauté phytoplantonique: 1) maintien de la capacité de produire des biomasses considérables (max. 20 163-205 084 ou même $422\ 140 \times 10^3$ cell l^{-1}), mais avec une tendance croissante développement en taches; 2) fréquence et densité des espèces nannoplanctoniques en augmentation jusqu'à la floraison de certaines d'entre elles (cell $\times 10^6$ l^{-1}): *Apedinella* (21,5), *Mantoniella* (5,97), *Hyalobryon* (13,25), *Coccolithus* (30,72). 3) Les organismes ultraplanctoniques représentés par les bactéries phytoplanctoniques ont produit des floraisons entre 1990 et 1994; 4) La chlorophylle *a* présente des valeurs maximales de 35 et 427 μg l^{-1} et la phéophytine entre 37,73 et 65,82 μg l^{-1}. Les corrélations avec les nutriments et la lumière sont discutées.

Oceanologica Acta, 1997, **20**, 1, 119-129.

INTRODUCTION

The Black Sea is a landlocked sea, constituting a "*unicum hydrobiologicum*" by virtue of its physical, chemical and biological conditions. Communication with the Mediterranean basin is also extremely important for the immigration of new taxa, and its status is strongly influenced by fresh water discharged by the rivers (4.83-19.34 salinity according to Popa *et al.*, 1985). During recent decades, the Black Sea has been strongly affected by human activities including, in particular, overfishing by bottom trawls (Tolmazin, 1985; Zaitsev, 1979, 1992).

A large quantity of inorganic and organic compounds is introduced every year both by rivers and by industrial and domestic discharges (Mihnea, 1992), producing many gradients through the inshore zones. Dramatic changes have occurred at all levels of the ecosystem (Bodeanu, 1984; Mihnea *et al.*, 1980; Mihnea, 1986; Gomoiu, 1987; Porumb, 1980; Tiganus, 1982, etc.).

The increasing concentration of nutrients during the 1960s and 1970s (Mihnea *et al.*, 1980) caused some qualitative and quantitative modification in the phytoplankton community, viz. shifts in the ratios between the main taxonomic groups, and the occurrence and increasing frequency of *Chrysophyta*, *Cryptophyta* and *Euglenophyta*. An extension of the biological season as well as a high amplitude of development of the main phytoplanktonic forms (*Skeletonema costatum*, *Cyclotella caspia* and *Prorocentrum cordatum*) was also recorded.

Our study performed during 1980-1994 has revealed new aspects of the phytoplanktonic subsystem in comparison with the 1960s and 1970s.

MATERIALS AND METHODS

Sampling programme

The study was based on transects of 13 stations perpendicular to the Romanian shore line. Station positions were selected to reflect gradients in properties with a control point situated 10 miles offshore (Fig. 1). At long time intervals, in the area situated in front of the Danube delta, 20 and 30 miles stations were also sampled. Sampling was performed at standard depths (0, 5, 10, 20, 30, 50 m) by Hydrobios bottles, with a monthly frequency from February to October. Physical, chemical and biological parameters were determined within the same programme.

Methods used for analysis

Samples for phytoplankton cell counts were preserved in buffered formaline. 1,000 ml samples were allowed to settle within two weeks of collection, the supernatant removed, sediments in aliquots of 10 ml sea water separated (Semina, 1978) and treated with Lugol's solution rendered basic with sodium acetate. Samples were counted on ordinary slides or Fuchs Rosenthal chambers, depending on the densities of taxa. The precision of the method was about ± 10 % although in some cases, due to high detrital levels, it reached only ± 20 % for nannoplankton.
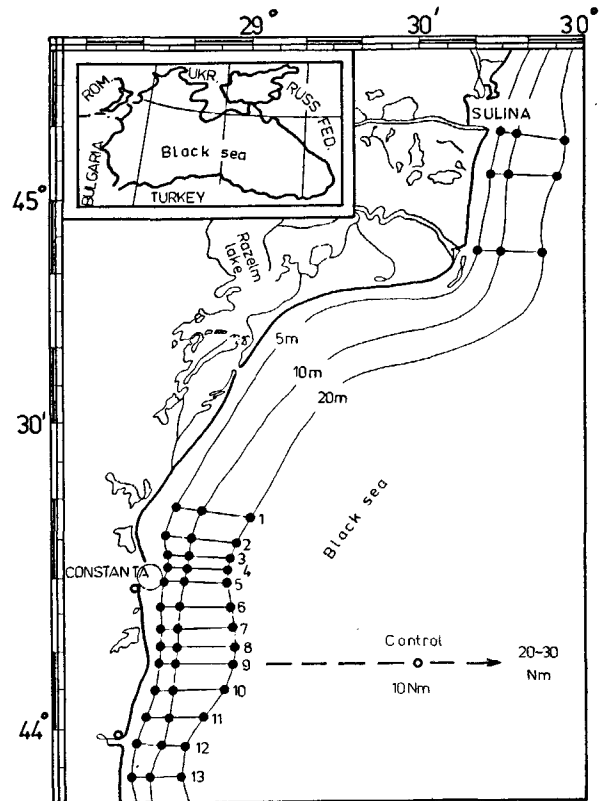

Figure 1

Location of sampling points. The circled Constantza Port area includes stations A, B, C.

Cyanobacteria were counted using the characteristic orange fluorescence of phycoerithrin excited by blue light. Phototrophic bacteria containing photosynthetic pigments were counted using green light excitation in at least 30 fields.

For pigment determinations (which include chlorophyll *a*, chlorophyll *650*, and chlorophyll *660*), 0.5 (in extreme situation 0.25) to 1.5 l of sea water was filtered through a Millipore HA filter. For chlorophyll *a*, the standard method (SCOR-UNESCO, 1966) was used. Chlorophylls *650* and *660* were extracted, measured and calculated (*cf.* methods described in Takahashi and Ichimura, 1968).

A rough estimation of total phaeopigments was based on the method of Strickland and Parsons (1972).

Incidental light was measured daily by the local Meteorological Service as well as during the 1980-1983 sampling cruises. Total light transmission was evaluated by Secchi disc and the data converted into 50, 10 and 1 % isolumes.

