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CHARACTERISTICS OF PHYTOPLANKTON FROM SOME EASTERN ADRIATIC COASTAL LOCALITIES

KARAKTERISTIKE FITOPLANKTONA NEKIH LOKALITETA UZ ISTOČNU OBALU JADRANA

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These phytoplankton investigations are a part of the pollution study along the middle Adriatic coast. Species composition, seasonal fluctuations of total phytoplankton and its major groups, interrelations between phytoplankton groups and dominat species, as well as vertical distribution of phytoplankton were determined.

INTRODUCTION

The principal aim of this paper was to establish the phytoplankton community state under different conditions of the coastal waters of the eastern Adriatic.

An extensive oceanographic survey was conducted from Zadar to Dubrovnik. It included coastal areas in the vicinity of bigger industrial centres and estuaries. The choice of characteristic stations depended on their being representative of a wider area.

1. Zadar area — Z_1 station	— 44°05'6"N;	15°15'0"E
2. Šibenik area — $Š_1$ station	— 43°44'0"N;	15°53'5"E
3. Split area — S_1 station	— 43°30'0"N;	16°26'3"E
4. Kardeljevo area — P_1 station	— 43°01'0"N;	17°05'0"E
5. Dubrovnik area — D_1 station	— 42°40'3"N;	18°04'2"E

MATERIAL AND METHODS

Phytoplankton samples were collected during the cruises of m/v »Bios« in 1979(April, June, July, September) and 1980 (January, April) from standard depths (0, 10, 20 and 30 m). Sampling was carried out by plastic reversing »Mécabolier« bottles.

Species composition, seasonal variations in phytoplankton, relative abundance of individual groups as well as environmental factors influencing phytoplankton were studied.

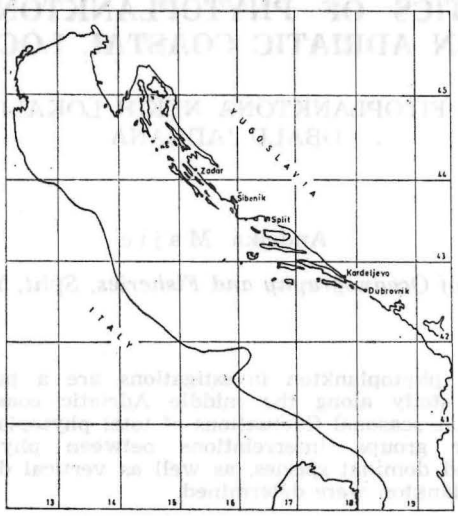

Fig. 1. Study area

Samples for phytoplankton quantitative and qualitative analyses were preserved in 2.5% formol previously neutralized by sodium borate. Material was left to sediment for 24 hours in chambers of 25 ccm and afterwards counted in an inverted Utermöhl microscope.

Phytoplankton organisms were separated in systematic groups: Diatoms (Centricae and Pennatae), Dinoflagellates, Silicoflagellates, Coccolithophorids and »Microflagellates«. »Microflagellates« included all minute, unarmoured flagellates belonging to different taxonomic groups which could not be determined by the routine analyses and according to available literature. Identification at species level followed Schiller (1913, 1925, 1930) and Kamptner (1936, 1939, 1941) for coccolitophorids; Gemeinhardt (1930) for silicoflagellates; Van Heurck (1899), Pavillard (1925), Hustedt (1927—1937), Cupp (1943), Proškina-Lavrenko (1955, 1963) and Hendey (1964) for diatoms; Jörgensen (1920, 1923) and Schiller (1928, 1933, 1937) for dinoflagellates; and Schiller (1925a) and Butcher (1959, 1961, 1967) for »microflagellates«.

The similarity index of two phytoplankton samples from different stations was evaluated from the method developed by Sørensen (1948). The following expression was used

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

where

A — the number of species in A sample
B — the number of species in B sample
C — the number of species in both samples

An important feature in the study of the structure, dynamics and development of life communities is the variety of species which may be expressed by species diversity index. Global diversity index after Margalef (1951) was used to obtain the dynamics status of phytoplankton species:

$$d = \frac{S - 1}{1\, nN}$$

where

S — the total number of species
N — the total number of organisms

Monthly diversity index was calculated for each individual station as well as the global diversity index.

RESULTS

Zadar area — Z_1 station

a) Hydrography

Station Z_1 (44°05'6"N; 15°15'0"E) of 32 metres depth, representative of this area is characterized by relatively small fluctuations of basic physical and chemical parameters.

During the time of investigations surface temperature ranged from 10.17 to 22.97°C, and bottom layer one from 9.58 to 14.4°C.

Salinity was very stable even at the surface where it varied from 37.23 to 38.26‰. It ranged from 37.72 to 38.68‰ at 30 m depth.

pH varied within the 8.21—8.22 range.

