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EUTROPHICATION IMPACT ON THE SPECIES COMPOSITION IN A NATURAL PHYTOPLANKTON COMMUNITY

DJELOVANJE EUTROFIKACIJE NA SASTAV VRSTA U PRIRODNOJ FITOPLANKTONSKOJ ZAJEDNICI

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An attempt has been made to estimate the proportion of dinoflagellate group in the total phytoplankton production of coastal middle Adriatic waters (Kaštela Bay) on the basis of long - term data series on the phytoplankton cell counts and level of primary organic production. The results of this analysis show considerable changes in the coastal sea (Kaštela Bay). These changes are manifested in the relationship between phytoplankton groups within the phytoplankton community which from a community of markedly diatom type has gradually been transformed into a community of dinoflagellates.

An increase of dinoflagellate proportion is accompanied with a respective increase of primary production. These results have also been compared to the results of eutrophication trend in the Kaštela Bay. It has been established that these parameters are closely related.

INTRODUCTION

This communication is an attempt to assess the contribution of dinoflagellates to the total phytoplankton production in the middle Adriatic. Long-term data series on primary production and qualitative-quantitative structure of the phytoplankton community of this area were used. Since this assessment has always been based on exclusively the number of organisms, which is often an unreliable indicator of the contribution of individual phytoplankton groups to the total production, it was attempted to evaluate their contribution indirectly. The relation of dinoflagellates to other phytoplankton groups was presented by the ratio of the dominant diatom group to dinoflagellates, that is D/DF (D - diatoms, DF - dinoflagellates) for the Kaštela Bay. This group was selected on the basis of results showing diatoms as markedly dominant in the middle Adriatic coastal waters (frequently accounting for over 90% of the total phytoplankton numerical abundance).

Since most dinoflagellates (qualitatively and quantitatively) occur during the warmer part of the year, between May and October, we believed that the data from this period would best describe the dinoflagellate biomass in relation to the biomass of the rest of phytoplankton organisms. This being the period of highest productivity in the coastal waters (Pucher-Petković and Homen, 1979) these results could give a fairly objective assessment of the contribution of dinoflagellates to the primary production of the middle Adriatic coastal waters.

RESULTS AND DISCUSSION

Numerical abundance of the total phytoplankton and percentage contribution of dinoflagellates to the phytoplankton community of the Kaštela Bay are given in Fig. 1 and Fig. 3. Monthly means for the water column during May-October over twenty years are given.

Fig. 1 depicts graphically the six-month mean numerical abundance of the total phytoplankton. An increase trend is clearly visible, the minimum mean values of cell numbers being continuously increased from the end of sixties onward.

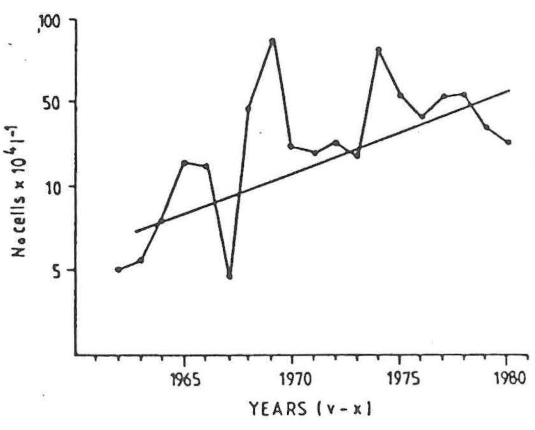

Fig. 1. Six-month mean numerical abundance of the total phytoplankton (N° cells l^{-1})

Primary production shows the same increase trend during that period (Fig. 2) pointing to the actual increase in phytoplankton biomass. Increase in the cell numbers coincides

