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ALGAL BLOOMS IN ROMANIAN BLACK SEA WATERS IN THE LAST TWO DECADES OF THE XXth CENTURY

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ABSTRACT

The paper represents a synthesis on algal blooms and quantitative development of the phytoplankton in the Romanian Black Sea area between 1981 and 2000. The extreme increase of the magnitude and frequency of the algal blooms in the 1980's and their decrease in the 1990's are prominent facts. It asserts the maximum intensification of the eutrophication of the western Black Sea in the penultimate decade of the XXth century, followed by a reduction of this process in the last decade.

The data for the mentioned period are subject to a comparison with historical data from the stage previous to eutrophication intensification (1960's) and from the decade when this intensification started (1970's); this ensures a larger base for the evaluation of the planktonic microalgae development in the 1980's and 1990's, as well as provision of fundamental informations concerning long-term trend of phytoplankton evolution in the Romanian Black Sea area during the second half of the XXth century.

KEY WORDS: algal blooms, blooming species, phytoplankton numerical density and biomass, eutrophication, Black Sea Romanian area

The intensification of the anthropogenic pressure in 1970's and 1980's induced a strong increase of the main nutrient stocks in the Romanian area of the Black Sea. Thus, in the second half of the 1970's, at Constantza nearshore, the phosphates content was almost 20 times higher than for the 1960's and nitrates one almost eight times higher (BODEANU, 1993; COCIASU *et al.* 1998).

The sea water became an authentic "complex nutritive medium", the most important consequence of this being the expansion of the frequency, amplitude and spatial extension of algal blooms. The mass mortality of marine animals caused by hypoxia and anoxia, which accompanied and succeeded much of these phenomena (BODEANU, 1984b; BODEANU, ROBAN, 1975, 1989; BODEANU *et al.*, 1998; GOMOIU, 1992; MONCHEVA *et al.*, 1995; ZAITSEV, 1993; ZAITSEV, ALEXANDROV, 1997), induced serious perturbations in the ecosystem, dramatic changes of the environmental conditions, and substantial reduction of the benthic fauna, which endangered the exploitable stocks of fishing resources (PRODANOV *et al.*, 1997; ZAITSEV, 1993).

In the recent period (1990 - 2000), although the blooms have still remained current phenomena, the diminution of their frequency and magnitude (Fig. 1) corresponding to a reduction of the nutrient contents, has been ascertained.

In the following, we make a shortly analysis of our data regarding the blooms and the adjacent processes of the planktonic algae developments during 1980's (with their maximum amplitude), as well as during 1990's (with relatively mitigation of its), as on this base, to identify the signals which the past developments and present state of the phytoplankton have done for subsequent evolution of its and generally of whole ecosystem. Also, for a better assesment of the phytoplankton development in the above mentioned periods, we shall refer to our historical data from the period before eutrophication intensification (1960's) and from the decade when this intensification started (1970's).