RESULTS AND DISCUSSION

Macronutrients

The eutrophication level of the survey area is very pronounced (Table 1). The essential macronutrients can sustain yearlong algal development, and even when their concentrations were decreased they could not be limiting factors. In limited areas, and on very rare occasions,

Table 1

Range of macronutrient concentration (µg at l⁻¹) within the inshore Romanian area of the Black Sea (min. and max. values)

Nutrient	Period		
	1980-1982	1983-1987	1990-1994
NO₂	0.02-15.0	0(*)-42.0	0.04-37.36
NO₃	0-67	0.12-90.5	0.33-114.51
NH₄	0.96-127.0	0-455.0	0.05-166.76
PO₄	0.25-133.0	0-156.4	0-284.0

(*) zero only after very heavy blooms and during short time.

undetectable values for all macronutrients were found; this was explained by the high quantities of phytoplankton developed at the time.

Phytoplanktonic community structure

Until two decades ago, the Black Sea phytoplankton community structure was reported as composed of two major groups: diatoms and dinoflagellates, together with less significant representatives of silicoflagellates, coccolithophores and xanthophytes.

The first reports of the importance of *Chrysophyta, Cryptophyta* and *Cyanophyta* were summarily published by Mihne (1978, 1986), Mihnea *et al.* (1980). These groups included most of the microplanktonic flora, and some of the common nannoplanktonic flora, but did not include a great proportion of nannoplanktonic microflagellates of uncertain origin, which are new arrivals. An original feature of our study consists in the introduction of all these representatives, even if most of them are still not identified.

Three periods of seasonal associations were characterized by species groupings.

The Winter-Spring (February-May) association mainly consisted of microplankton (cells l⁻¹) having as dominants: *Skeletonema costatum* $(1.4 \times 10^3 - 109 \times 10^6)$; *Heterocapsa triquetra* $(127 \times 10^3 - 65 \times 10^6)$; *Cerataulina bergonii* (1.138×10^6); *Thalassiosira gravida* $(4-47 \times 10^3)$; and *Detonula confervacea* $(0.03-10 \times 10^6)$. Nannoplanktonic forms also formed part of this association, developing when *Heterocapsa* ceased its division. *Chrysophyta* account for a large number of unidentified species $(1 \times 10^3 - 1.64 \times 10^6)$ and the dominant species *Apedinella spinifera* $(313 \times 10^3 - 18 \times 10^6 - 21.5 \times 10^6)$ and *Hyalobryon* sp. $(2.5-13.25 \times 10^6)$. The *Cryptophyta* division is represented by *Rhodomonas minuta, R. lens* and *Cryptomonas*; these species were frequent every year, but their low level increased with time (*e.g.* for R. lens : 1×10^3 1980-1989 and up to 877×10^3 in 1993). *Chlorophyta* are represented by *Ankistrodesmus falcatus v.spiriliformis* (221×10^3), *Ankistrodesmus falcatus acicularis* (61×10^3), *Scenedesmus quadricauda* (51×10^3), *Chlamydomonas* sp (5×10^3), *Tetraedron minimum* (3×10^3), *Oocystis pelagica* (24×10^3), *Tetracoccus botryoides* (16×10^3), *Crucigenia quadrata* (32×10^3), etc. During 1990-1994, the density of some species increased, *e.g.* *Crucigenia quadrata*

(517×10^3). Extremely rare during the 1970s, species belonging to *Cyanobacteria* increased in both frequency and density throughout the study period $(0.47 \times 10^6$ in 1980 and $40.8 \times 10^3 - 63.573 \times 10^6$ in 1994).

The Summer (June-July-early of August) association has as a first-rank dominant *Prorocentrum cordatum* $(37 \times 10^3 - 204.79 \times 10^6 - 421 \, 'x \, 10^6)$; the remnant species *Skeletonema* (up to 12×10^6) and *Cerataulina* $(6 \times 10^3 - 9.39 \times 10^6)$ usually resume division in sheltered or half-open zones.

When the bloom of *Prorocentrum* is ended, *Euglenophyta* represented by *Eutreptia lanowii* developed (23.99×10^6), followed by Dinophyta sp. *Glenodinium lenticula f. minor* $(1.523 \times 10^6$ in 1984), or sometimes the diatom *Chaetoceros socialis* $(224 \times 10^3 - 53 \times 10^6$ in 1987).

Chrysophyta and *Cryptophyta* were represented by many species, but usually at a lower level of density (approx. -10×10^3), giving them an inferior position in the hierarchy of association.

Since 1990-1994 some have crysophytes developed to high levels, *e.g.* *Mantoniella squamata* $(768 \times 10^3$ in 1993 and 5.973×10^6 in 1992) and *Coccolithus huxleyi* $(537 \times 10^3 - 30.72 \times 10^6)$, thereby competing for the first or the second rank position in the association.

Most important are Cyanobacteria: *Sinecococcus marinus* $(10-33.3 \times 10^6$ in 1986), *Phormidium micoideum*-like cells $(50 \times 10^3 - 13.393 \times 10^6$ in 1987) and huge quantities of unidentified species, free or aggregated (1994).

The Autumn association (middle August-October) is composed of three groups.

Diatoms are represented during August-September by *Skeletonema* $(1.33-6.9 \times 10^6)$, *Cerataulina bergonii* $(5.85 \times 10^3 - 9.47 \times 10^6)$ and *Leptocylindrus danicus* (2.96×10^6). Among these species, *Skeletonema* is the most productive, being able to continue to develop in deep autumn (October) when it can reach another maximum (52.91×10^6). During August-September, strongly developed *Chrysophyta* and *Cryptophyta* representatives are also observed, in association .

The second group includes *Dikrateria vlkianum* $(2.25 \times 10^6$ in 1994); *Apedinella* s. $(2.53 \times 10^6$ in 1994); *Mantoniella squamata* $(1.326 \times 10^6$ in 1993 and 4.267×10^6 in 1994), etc. *Cryptophyta* representatives as a whole are present throughout the study area. They reached high densities year by year. With the exception of *Rhodomonas lens* $(432-738 \times 10^3)$ and *R. salina* (707×10^3), the rest of group as a whole did not exceed 5×10^3 cell l⁻¹.

Cyanobacteria is the third group that contributes to the autumn association: *Phormidium micoideum*-like cells $(283 \times 10^3 - 2.45 \times 10^6$ during 1983-1986); *Aphanothecae clatratha* $(1 \times 10^6$ in 1983-1984); *Microcystis* sp. $(30.62 \times 10^6$ in 1984) and unidentified small-sized (3-1 µm) species $(1.23-50.355 \times 10^6)$.