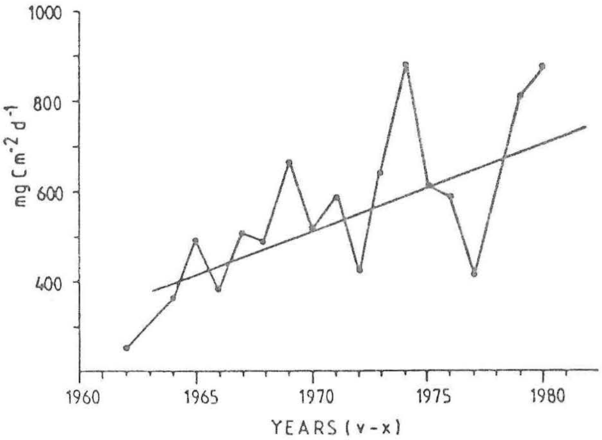

Fig. 2. Monthly mean values of primary production (mg C m^{-2} day^{-1}) in the Kaštela Bay

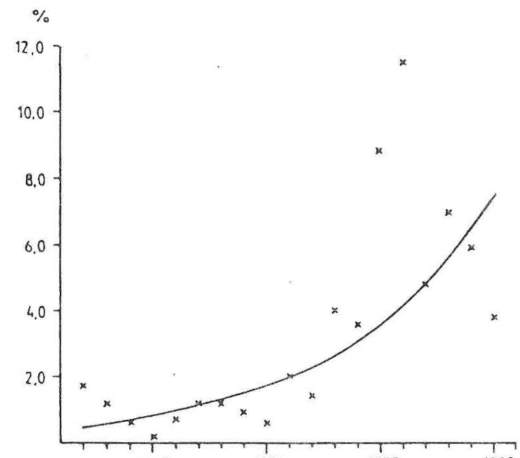

Fig. 3. Percentage of dinoflagellate abundance in total phytoplankton abundance in the Kaštela Bay

with the quantitative increase of dinoflagellates in the phytoplankton community (Fig. 3), that is decline in the contribution of diatoms which, up to mid-seventies, had been markedly dominant phytoplankton group (P u c h e r - P e t k o v i ć , 1966).

It is noteworthy that all the parameters still show intense year-to-year natural fluctuations, which did not disappear under the eutrophication conditions but on the contrary, increased.

Monthly values of primary organic production (mg C m^{-2} d^{-1}) during twenty years are presented in Table 1 and the six-month values of the ratio of diatom to dinoflagellate abundance in the Kaštela Bay in Table 2. High values of this ratio point to the high proportion of diatoms in the total phytoplankton community, whereas lower values of this ratio are indicative of an increase in dinoflagellate contribution. Six-month means of this ratio (D/DF) and six-month means of organic production are graphically presented in Fig. 4. It is obvious that at the beginning of seventies these two curves diverge. Up to that time diatom phytoplankton component had been a determining factor of productivity, whereas thereafter dinoflagellates got in importance. This period is characterized by a significant increase of primary organic production not only during May-October but all year round (P u c h e r - P e t k o v i ć *et al.*, 1988). In addition, along with the decline in diatom dominance, growing significance of both dinoflagellates and other flagellate groups was recorded.

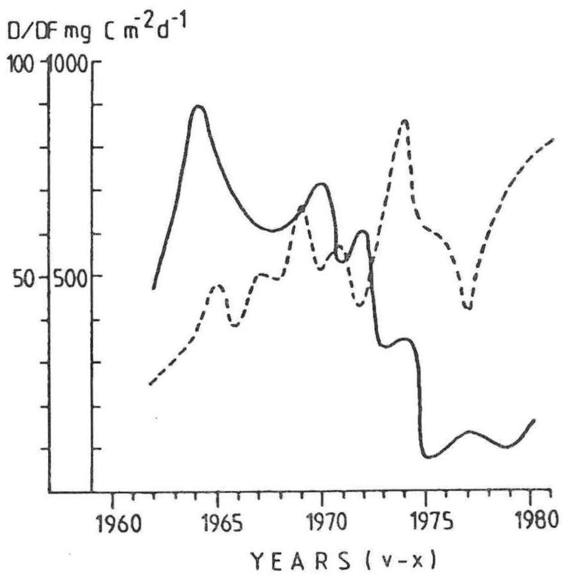

Fig. 4. Relation between diatom and dinoflagellate abundance (D/DF) - solid line and primary production (mg C m^{-2} d^{-1}) - dashed line in the Kaštela Bay

Changes in the ratio of diatom to dinoflagellate abundance under the conditions of increased eutrophication

Aiming at characterization of the phytoplankton community under the conditions of increased eutrophication, it was attempted to establish the differences within the phytoplankton community in a relatively small but highly diverse region.