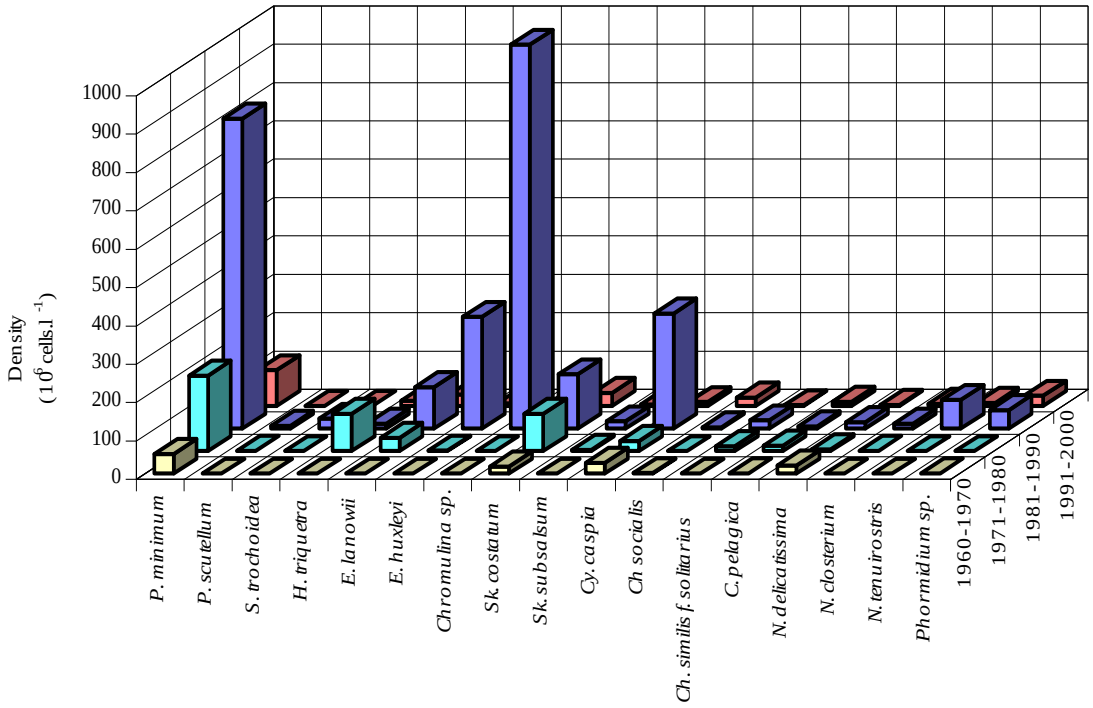

Fig. 1- Abundance of the species involved in the main blooms, by decades between 1960 - 2000

Algal blooms in eighties

In 1980's, when the microalgal growth reached its maximum intensity, a total of 49 monospecific blooms were recorded in the Romanian coastal waters, 15 of them had an exceptional amplitude (with concentrations of species involved within the range of 50 million to 1 billion cells·l^{-1}) (Table 1).

Table 1

Number of monospecific algal blooms registered in the Romanian area during 1981 - 1990 and 1991 - 2000

Period	Number of blooms	
	Total	**with densities > 5 □ 10^7 cells.l^{-1}**
1981-1990	49	15
1991-2000	29	4

15 species (with cells concentration per litter higher than 7 millions) have been involved in the generation of blooms during eighties, 13 of them reaching their maximum density at the Romanian littoral for the entire historical period (more than 40 years) of quantitative research of the phytoplankton in the area (Table 2). The most frequent blooms were produced by *Prorocentrum minimum*, *Skeletonema costatum*, *Eutreptia lanowii* and *Heterocapsa triquetra* (the first two species generating such phenomena almost every year). Many species of rather low abundance during the pristine period, such as *Scrippsiella trochoidea*, *Heterocapsa triquetra*, *Eutreptia lanowii*, *Chaetoceros similis* f. *solitarius*, *Nitzschia tenuirostris*, *Nitzschia closterium*, induced blooms during the late 1970's and especially the 1980's (Table 2).

The bloom amplification has been accompanied by other two processes, which, together with the first one, characterized the phytoplankton development during the eutrophication intensification period: increase in numerical density of the majority of planktonic algae (Fig. 2), and increase of the number of algal mass species (Fig. 3). The consequence of these processes, amplified in the eighties, was a substantial increase of the total phytoplankton abundance and biomass.

Thus, the mean of the numerical densities for the Romanian shelf waters was of 2,235,600 cells·l^{-1} in the 1980's, a value of about 10 times higher than the average (of 225,800 cells·l^{-1}) reported by SKOLKA (1967) for the period 1959-1963. The mean biomass for these waters was 4,105 mg·m^{-3} in the 1980's, that is more than 8 times higher than the mean (only 495 mg·m^{-3}) estimated by SKOLKA (1967) for the same reference period (Table 3). The numerical density and biomass for the waters closed to Constantza shore in the eighties are

almost seven and four times higher respectively than those found in the same area in 1962-1965.

Table 2

Maximum densities (10^3 cells□l^{-1}) of the species causing algal blooms in the Romanian area (by decades)