Chlorophyta also occurred, but only *Carteria* sp (4.1×10^6) is of significance. *Dinoflagellates, e.g. Prorocentrum micans, Ceratium furca, C. fusus, etc.*, usually occurred at the beginning of Autumn but occupied inferior positions within the association.

Table 2

Maximum density produced by certain dominant species (cell no $l^{-1} \times 10^{-6}$) during 1980-1994.

Species	Year												
	1980	1981	1982	1983	1984	1985	1986	1987	1990	1991	1992	1993	1994
Skeletonema costatum	39.96		87.55	3.68	107.85	41.22	50.42	16.50	21.86	0.45	15.02	52.05	52.97
Cerataulina bergonii		0.80		0.95		0.10	0.56	7.09	11.09	2.73	9.38	9.46	2.13
Detonula confervacea								33.73					
Chaetoceros socialis								53.60				4.13	
Chaetoceros similis		1.38						0.25				0.57	
Cyclotella caspia			1.63		0.25	1.29	2.40	0.53	0.65				
Prorocentrum cordatum		420.7	47.79	6.89	13.51		30.93	163.84	3.27	115.19	204.79		
Heterocapsa triquetra	65.21		3.12		5.35	0.30	7.73					29.54	3.49
Apedinella spinifera				21.50						0.40		21.33	2.52
Mantoniella squamata											5.97	1.36	12.48

During the long period of study, the associations were not precisely defined; overlapping occurred, and some species changed cycles as physical factors were modified.

Certain species produced massive populations every year, whereas others were extremely inconsequential (Table 2). These inconsistencies are attributed to the development of nannoplanktonic and ultraplanktonic forms, represented by new incomers that found appropriate conditions for their development and occupied niches in the phytoplanktonic subsystem.

Diversity index

Shannon-Wiener's diversity index (H') scaled by units of 1.0 and monthly intervals on the totality 2,448 samples showed no change between the two compared periods. Limits of variation (0-4.55) demonstrated that the phytoplanktonic community maintained the ability to develop one or four dominants with very high density, irrespective of the number of species contained in a sample. The frequency of size class diversity index was bigger for the intervals of 0-1 to 2-3 (Table 3). The significance of

Table 3

Frequency (%) of size class diversity index during 1980-1994 (Shannon-Wiener eq.).

Year	Size class diversity index H' (bits)				
	0-1	1-2	2-3	3-4	4-5
1980	20.68	44.14	26.90	8.27	0
1981	55.72	21.37	17.55	5.34	0
1982	33.24	34.10	27.22	5.16	0.28
1983	8.58	19.85	39.95	29.90	1.71
1985	17.05	17.51	36.40	25.34	3.69
1986	32.57	20.00	21.14	26.28	0
1987	38.09	32.47	18.18	10.82	0.43
1990	6.43	29.70	40.10	21.78	1.98
1991	35.48	33.55	22.58	4.52	3.87
1992	29.27	35.36	25.00	10.36	0
1993	33.33	26.67	34.81	5.18	0
1994	27.40	40.41	28.77	3.42	0

these values is that the system has limited information and a high entropy.

Phytoplankton densities

From the 2,864 samples analysed for cell density, the average values (in cell no $\times 10^3$ l^{-1}) ranged from 911 to 13,474 with minimum values between 0.3 and 20 and maximum values from 20,163 to 205,084 or 422,140 in sheltered zones (Table 4).

The distribution of phytoplankton is not uniform; variations between different depths, or between inshore and offshore areas must be considered. In addition, the coastline has many hydrotechnical works (dams, ports, *etc.*) that comprise sheltered or half-open zones, permitting mechanical accumulation or prolonged vegetation of remnant species. Comparison of the distributions of the phytoplanktonic densities during the 1980s and 1990s clearly shows that the phytoplankton's ability to develop in "patches" has become much more pronounced (Figs. 2, 3).

The huge quantities of phytoplankton usually found are evidence of the imbalance between the two subsystems: primary producers and consumers. Because of the massive development of the phytoplankton community due to the high level of nutrients, both the species number and biomass of zooplankton declined dramatically (Petran 1990, 1992).

The distribution of cell densities among different size classes of phytoplankton (Fig. 4a) has frequently shown values of 0.5 to 5×10^6 during 1984-1990; in 1980 and in 1991-1994, values greater than 5 and up to 100×10^6 were also frequent (1992). Since the biomass in 1980 was predominantly produced by microplankton, during 1984-1994 nannoplankton and ultraplankton contributed consistently to the high level of phytoplankton density.

During 1980-1985, the frequency of nannoplankton, including large *Cyanobacteria*, increased from an order of tens to hundreds of thousands of cells l^{-1}. Very rarely did densities of greater than a million cells occur, except in the case of one species: the chrysophyte *Apedinella*, which produced in 1983 a bloom (21.5 $\times 10^6$ cell l^{-1}).

Table 4

Average, minimum and maximum densities (cell no l⁻¹ × 10⁻³) of the phytoplanktonic community during 1980-1994.

Determinant	Year						
	1980	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**
No of samples	141	132	374	405	320	218	175
Average	7,607	13,474	5,483	911	12,311	1,496	5,963
Minimum	9	0.3	1.1	0.4	2.33	1.5	9
Maximum	65,562	161,015-422,14 (*)	20,163-91,041 (**)	40,736	108,079	56,324	51,548
	1987	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**
No of samples	235	83	202	134	164	135	146
Average	8,241	8,462	2,135	11,674	12,270	7,506	4,732
Minimum	17	7	5	5	20	6	0.6
Maximum	164,214	112,589	22,023	119,211	205,084	73,859	105,793