Table 1. Monthly mean values of primary production (mg C $m^{-2}day^{-1}$)in the kaštela Bay

Year	May	June	July	Aug.	Sept.	Oct.	Mean value
1962	532	106	247	321	150	201	259
1963	452	-	-	-	-	-	-
1964	115	480	404	572	246	-	363
1965	478	589	481	-	-	439	497
1966	178	876	521	386	136	147	374
1967	621	489	881	499	193	398	512
1968	452	599	556	480	333	572	499
1969	252	866	497	1198	668	580	677
1970	468	592	471	484	530	562	518
1971	867	327	669	560	446	678	591
1972	471	555	379	422	307	373	418
1973	613	680	850	699	690	357	648
1974	1390	928	1462	427	683	382	872
1975	1364	663	173	392	-	419	602
1976	721	1068	-	557	462	159	593
1977	101	825	283	68	1012	131	403
1978	-	-	479	52	-	-	-
1979	633	826	303	1323	982	-	813
1980	1613	1050	368	772	563	-	873
1981	1533	734	853	534	974	-	925

Samplings were carried out in the Brač Channel (area C), in the central (area B) and eastern (area A) part of the Kaštela Bay during winter and summer 1984 (Fig. 5).

Our results confirmed the opinion that closed circulation is established in the eastern bay part every summer (Z o r e - A r m a n d a , 1979) due to which a specific phytoplankton community is formed (P u c h e r - P e t k o v i ć and M a r a s o v i ć , 1979).

The analyses of the phytoplankton community in December 1984 showed a homogeneous phytoplankton structure throughout the Kaštela Bay, very similar to that of the Brač Channel (Table 3). This is indicative of the fact that water circulation is intensified in all bay parts in winter and that the water exchange with the Brač Channel

Table 2. Monthly mean values of D/DF ratio (relation between diatom and dinoflagellate abundance) in the Kaštela Bay

Year	May	June	July	Aug.	Sept.	Oct.	Mean value
1962	28.0	77.2	47.9	24.7	6.6	99.0	47.2
1963	95.8	94.2	68.2	66.9	14.5	71.5	68.5
1964	94.6	92.3	94.0	97.1	78.5	99.3	91.3
1965	97.9	53.6	72.0	37.6	98.6	99.5	76.5
1966	99.5	95.1	57.1	28.7	26.1	97.5	67.3
1967	95.6	32.5	91.7	49.0	8.7	96.8	62.4
1968	98.8	89.5	13.6	57.8	53.8	60.6	62.3
1969	48.3	22.2	27.5	99.5	98.2	96.4	65.4
1970	40.8	98.2	93.7	23.9	93.4	87.9	73.0
1971	24.2	18.3	63.8	19.6	89.8	95.6	51.9
1972	64.0	45.2	94.9	93.5	67.7	12.1	62.9
1973	5.4	21.8	5.0	71.0	49.7	41.5	32.4
1974	17.8	14.9	37.8	21.0	68.4	52.8	35.4
1975	7.5	3.7	3.3	11.6	14.4	8.6	8.1
1976	5.8	1.1	1.5	4.4	19.7	34.6	11.1
1977	9.2	4.4	-	3.3	39.3	3.6	15.3
1978	8.0	-	5.3	3.8	36.7	-	12.3
1979	19.8	13.5	8.8	7.5	2.7	-	10.5
1980	12.0	5.8	3.9	6.1	10.3	57.1	15.9
1981	-	-	-	-	-	-	-

is quite satisfactory. On the contrary, during summer a distinct phytoplankton community was formed in the eastern bay part. This community differed from the one in the central bay part and from that in the Brač Channel (Table 3). At the same time it was found that the phytoplankton community in the central Kaštela Bay part differed from that in the Brač Channel, more by different proportion of individual species than by their diversity.