Species	Period			
	1960-1970	**1971-1980**	**1981-1990**	**1991-2000**
Prorocentrum minimum (Pavill.) Schill.	50814	196920	807600	93720
Prorocentrum scutellum Schrod.	-	447	7200	360
Scripsiella trochoidea (Stein.) Lam.	-	-	25800	290
Heterocapsa triquetra (Ehr.) Lam.	-	97600	12850	13620
Eutreptia lanowii Steuer	-	34950	108000	29700
Emiliania huxleyi (Lohm.) Hay et Mohler	95	1230	291200	6650
Chromulina sp.	-	-	1000000	-
Skeletonema costatum (Grev.) Cl.	18080	97360	141400	34170
Skeletonema subsalsum (A.Cl.) Bethge	-	3300	18710	4440
Cyclotella caspia Grun.	28072	26400	300000	10460
Chaetoceros socialis Lauder	1342	-	3570	22180
Chaetoceros somilis f. *solitarius* Pr.-Lavr.	-	13200	21540	2400
Cerataulina pelagica (Cl.) Hendey	922	14000	5980	10900
Nitzschia delicatissima Cl.	21000	4570	17237	2820
Nitzschia closterium (Ehr.) W.Sm.	110	259	13130	6330
Nitzschia tenuirostris Mer.	-	-	74840	8960
Navicula cryptocephala Kutz.	-	-	-	12860
Microcystis pulverea (Wood.) Forti.	-	19403	-	60000
Microcystis orae (Hang.) Kossinsk.	-	-	-	204750
Phormidium sp.	488	-	47750	27000

The phytoplankton has became superfluous to its consumers, the ratio between its biomass and zooplankton biomass exceeding sometimes 1000:1 (BODEANU, 1984a).

Algal blooms in nineties

The number of blooms and concentrations of algal cells produced during those events decreased between 1991 and 2000, when 29 blooms were registered (a number hardly exceeding a half comparatively with that for 1981-1990), out of which only four had a rather high abundance (ranging from 50 to 205 million cells·l^{-1}) (Table 1). 12 species (with densities exceeding 7 million cells·l^{-1}) have generated blooms, comparatively with 15 species in

previous decade (Table 2). But, six of the respective species (*Prorocentrum minimum*, *Eutreptia lanowii*, *Skeletonema costatum*, *Cyclotella caspia*, *Nitzschia tenuirostris* and *Phormidium* sp.) attained concentrations much lower than those in the eighties. The rest of six blooming species have reached higher values than in 1980's, three of them (*Heterocapsa triquetra*, *Cerataulina pelagica* and *Chaetoceros socialis*) are marine forms, autochtonous for the Pontic basin, the other three (*Navicula cryptocephala*, *Microcystis pulverea* and *Microcystis orae*) being allochtonous fresh-brackish species, introduced into the sea mainly by the Danube waters; the temporary growths of the last three species, only in the superficial layer, were obviously atypical, restricted to small areas and periods, when salinity decreased up to values of about 10.0-12.0.

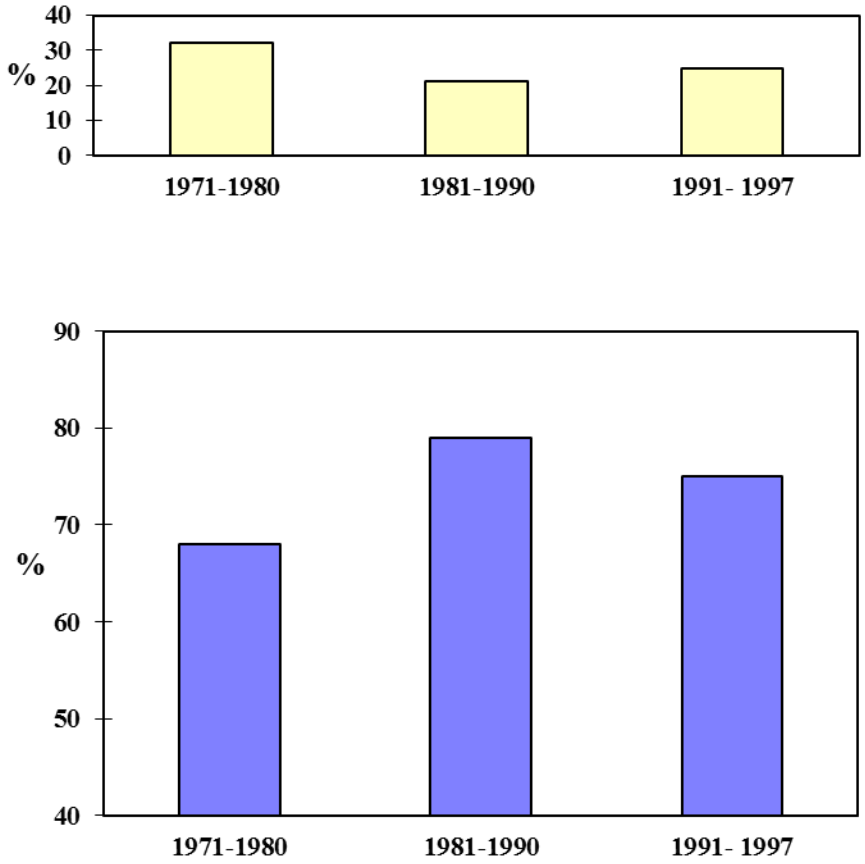

Fig. 2 - Proportion (%) of the mass species exhibiting numerical increases (lower panel) or decreases (upper panel) by decades relative to their maximum densities during 1960 - 1970. (All species exceeding 10^5 cells·l^{-1} at least one time in 1960 - 1997