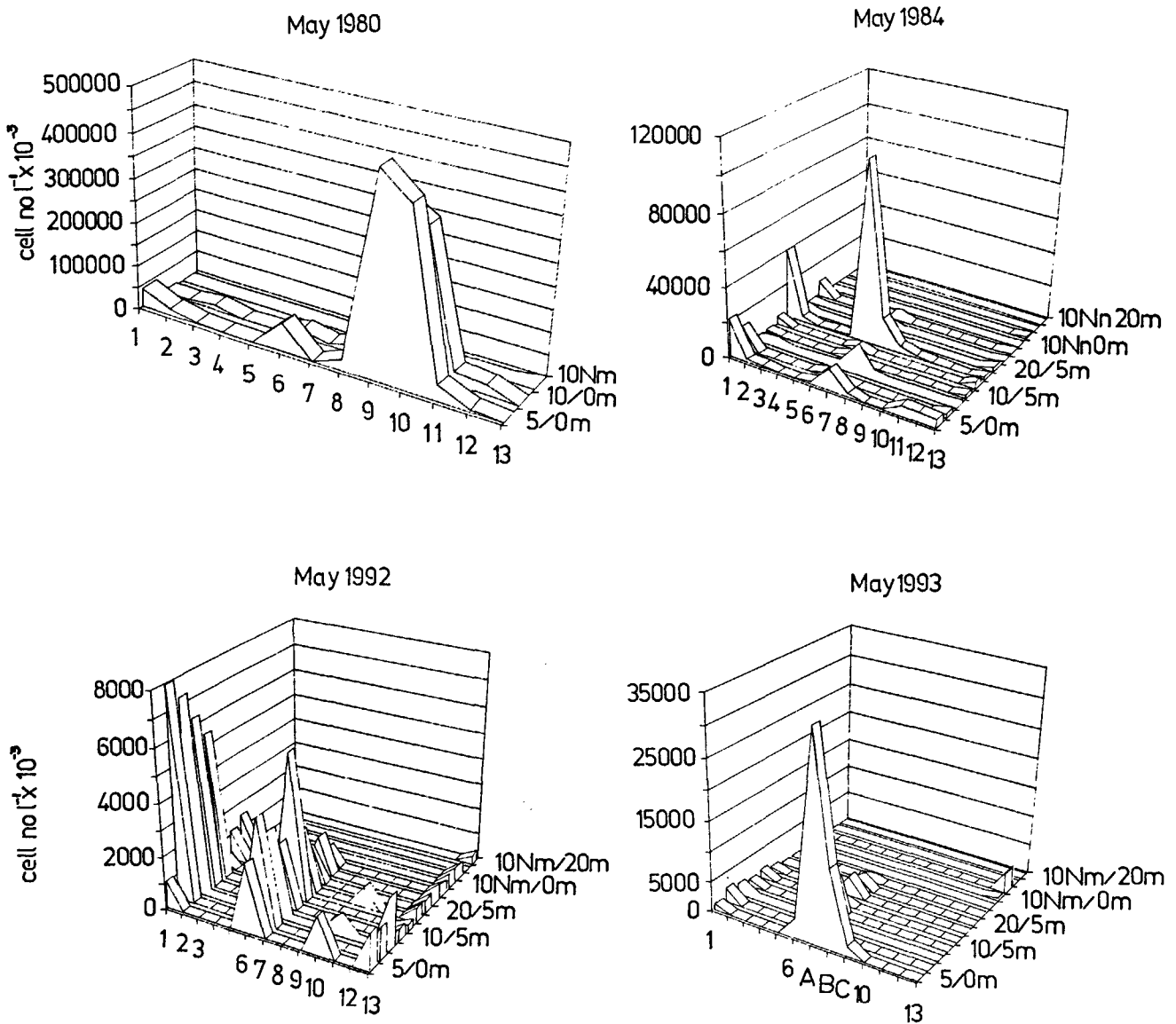(*) and (**): in these cases maximum values were found only in sheltered zones.

Figure 2

Density of total phytoplankton in a Spring month during selected years. Isobaths of 5, 10, 20 m and control area at 10 miles with sampling depths (0, 5, 10, 20 m).
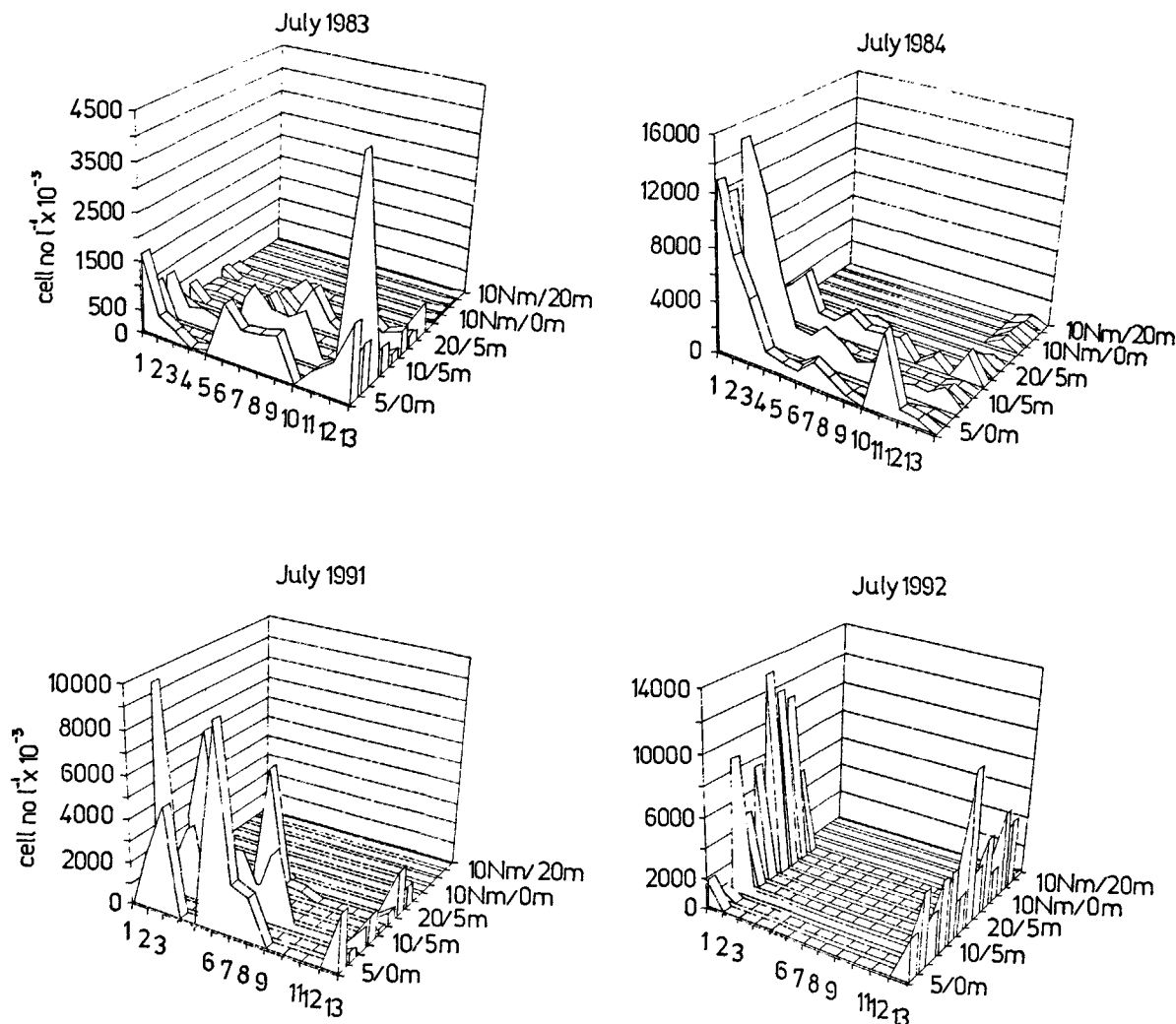
Figure 3