It is of interest to mention that the coccolitophorid species *Calciosolenia murrayi*, predominant in the central bay part (making up about 20 % of total phytoplankton density) at that time, was rather abundant in the Brač Channel however with a far lower percentage (about 5 %) since some species of the genus *Chaetoceros* were predominant there. *Gonyaulax polyedra* constituted over 93 % of the phytoplankton density in the eastern bay part ($1 x 10^7$ cells l^{-1}) with rather high quantity of the coccolitophorid *C. murrayi* which percentage became almost in significant during mass bloom of *G. polyedra*. The species *C. murrayi* occurs in the Kaštela Bay from time to time in large numbers so that it is presumably one of the opportunistic phytoplankton species, the conditions of eutrophicated environment being advantageous for its development.

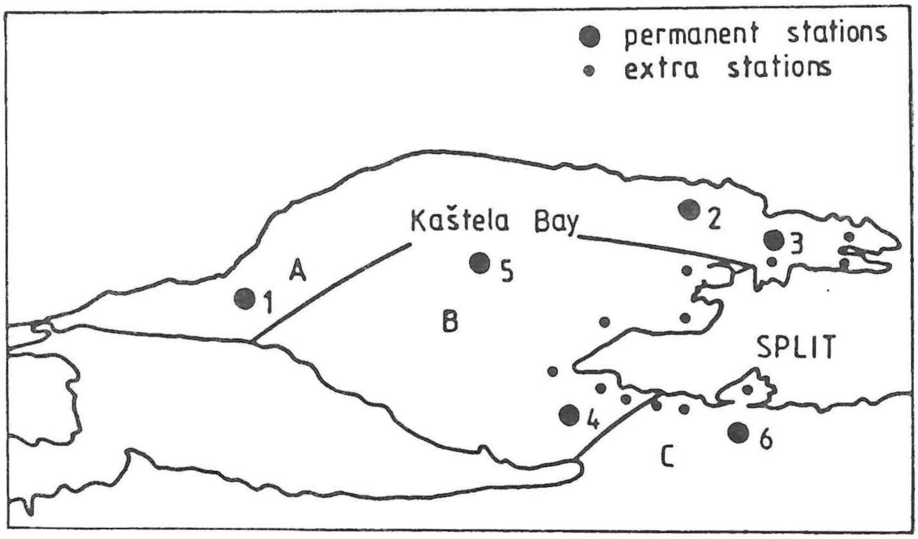

Fig. 5. Location of sampling sites

It was attempted on the basis of the above results and applying similarity index (S ø r e n s e n , 1948) to establish the similarity between these three study areas. This index, based on the number of common species, renders possible the determination of similarity of species between two or more areas. The following equation was used:

$$\%S = \frac{2C}{A + B} \times 100$$

where

A = the number of species in sample A
B = the number of species in sample B
C = the number of common species in both samples

The index was very low for the eastern part of the Kaštela Bay and Brač Channel (A/C = 35.3%) for summer and only slightly higher for the eastern and central part (A/B = 38.9%) (Fig. 5). The highest similarity index was obtained comparing the central bay part and the Brač Channel (B/C = 69.6%). Contrary to summer values the

Sørensen index for winter was quite different in the same area, that is pointed to the high similarity between all three study areas (A/C = 61.5%, A/B = 60.5% and B/C = 66%). These results confirm the difference between winter and summer circulation in this area.

The above observations suggest which and of what extent is the impact of waste waters on the changes in ecosystems, since two completely different communities are formed in the same region at the same time, under the same climatic conditions but under the conditions of reduced sea water dynamics.