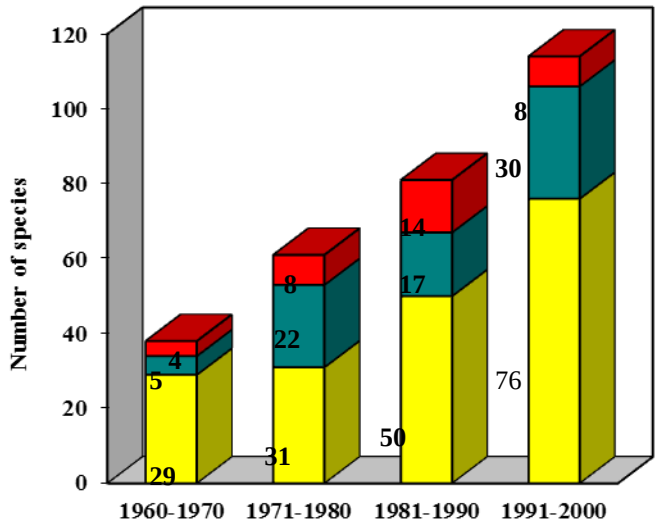

Fig. 3 - Number of phytoplankton species with massive development in the Romanian coastal waters by decades during 1960 - 2000

Table 3

Average phytoplankton quantities in the period before eutrophication (1959 - 1965) and during 1983-1990 and 1991-2000

Parameter	Years	Portitza- Mangalia (offshore)	Constantza (near shore)
cells□l^{-1}	1959-1965	225800	887067
	1983-1990	2235601	5869930
	1991-2000	1002853	2260708
mg□m^{-3}	1959-1965	495.14	2004.13
	1983-1990	4105.24	7143.23
	1991-2000	3797.02	5960.66

Concurrent with the blooms reduction, the share of species with increasing numerical densities was slightly lower than that of the eighties (Fig. 2).

Despite of the maintained trend of increase in the diversity and total number of mass species, the decrease in number of species generating exceptional outbursts (over 10 million cells□l^{-1}) is important (Fig. 3): from 14 species in the 1980's, to only 8 in 1991-2000 (excluding the three fresh-brackish water species mentioned, because of their ephemeral externally-induced pattern of growth, and even occurrence in the coastal waters) (Fig. 3).

Obviously, among the blooming species typical for the 1980's, the non-diatom species seem more affected in terms of numerical densities reduction after 1990. Some of them, involved in ample blooms in the 1980's (such as *Scrippsiella trochoidea*, *Prorocentrum scutellum*, *Emiliania huxleyi*, *Chromulina* sp.), did not produce such events at all in 1990's. Even the non-diatoms which generated blooms after 1990 had densities and frequencies much lower comparatively with the 1980's. In the first place, is the case of the dinoflagellate *P. minimum*, the most commun recurrent producer of annual ample blooms in 1970's and 1980's, and which realized such phenomena of magnitude exceeding $20x10^6$ cells·l^{-1} in three years only (comparatively with the eighties, when this quantitative level was excedeed in 8 years). Other two species - *Eutreptia lanowii* and *Phormidium* sp. - reached densities and frequencies generally lower in comparison to the eighties (Table 2).

The reduction of blooms frequency and magnitude was reflected in a decrease of the total phytoplankton abundance (Table 3). The values of numerical densities have diminished after 1990, approximately 55 - 60% comparatively with those for eighties. However, the biomasses did not suffer such a drastic reduction; for the large continental shelf the diminution was with about 7.5% only, and for the waters near Constantza shores with about 17% comparatively with eighties (Table 3). This could be related to the modification in the size-structure of phytoplankton communities, due to increased of the large-sized diatoms, especially the robust species *Cerataulina pelagica* (Table 2).