Density of total phytoplankton in a Summer month during selected years. Isobaths of 5, 10, 20 m and control area at 10 miles with all conventional depth (0, 5, 10, 20 m).

Since 1983, species number, frequency and especially densities have progressively increased, and some of the representatives have become dominant in the community (in cell no × 10^6 l^{-1}): *Mantoniella squamata* (5.97 in 1992; 1.36 in 1993 and 12.48 in 1994); *Apedinella spinifera* (21.33 in 1993); *Hyalobrion* sp (13.25 in 1993); *Coccolithus huxleyi* (4.72 in 1990; 30.72 in 1993), etc. The cell density of *Chrysophyta* and *Cryptophyta* became larger than 1 × 10^6 cell l^{-1} in the majority of samples (Fig. 4b, c).

Ultraplanktonic organisms represented by *Cyanobacteria* were detected from 1990, but at low levels (less than 1 × 10^6 l^{-1}). During 1992-1994, the members of this group increased very rapidly. Ultraplanktonic *Cyanobacteria* produced blooms reaching (cell no × 10^6 l^{-1}): 103.68 (1992) and 63.57 (1994). Figures relate to free forms of this group, as the quantity of aggregates could not be assessed.

Studies have documented that nannoplankton usually account for 80 to 100 % of the observed productivity and standing crop in temperate and tropical waters. Revelante

and Gilmartin (1976) demonstrated that for the northern part of the Adriatic Sea the presence of this group is closely related to the degree of eutrophication. The small surface-to-volume ratios of nannoplanktonic organisms also influences the kinetics of nutrient uptake/growth rates, sinking rates, etc. (Eppley and Thomas, 1969; Smayda, 1976). Nannoplanktonic populations described here developed during microplanktonic species blooms as well as following these phenomena, when the level of nutrients is diminished; the high versatility of these organisms in adapting from autotrophy to mixotrophy or heterotrophy (Mihnea *et al.*, 1991), as well as the fact that the Romanian area of the Black Sea is mainly affected by organic pollution (oxydability as mg O_2 l^{-1} min. value 1.96-3.05 and max. value 8.38-12.99, Cociasu *et al.*, 1981; Cociasu, pers. comm.) should be also taken into account.

Together with the massive input of chemical compounds during recent decades, dramatic changes have occurred in the characteristics of the Black Sea chemocline (Murray
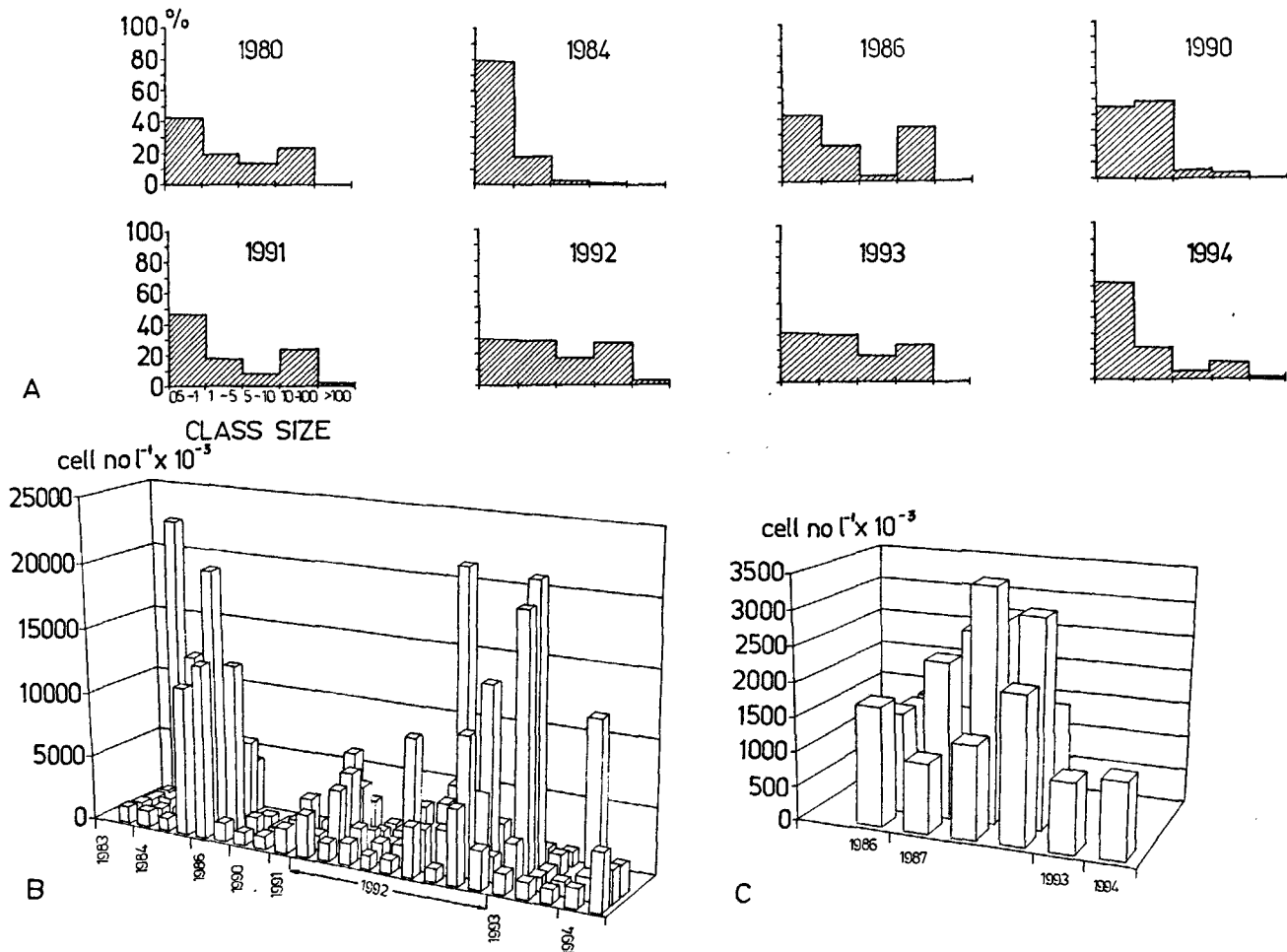
Figure 4