Table 4. Numerical abundance of phytoplankton (N° cells l^{-1}) in the eastern part (area A) of the Kaštela Bay during 1975-1976

	August, 1975	December, 1975	March, 1976	June, 1976
Total phytoplankton (N° cells l^{-1})	2.4×10^5	7.4×10^5	2.6×10^5	3.8×10^5
Total number of diatoms (N° cells l^{-1})	1.6×10^5 (67.5%)	7.2×10^5 (97.1%)	2.2×10^5 (84.8%)	6.4×10^4 (16.9%)
Total number of dinoflagell. (N° cells l^{-1})	4.5×10^4 (18.8%)	7.3×10^3 (1.0%)	1.3×10^4 (5.0%)	2.2×10^5 (56.6%)
Total number of *G. polyedra* cells (N° cells l^{-1})	-	-	-	2.0×10^4
% *G. polyedra* in the total phytoplankton	-	-	-	5.2%
‰ *G.polyedra* in the total phytoplankton	-	-	-	9.0%

The data from 1975 and 1976 (Pucher-Petković and Marasović, 1979) show that some changes had already taken place in the area A and that it was no longer suitable for recreational activities. However, the same data also show that the phytoplankton community, even though very rich, was still diverse and predominantly of diatom type, like that in the rest of the Kaštela Bay (Table 4). At that time dinoflagellate populations were in general very poorly represented in the bay, the contribution of *G. polyedra* being almost negligible (see Table 4).

Even though dinoflagellate component formed a significant part of over 50% of the phytoplankton community in June 1976, its contribution was of almost no significance during other months.

It is noteworthy that the phytoplankton community was considerably richer in winter of this period. This is completely contrary to the present situation when surface chlorophyll *a* during summer red tide reaches almost 200 mg m^{-3} (measured on July 22, 1987) and the number of *G.polyedra* cells exceeds the value of $1x10^7$ cells l^{-1} (Table 5).

Table 5. Number of *G. polyedra* cells during red tide in the Kaštela Bay

Period	N° of *G. polyedra* cells
July, 1983	1.0×10^6
June, 1984	1.2×10^6
July, 1984	1.0×10^7
August, 1984	1.1×10^7
July, 1985	red tide existed (no numerical data)
June, 1986	1.3×10^6
September, 1987	2.5×10^7
June, 1988	3.5×10^6
July, 1988	3.8×10^6
August, 1988	4.0×10^6
September, 1988	3.2×10^7
July, 1989	4.3×10^7
July, 1990	1.1×10^7

CONCLUSION

The results of our analysis show significant changes in the phytoplankton community of the Kaštela Bay during the twenty years of investigations. These changes are manifested as the changes in the relationship between phytoplankton groups within the phytoplankton community which from a community of markedly diatom type has gradually been transformed into a community of dinoflagellates. It was established that for the last two decades the abundance of dinoflagellates and their proportion in phytoplankton production have increased, which may be due to the increased organic load of coastal area. These results have also been compared to the results of eutrophication trend in the Kaštela Bay and it has been established that these two parameters are closely related.

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DJELOVANJE EUTROFIKACIJE NA SASTAV VRSTA U PRIRODNOJ FITOPLANKTONSKOJ ZAJEDNICI

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KRATKI SADRŽAJ

U radu se na temelju dugogodišnjih nizova podataka o primarnoj proizvodnji i fitoplanktonskoj abundanciji, pokušalo utvrditi veličinu udjela pojedinih fitoplanktonskih grupa u primarnoj proizvodnji Kaštelanskog zaljeva. Rezultati ove analize pokazali su da se zajedno s porastom eutrofikacijskog nivoa mijenjao odnos medju glavnim fitoplanktonskim grupama, odnosno rastao je udio dinoflagelata u odnosu na dijatomeje (sniženje D/DF omjera). Istodobno je bilježen porast, kako ukupne fitoplanktonske abundancije tako i primarne organske proizvodnje. Dobiveni rezultati ukazuju na to da viši stupanj zagadjenja pogoduje razvoju flagelatne komponente fitoplanktona, odnosno da je promjena strukture fitoplanktonske zajednice usko vezana uz porast eutrofikacijskog stupnja vode u zaljevu.