The decrease of the non-diatom blooms together with the rather frequent outbreaks of *Cerataulina pelagica* and other diatoms after 1990, resulted in an increase of the diatoms proportion in the numerical density and biomass of the phytoplankton communities (Fig. 4). Consequently, the phytoplankton quantitative taxonomic structure was quite different comparative with 1980's and even 1970's, and it is closer to that of the 1960's, before the onset of eutrophication intensification.

The increase of the diatoms proportion during the 1990's is demonstrated also by the comparison of the monthly structure of phytoplankton numerical density and biomass between the nineties and eighties (Fig. 5,6). Generally, the non-diatoms (including dinoflagellates and other groups in which most species are rather termophile) had their

maximum in summer, and this determined their higher proportion in the phytoplankton. While in the eighties the non-diatoms prevailed during the warm period, in the nineties their share decreased and the diatoms dominated the communities.

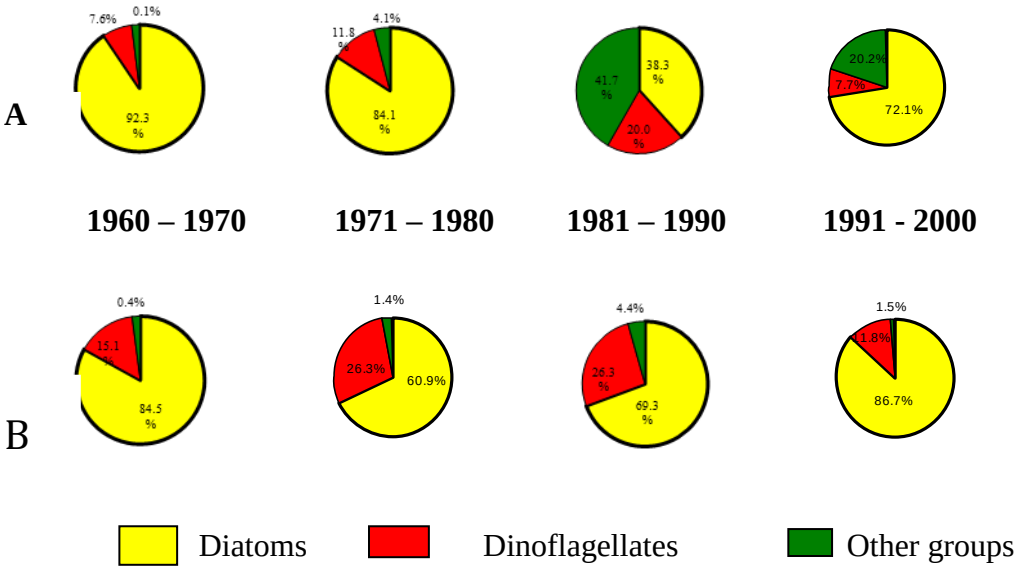

Fig. 4 - Proportion (%) of the main algal groups in phytoplankton densities (A) and biomass (B) by decades during the 1960 - 2000 period in the Portitza - Mangalia zone

As summer blooms caused by the non-diatoms decreased during the recent period, the annual maximum of the algal abundance shifted to spring or autumn. Thus, while in 1986-1990 this maximum was always during summer, in 1991-2000 it was recorded six times in spring, and once in autumn (Table 4). The shift of the annual maximum from summer to spring or autumn marks a sign of restoring the succession of phytoplankton to the natural annual dynamics for the Black Sea before the period of anthropogenic eutrophication, when the annual maximum was generally in spring (BODEANU, 1987-1988; PETROVA-KARADJOVA, 1984; NESTEROVA, 1987).