Frequency of total phytoplankton densities (A) sized in classes greater than 0.5×10^6 l^{-1} (smaller values are omitted) and densities greater than 1×10^{-6} of Chrysophyta (B) and Cryptophyta (C) representatives.

et al., 1989). First and foremost, the anoxic, sulphite-containing zone has shoaled by perhaps as much as 30 m (Fashchuk and Ayzatullin, 1986).

An estimate of contemporary bacterial abundance and bacterial biomass plankton was performed in the upper portion (0-500 m) of the offshore area by Bird and Karl (1991). Pigmented bacteria at their population density maximum accounted for approximately 10-20 % of the total bacterial community. The majority of pigmented cells were short (1-3 μm), narrow rods, with rare half-circle and coccoidal forms. On the basis of high-pressure liquid chromatographic pigment analyses, the authors considered the community to be primarily made up of the green sulphur bacterium, *Chlorobium phaeovibroides*. Notwithstanding the absence of a general enrichment in total microbial or bacterial biomass across the oxic-to-anoxic boundary, Bird and Karl (1991) found "sharply delineated populations of microorganisms living at specific depths within the redoxline". Among the microbial groups they described phototrophic bacteria/ciliates bearing attached bacteria and putative *Achromatium* cells. This flora has been shown to have a specific oxido-reductive effect on different compounds.

The inshore zone we studied has been and remains strongly affected by hypoxia (temporary oxygen down to 0.32-0.33 ml l^{-1}, Cociasu *et al.,* 1983). During 1975-1980, hypoxia existed throughout the year in a large area beyond the 30 m depth. Its level was maintained until 1990, but over a smaller area (Cociasu, pers. comm.).

Phototrotrophic bacteria were isolated in monocultures and grown in our laboratory on the same media as that used for photoautotrophic algae. Attributed to a great number of species, the strains are green, blue-green, red, yellow, gray and brown in color, shaped and sized identically to the species described by Bird and Karl (1991). They do not correlate with H_2S, since the isolated species will grow without it, but they correlate with the oxidative-reductive processes.

Interrelations between total biomass of phytoplankton and the vertical light proprieties of sea water

There is a very close correlation between the total light penetrating the sea water column and the species or/and their total quantities (Mihnea, 1984). Throughout the study area, large amounts of suspended matter and the huge

phytoplanktonic biomass limited the depth of vertical light transmission. Values varied annually from season to season and from site to site, depending on the physical and biological properties of the sea area. Areas situated in front of discharges as well as those located in sheltered zones were found to have the lowest values (0-0.5 m).

From the 1,519 measurements (Table 5) of Secchi disc transparency, a depth of 0-2 m was found to occur in 36% of cases, 2-3 m in 22%, 3-4 m in 16%, 4-5 m in 10%, 5-10 m in 12% and more than 10 m only in 4% of cases. Special peculiarities of isolumes were observed; only some years are given as examples with very significant densities of phytoplankton (average and maximum values in cell no $l^{-1} \times 10^3$): 1983 (911-40,735), 1986 (5,962-51,548), 1990 (2,135-22,023) and 1994 (4,732-105,792). Tables 6 and 7 present the limits of depth for the depth of 50, 10 and 1% isolumes from the total quantity of radiant energy that can penetrate the sea water.

The range of isolume depths (in m) was: 0.04-4.10 (50%), 0.13-13.5 (10%) and 0.27-27 (1%).

The analysis of the long data series of the total radiant energy measurements (corrected for albedo coefficient, cf. Ivanoff, 1975) for the Black Sea (Diaconu, pers. comm.) gave us approximate values of light energy for each isolume depth. We chose for our example data for 1981 a period characterized by predominantly clear days during cruises, which permits discussion of optimal conditions.

The 10-day average of total radiant energy on the sea surface ranged between 35,778 and 91,791 lx. The mean value corrected for albedo coefficient varied from 40,805 to 68,504 lx. The approximate value of light penetrating the water column at the isolume depth was: 20,402-34,252 lx for 50%; 4,080-6,850 lx for 10% and from 408 to 685 lx for 1% (Table 8). The results indicate that the euphotic layer is very shallow and would explain the occurrence and development of the two categories of incomers, Chrysophyta and Cryptophyta, mentioned above.

Representatives of these divisions are mobile and can "swarm" into the upper part of the euphotic zone where the total quantity of penetrated light satisfies their photosynthetic needs.

Cyanobacteria and the other phototrophic bacteria are able to develop beyond the 1% isolume depth, as these representatives need low levels of light.

The green sulphur bacteria have the lowest minimum light requirements of any photosynthetic organisms: photosynthesis saturates at light intensities of 700 lx (=4.48 μEinstein m^{-2} s^{-1}, according to Lippert and Pfenning, 1969). Biebl and Pfenning (1978) have shown that Chlorobium phaeovibrioides is capable of growing very slowly even at 5 lx (=0.032 μEinstein m^{-2} s^{-1}) in syntrophic mixed cultures with sulphate-reducing heterotrophic bacteria and with added acetate.

Figures for light availability (Table 8) converted in μEinstein for each isolume depth provided general information about the 50% (130.6-216.4); 10% (26.11-43.84) and 1% (2.61-4.38) isolumes and permit us to sustain our theory. However, this correlation is approximate, since both the attenuation coefficient and

Table 5

Size class frequency (%) of the transparency value into the water column (Secchi disc measurements).