Table 3. List of phytoplankton species recorded on August 30 and December 24, 1984 and relative abundance (%) of the most important phytoplankton groups (M a r a s o v i ć and P u c h e r - P e t k o v i ć , 1989)

August 1984	December 1984
Area A	
Rhizosolenia alata f. gracillima *Thalassionema nitzschioides* *Prorocentrum micans* *P. minimum* *P. triestinum* *Dinophysis sacculus* *Gyrodinium sp.* *Glenodinium sp.* *Scrippsiella trochoidea* *Gonyaulax polyedra* *Ceratium karstenii* *Oxytoxum longiceps* *Calciosolenia murrayi* *Rhabdosphaera longistylis* *Dictyocha speculum* *Eutreptiella pascheri*	*Thalassiozira rotula* *Thalassiosira sp.* *Skeletonema costatum* *Leptocylindrus adriaticus* *Rhizosolenia fragilissima* *Chatoceros danicus* *Ch. neapolitanus* *Ch. lorenzianus* *Synedra sp.* *Thalassiothrix frauenfeldii* *Th. mediterranea* *Thalassionema nitzchioides* *Pleurosigma angulatum* *Nitzschia delicatissima* *N. longissima* *N. seriata* *Prorocentrum micans* *Gymnodinium sp.* *Gyrodinium fusiforme* *Podolampas spinifer* *Calciosolenia murrayi* *Pontosphaera sp.*
Diatoms 1% Dinoflagellates 94%	Diatoms 95% Dinoflagellates 2
AREA B	
Skeletonema costatum *Leptocylindrus adriaticus* *Rhizosolenia alata f. gracillima* *Rh. fragilissima* *Rh. setigera* *Rh. stolterfothii* *Chaetoceros curvisetus* *Ch. danicus* *Ch. pseudocurvisetus* *Eucampia cornuta* *Thalassionema nitzschioides* *Navicula sp.* *Nitzschia delicatissima* *N. longissima* *N. seriata* *Prorocentrum micans* *P. triestinum* *Gyrodinium pingue* *Glenodinium sp.* *Heterocapsa triquetra* *Scrippsiella trochoidea* *Peridinium diabolus* *P. pyriforme* *Gonyaulax polyedra* *Syrachosphaera pulchra* *Syrachosphaera spp.* *Calciosolenia murrayi* *Eutreptiella pascheri* *Carteria sp.*	*Thalassiosira rotula* *Thalassiosira sp.* *Skeletonema costatum* *Leptocylindrus adriaticus* *Rhizosolenia fragilissima* *Chaetoceros danicus* *Ch. neapolitanus* *Ch. lorenzianus* *Synedra sp.* *Thalassiothrix frauenfeldii* *Th. mediterranea* *Thalassionema nitzschioides* *Pleurosigma angulatum* *Nitzschia delicatissima* *N. longissima* *N. seriata* *Prorocentrum micans* *Gymnodinium sp.* *Gyrodinium fusiforme* *Podolampas spinifer* *Calciosolenia murrayi* *Pontosphaera sp.*
Diatoms 1% Dinoflagellates 94%	Diatoms 95% Dinoflagellates 2%
AREA C	
Skeletonema costatum *Leptocylindus adriaticus* *Rhizosolenia stolterfohtii* *Rh. styliformis var. longispina* *Chaetoceros danicus* *Ch. curvisetus* *Ch. pseudocurvisetus* *Ch. sp.* *Thalassionema nitzschioides* *Amphora sp.* *Nitzschia delicatissima* *N. longissima* *N. seriata* *Prorocentrum micans* *P. minimum* *P. triestinum* *Gymnodinium sp.* *Glenodinium sp.* *Heterocapsa triquetra* *Scrippsiella trochoidea* *Gonyaulax polyedra* *Oxytoxum viride* *Syracosphaera sp.* *Rhabdosphaera sp.* *Calciosolenia murray* *Eutreptiella pascheri*	*Thalassiosira rotula* *Thalassiosira sp.* *Skeletonema costatum* *Leptocylindrus adriaticus* *Rhizosolenia fragilissima* *Chaetoceros sp.* *Eucampia cornuta* *Thalassiothrix frauenfeldii* *Th. mediterranea* *Thalassionema nitzschioides* *Striatella unipunctata* *Licmophora sp.* *Cocconeis scutellum* *Navicula sp.* *Nitzschia delicatissima* *N. seriata* *N. longissima* *Pontosphaera sp.*
Diatoms 81% Dinoflagellates 13%	Diatoms 93% Dinoflagellates 0%