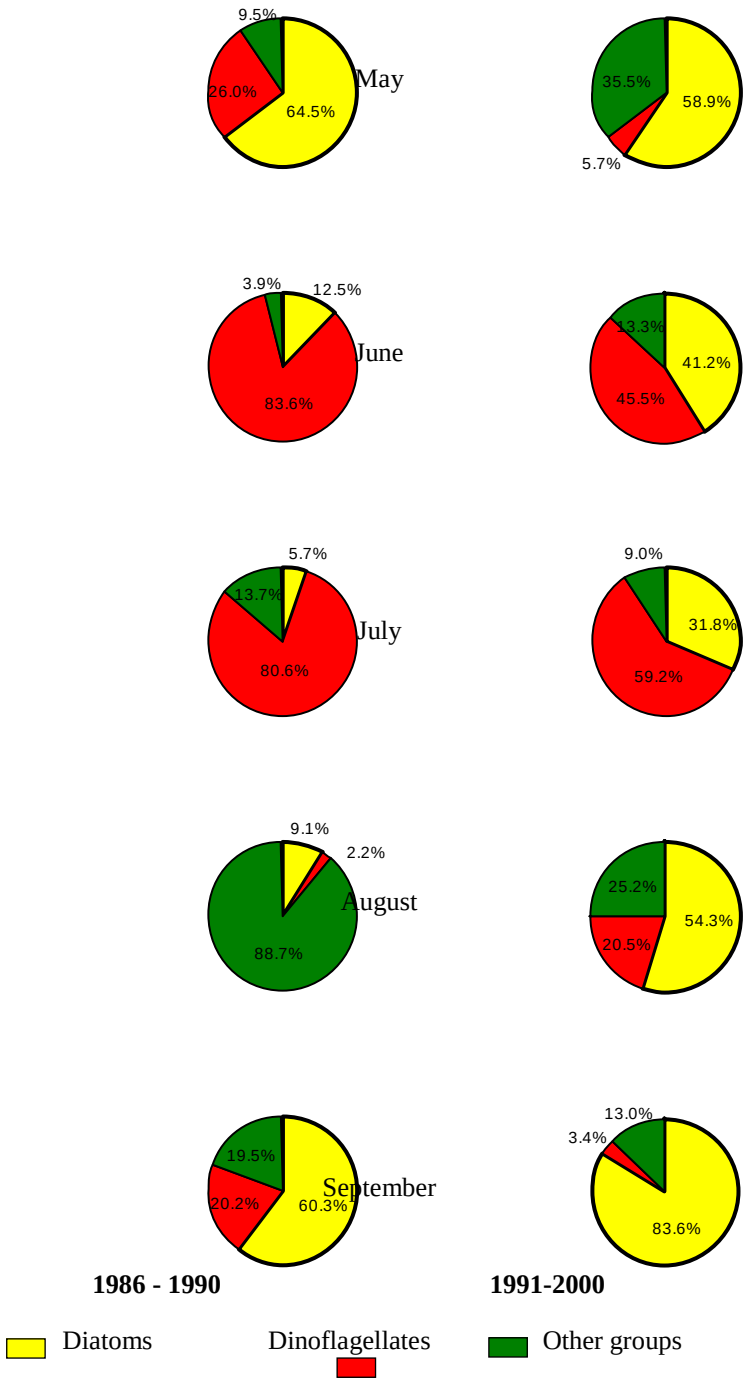

Fig. 5 - Multiannual monthly phytoplankton numerical density structure during the warm season of the years 1986 - 1990 and 1991 - 2000 in Constantza shallow waters