Year	No. of samples	min.-max	Size class of transparency (m)						
			0-1	1-2	2-3	3-4	4-5	5-10	>10
1982	77	0.5-6	9.09	18.18	11.69	33.77	19.48	7.79	0
1983	245	0.7-7.5	3.70	8.60	32.24	26.53	13.47	14.70	0
1984	272	1.0-9	2.20	22.43	20.22	20.95	12.13	21.32	0.73
1985	225	0.2-11	3.11	20.89	30.67	15.55	9.33	16.89	3.56
1986	166	0.5-10	30.12	39.76	13.25	5.42	6.02	5.42	0
1987	151	0-10	16.55	21.20	26.50	9.93	15.90	9.93	0
1989	14	0.35-4	28.60	35.71	7.14	21.43	7.14	0	0
1990	76	0.90-6.2	2.63	11.84	23.68	44.74	7.89	9.21	0
1991	114	0.3-10.5	28.95	35.09	12.28	5.26	9.65	8.77	0
1992	48	0.3-7.5	22.92	25.0	35.42	10.41	6.25	0	0
1993	42	0.1-10	38.09	40.48	14.28	9.52	4.76	16.67	0
1994	89	0.4-8	25.84	40.45	10.11	4.49	5.62	13.48	0

Table 6

Range of 50, 10 and 1% isolume depths measured in the water column during 1983 and 1986 (in m; when a min. or a max. value was isolated it is doubled by another more common value).

Month	minimum-maximum isolumes 1983			minimum-maximum isolumes 1986		
	50	10	1	50	10	1
II	0.21-2.67	0.68-8.10(5.40)	1.35-16.20(10.8)	–	–	–
IV	0.72-2.26	2.36-7.43	4.72-14.85(10.8)	0.20(0.41)-2.46(0.82)	0.67(1.35)-8.10(2.7)	1.35(2.7)-16.2(5.4)
V	0.41-2.87	1.35-9.45	2.70-18.9(13.5)	0.37-0.82	1.21-2.70	1.89-5.40
VI	0.39-3.08	1.28-10.13(5.4)	2.57(4.05)-20.25(10.8)	0.41-1.64	1.35-2.70	2.7-10.8(5.94)
VII	0.41-4.10	2.0-13.50	4.05(9.45)-27.0	0.41-3.07	1.35-10.12	4.05-20.25(16)
VIII	0.62-.26(2.67)	2.03-8.78(7.43)	4.05-17.55(11.34)	0.41-1.64	1.35-5.40	2.7-1.02
X	0.25-2.67	0.68-8.78	1.35(5.4)-16.20	–	–	–

Table 7

Range of 50, 10 and 1 % isolume depths measured in the water column during 1983 and 1994 (in m; when a min. or a max. value was isolated it is doubled by another one more common).

Month	minimum-maximum isolumes 1993			minimum-maximum isolumes 1994		
	50	10	1	50	10	1
March	–	–	–	0.08-3.28	0.27-10.80	0.54-21.60(16.20)
April	0.33-2.46	1.08-8.10	2.16-16.20	–	–	–
May	0.04-2.46	0.13-8.10	0.27-16.20	0.20-2.46	0.67-8.10	1.35-16.20(9.45)
June	0.20-2.05	0.61-6.75	1.35-9.45	0.16-2.46	0.54-8.10	1.08-16.20(13.15)
July	–	–	–	0.20-1.23	0.67-4.05	1.35-8.10
August	0.20-2.66	1.08-8.77	1.89-17.55(13.50)	0.20-0.81	0.67-2.70	1.35-5.40
September	0.16-4.10	0.54-13.50	1.08-27.00(24.30)	–	–	–
October	–	–	–	0.72-1.43	0.70-4.72	4.72-9.45

conversion factors between various units are dependent on the spectra composition of the light.

Chlorophyll *a* standing crop and chlorophyll *650* and *660*

Chloropyll a standing crop

The present 11-year data set (1983-1994), unique in its geographical and temporal coverage of the Black Sea inshore zone, has identified consistent patterns of variations primarily controlled by the input sources.

The levels are very high within inshore areas influenced directly by discharges, with much lower standing stocks for the offshore zone.

Into the former area, seasonal variation of the phytoplankton crop rapidly responds to physico-chemical shifts and appears to be correlated both with discharge pulses from the Danube River and outfalls.

Most of the low values (0.04-1 μg chlorophyll a l^{-1}) were determined for the control area situated 10 miles or 20, 30 miles from the coast. The largest values (5-163-292-267 or 427 μg l^{-1}) were measured at Station 1, influenced by a fertilizer plant, and at Station 6 (8.54-51.55-18.18 or 96.8 μg l^{-1}), influenced by the greatest

discharge of both industrial and domestic wastes from a town of approximately 360,000 inhabitants.

Our data suggest that fluctuations in the high standing crop and chlorophyll a relate to the Spring-Summer periods which show an increased flushing of the Danube River and outfalls.

Maximum values were determined during March-July (in μg l^{-1}): 13-40.13 (1983); 5.56-40 (1986); 18-111 (1987); 8.54-10.82 (1990); 11.45-96.8 (1991); 6.71-292 (1992); 44.64-267-427 (1993) and 5.34-36.5 (1994).

In summary, chlorophyll a varied between min.values of 0.01-0.17 and maximum values 35 and 292; a unique maximum of 427 g l^{-1} was determined during 1993 in front of the fertilizer plant (Figs. 5, 6). It should be emphasized that the majority of high values were usually measured at the surface.

Subsurface chlorophyll a concentrations

The subsurface chlorophyll a maximum was strongly developed during April-May, and exceptionally in July; e.g. in May 1993 at Station 1, data from 0 to 20 m depth: 2.67; 0.8; 0.49 and 7.69 μg l^{-1}.