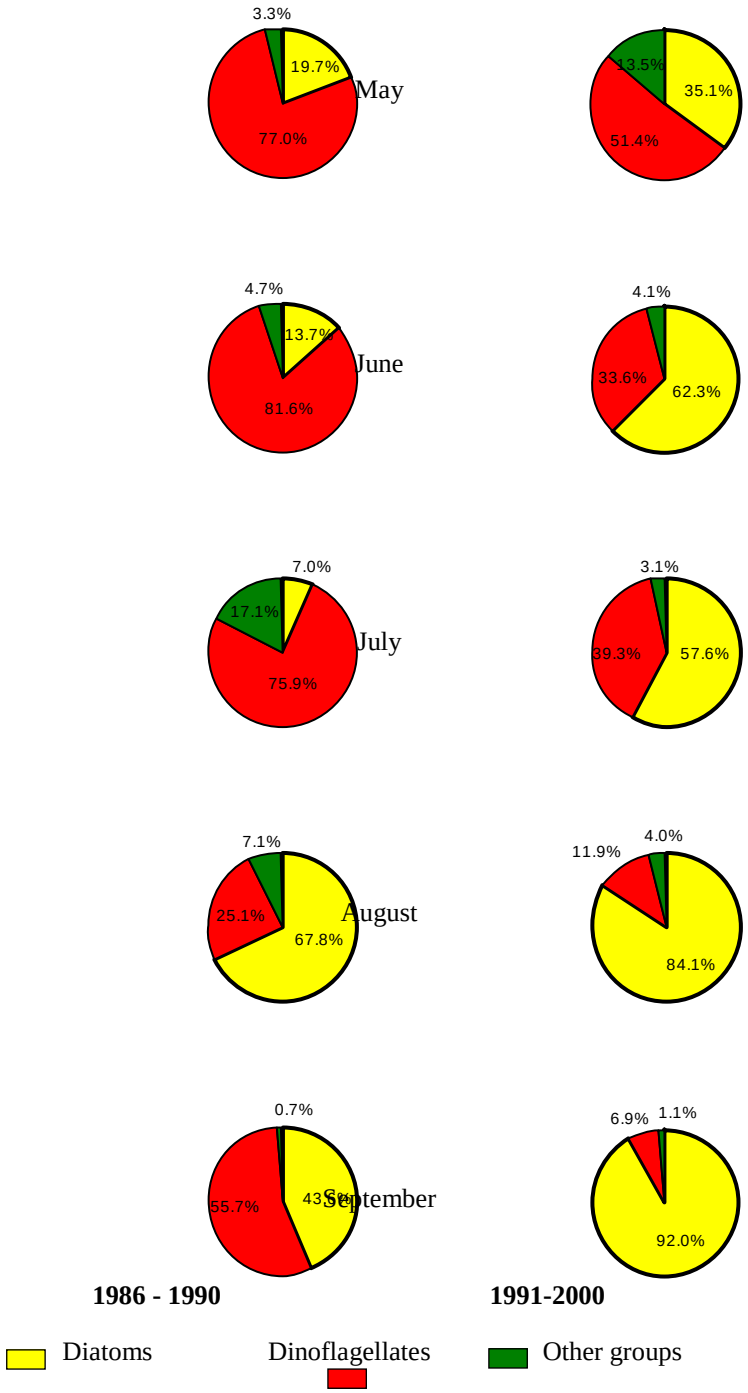

Fig. 6 - Multiannual monthly phytoplankton biomass structure during the warm season of the years 1986 - 1990 and 1991 - 2000 in Constantza shallow waters

Table 4

Months of maximum phytoplankton abundances (during the annual cycle) in Constantza coastal waters

Year	Months	Year	Months
		1991	May
		1992	June
1986	June	1993	May
1987	July	1994	March-July
1988	August	1995	July
1989	June-July	1996	April
1990	August	1997	October
		1998	March
		1999	June
		2000	May

The modification of quantitative structure of phytoplankton coincides well with the large increase of the Si:P molar ratio, from 1.8 in eighties up to 6.8 in nineties (Table 5), which can explain the increase of the diatoms' share (whose necessity of silicium is clear).

Table 5

Concentration of main ions of mineral salts (μM) and their ratios in Constantza water

	1983-1990	1991-2000
N total *	12.74	13.83
$P\text{-}PO_4$	6.54	1.86
$Si\text{-}SiO_4$	11.63	12.64
Si:N	0.91	0.91
Si:P	1.78	6.80
N:P	1.95	7.44

* The sum of the N ions of $N\text{-}NO_3$, $N\text{-}NO_2$ and $N\text{-}NH_4$

The decrease of algal blooms and the total phytoplankton quantities could also be related to the reduction of phosphates, whose content in Constantza waters has been 3.5 times smaller in nineties as compared with eighties (Table 5).

The great reduction of the phosphates implied an important increase of the N:P ratio, from 1.9 in eighties to 7.4 in nineties (Table 5), which could contribute to the structural modifications of the phytoplankton.

The diminution of blooms due to the non-diatoms and the increasing of the diatoms' share - implicitly of the autotrophic microalgae - could be considered as signs of an evolutive tendency towards the normal status of the phytoplankton before the anthropogenic eutrophication of the Romanian coastal waters (BODEANU, 1969; 1987-1988). These signs are in agreement with some indications of the recent improvement of the ecological conditions of the western part of the Black Sea, and especially with the recovering trends of the benthic community which have been seriously affected by the mass mortality following the ample blooms during the eighties and seventies.

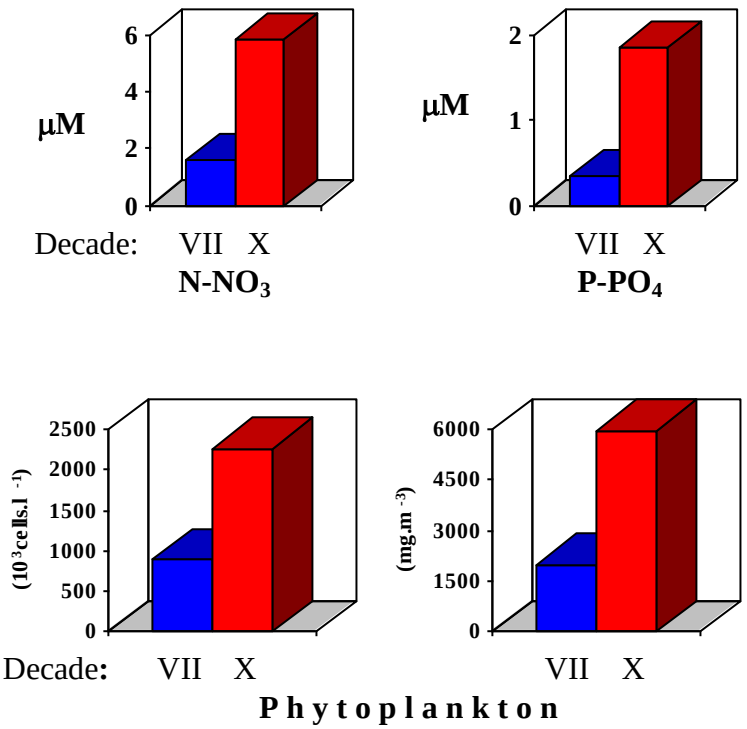

Fig. 7 - Mean content of nitrates, phosphates and phytoplankton in Constantza waters in VII and X decades of XX century

However, this trend is still fragile and should be treated only as a hypothesis, because, despite of the nutrients reduction, their concentrations are still high, and under favourable hydrological and meteorological conditions, they could trigger other ample blooms with their undesirable ecological and economical effects. As a matter of fact, the capacity of the ecosystem to produce and maintain high phytoplankton biomass is still visible. In comparison to the 1960's, in 1991-2000 in the Romanian waters (near Constantza) the concentration of nitrates and phosphates were 3.7 and 5.5 times higher respectively, and consequently the mean numerical density and biomass of phytoplankton were three times higher (Fig. 7).

The control of nutrient discharge into the sea is still a major concern for the continuous diminution of eutrophication and blooms with their negative effects, for the improvement of ecological conditions in the Romanian waters and in the entire north-western part of the Black Sea.

CONCLUSIONS

- During the last two decades, the phytoplankton registered different abundance - very high in eighties, more reduced in nineties - conforming with the extremely ampleness of the blooms produced in the first mentioned decade, and with their relative diminution from the last period. The processes of the development at different degree of the phytoplankton, in each of the two decades, are themselves proofs for intensification (during eighties), and relative reduction (during nineties) of the eutrophication in the western part of the Black Sea.

- Between 1981-1990, in the Romanian sector of the Black Sea 49 monospecific blooms were produced, many of them having an exceptional magnitude (when the species abundance reached 50 million - 1 billion cells$\cdot l^{-1}$). The blooms intensification was associated to a series of processes that characterized the quantitative development of the phytoplankton in the given period: the increase of mass species number, increase of non-diatoms share in the quantitative structure of the planktonic algae community, increase of the abundance and biomass of total phytoplankton which exceeded the usage of its direct consumers.

- After 1990, the blooms number reduced up to 29, those of more than 50 million cells$\cdot l^{-1}$ magnitude getting markedly reduced (at only four). Consequently, the mass species number with very high abundance diminished, and the phytoplanktonic total quantities reduced. The diminution of non-diatoms blooms and the tendency of their replacement with diatom developments have induced changes in the phytoplanktonic quantitative structure; this became altogether different comparatively with that from the eutrophication intensification period, resembling with that from the period before this process.

- Coinciding with some reductions of the nutrients, and with the remarkable increasing of Si:P ratios in coastal waters, the diminishing of blooms and total phytoplankton abundance, together with the increasing of diatoms share and the tendency of shifting of annual maximum algal development from summer to spring and autumn, seem to be signs for evolution toward the normal status of planktonic algal community. These positive signs, concomitantly with some fragile tendencies of improvement of benthic ecological conditions, remain however uncertain, in the circumstances when the nutrients have still higher concentrations than those before the anthropogenic eutrophication period, even if they were reduced.

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