Subsurface chlorophyll values were correlated with high phytoplanktonic densities (in μg chlorophyll l^{-1}/depth (m)

Table 8

Total radiant energy (lx) and the average of light penetrated at 50, 10 and 1 % isolume depths.

| Month	Total radiant energy average on 10 days	mean value correct. for albedo coefficient	light (lx)/μEinstein's		
			50 %	10 %	1 %
III	43,376-37,427-55,216	40,805	20,402/129.3	4080/26.11	408/2.61
IV	43,902-61,665-65,556	51,337	25,668/164.3	5134/32.86	513/3.28
V	61,065-80,865-86,417	68,504	34,252/219.2	6850/43.84	685/4.38
VI	91,791-77,476-74,038	52,072	26,036/166.6	5207/33.32	521/3.33
VII	50,110-89,077-77,815	65,101	32,550/208.3	6510/41.66	651/4.17
VIII	78,450-74,393-72,616	67,638	33,819/216.4	6764/43.29	676/4.33
IX	59,901-56,769-37,144	46,144	23, 079/147.7	4614/29 .52	461/2.95
X	53,911-51,288-35,778	42,293	21,147/135.3	4229/27.06	423/2.71
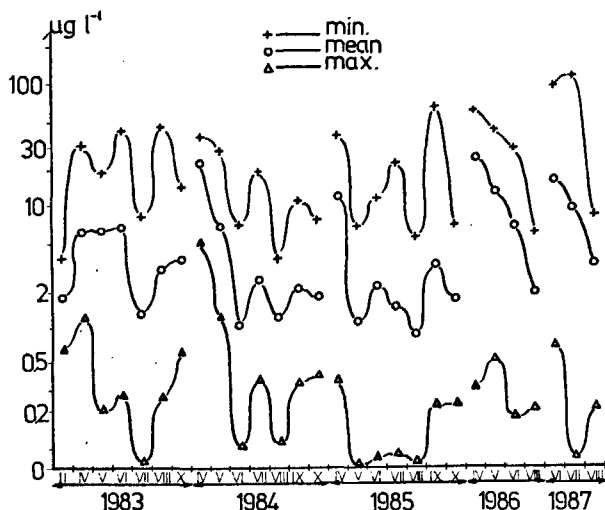
Figure 5

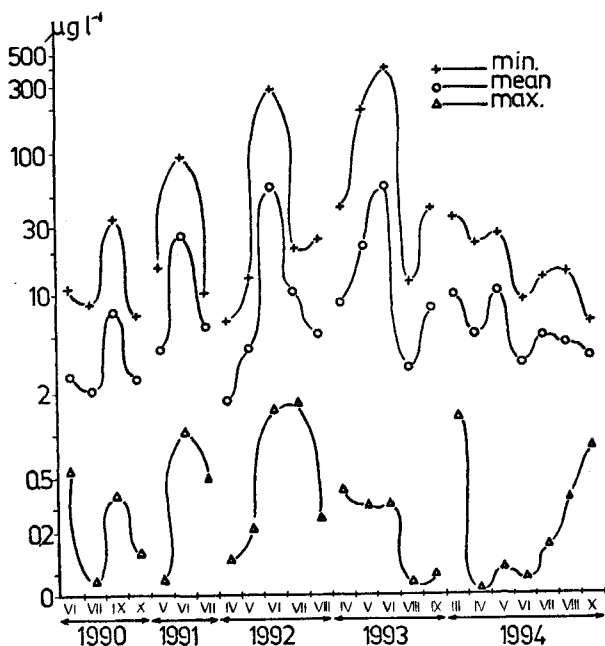*Maximum, mean and minimum values of Chlorophyll a (1983-1987).*

Figure 6

Maximum, mean and minimum values of Chlorophyll a (1990-1994).

/time): 35-45/10, 5/April 1986; 11-23/20, 5/May 1986; 20/20 /July 1987; 2.05/20/June 1990; 14.41/10 /May 1992; 46.78/5/May 1983, etc.

The subsurface chlorophyll maximum is a recognized phenomenon in the world ocean. Various explanations have been suggested for its formation: cells sinking out of the upper euphotic layer after the exponential growth phase; differential grazing by herbivores; active biological growth at depth; an increase in the amount of chlorophyll *a* per cell as an adaptation to low light levels; and the horizontal layering of water masses and plant populations (Revelante and Gilmartin, 1973). To this list can be added the development of spore stages and cyanobacteria.

Phaeophytin distribution

In the upper 20 m, phaeopigments were exceptionally less than 0.1 or larger than 10, and were distributed throughout the water column.

The distribution on class (each 5 unit of μg l^{-1}) size as frequency was: 0-1:40%; 1-5: 44.44%; 5-10: 12.59%; 10-20: 1.48% and more than 20: 1.49%. The minimum value was 0.03 and the maximum was 37.73 and 65.82, both later values found within the half-open, highly polluted area of Constanta Port (Stations B and C).

Chlorophyll 650 and 660

The study of chlorophyll *650* and *660* was performed during 1990-1994 as the level of Cyanobacteria increased. They were both correlated with photosyntethic bacteria.

A range of 0.1 up to 42.84 for *650* fraction and a variation from 0.07 to 24.10 μg l^{-1} for *660* fraction were determined. Maximum values were found during 1994 (42.84 chlorophyll *650* and 24.10 chlorophyll *660*) at the A-B-C stations of Constantsa Port.

CONCLUSIONS

1) During the 1980-1994 period, phytoplanktonic species developed seasonal associations characterized by species groupings: representatives of Winter-Spring (February-May), Summer (June-July-beginning of August) and Autumn (August-October).

2) A change in dominant species was observed, which could be due to the high degree of eutrophication in the Black Sea, permitting new immigrants to compete for niches. Those that have mechanisms to adapt from autotrophy to mixo-or heterotrophy, or are capable of adjusting to the reduced quantities of light will develop more successfully.

3) The community maintained the capacity to produce large biomasses (max. 20,163 to 205,084 or even 422,140 × 10³), but a tendency to develop in "patches" became increasingly evident.

4) The high densities of phytoplankton found testify to an imbalance between the phytoplanktonic and consumer compartments.

5) The frequency and cell density of nannoplanktonic species has greatly increased: from an order of tens or hundreds of thousands they reached the order of millions: *Apedinella, Mantoniella, Hialobryon* and *Coccolithus* etc.

6) Ultraplanktonic organisms represented by *Cyanobacteria* developed during 1990-1994 and had maximum densities of 103.68 × 10⁶ cell l^{-1} in 1992 and 63.57 × 10⁶ cell l^{-1} in 1994.

7) The occurrence of and blooms produced by nannoplankton and ultraplankton are hypothetically attributed both to light shortage in the water column and to high levels of organic compounds.

8) Chlorophyll *a* and phaeophytine maximum values (35-427 and 37.73-65.82 μg l^{-1}, respectively) demonstrate

that photosynthethic activity and senescent phytoplanktonic cells are represented in close proportions in a system with low grazing pressure.

9) Our study must be pursued with further work on phytoplankton pigments and nanno- and ultraplanktonic species ecophysiology.

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Acknowledgements