Nitrates ranged from 0.41 to 0.93 μg at 1^{-1} at the surface, and from 0.56 to 0.88 μg at 1^{-1} at 30 m depth.

Phosphates were present in the concentrations of 0.060—0.111 μg at 1^{-1} at the surface and of 4.82—6.61 μg at 1^{-1} at 30 m depth.

Average sea water transparency was 15.3 m.

b) Phytoplankton species composition

Between April 1979 and April 1980 a total of 123 phytoplankton species were determined at this station. This number includes 63 diatom species (39 centrice and 24 pennates), 30 dinoflagellates, 17 coccolitophorids, 2 silicoflagellate species and langer number of »microflagellates«.

The highest number of phytoplankton species was recorded in spring 1980 and the lowest number in summer 1979. Numbers of diatoms varied from 21 in July to 50 in April. Dinoflagellates showed maximum numbers in summer and minimum ones in winter. Maximum of coccolitophorids was recorded in spring and minimum in winter. Only two species of silicoflagellates were found in the September sample. Neritic forms of diatoms were predominant while the number of oceanic species was low and occurred mainly in spring when they significantly affect the density of this phytoplankton group. There was no record of any oceanic species from this station.

The following species occurred in every sample every month: *Thalassiosira sp., Leptocylindrus danicus, Guinardia flaccida, Skeletonema costatum, Nitzschia closterium, N. delicatissima** and *N. seriata.***

The following species occurred only during the warmer part of the year: *Rhizosolenia calcar-avis, Rh. alata, Rh. alata, f. gracillima, Thalassiothrix frauenfeldi* and *Hemiaulus haucki.*

The species *Amphora cymbifera, A. proteus* and *N. panduriformis* were found only in winter samples.

Dinoflagellate species *Prorocentrum micans, Gymnodinium symplex, Amphidinium sp., Gyrodinium sp.* and *Glenodinium sp.* were constantly present.

The species *Gymnodinium caput, Gymnodinium cori* and *Gyrodinium pingue* were present during the warmer part of the year.

Of coccolitophorid species *Calyptrosphaera spaheroidea, Coccolithus huxley* and *Syracospharea sp.* were found in all months.

»Microflagellate« genera *Carteria* and *Chlamydomonas* persisted in all months.

c) Seasonal fluctuations of the total phytoplankton and density of phytoplankton groups

Phytoplankton density, determined in 0, 10, 20 and 30 m layers at the Zadar station, varied from 53×10^3 cells per liter in January 1980 to 1556×10^3 cells per liter in April of the same year. These are in fact relatively high density variations. Minimum to maximum ratio was 1 : 29,5. Seasonal fluctuations of phytoplankton density for Z_1 station are given in Table 1.

Table 1. Numerical abundance of the total phytoplankton at Z_1 station (expressed as number of cells per liter of sea water)

	1979				1980	
Depth (m)	April	June	July	September	January	April
0	402360	189840	312480	800520	42800	1782480
10	404040	189840	110040	147000	67200	929040
20	437640	169000	63000	—	—	1044960
30	266280	441000	147840	165480	47880	2467080
Mean	377580	241170	158340	371000	52640	1555890

The observations of seasonal occurrences of individual phytoplankton groups showed that all minima were recorded in winter.

Maxima, however, were recorded in different months (see Table 2).

Table 2. Numerical abundance of individual phytoplankton groups in the water column (0—30 m) at Z_1 station (expressed as the number of cells per liter)

Year	Month	Diat.	Dinofl.	Cocc.	Sil.	»Microfl.«
1979	April	480480	143640	830760	—	55440
	June	556920	155400	187320	—	89040
	July	159600	129360	242760	—	101640
	September	857640	52920	180600	1680	20160
1980	January	81480	25200	42840	—	8400
	April	5648160	142800	227640	—	204960
Mean		1297380	108220	285320	336	79940

Diatoms are responsible for the total phytoplankton density variations.

* and ** Species determined in the Mediterranean as *N. delicatissima* and *N. seriata* were determined by Dr G. R. Hasle by electric microscopy as *N. pseudodelicatissima* and *N. fraudulenta.*

d) Interrelations between phytoplankton groups and dominant species

The contribution of individual phytoplankton groups to the total phytoplankton varied with seasons. Diatoms constituted on the average 73.25% of the total phytoplankton. Relative abundance of other groups was considerably lower. Coccolitophorids made up 16.1%, dinoflagellates 6.1%, silicoflagellates 0.02% and »microflagellates« 4.5%.

Phytoplankton of this area shows high species diversity however the number of dominant species was low in some months.

Dominant diatom genera at Z_1 station were *Bacteriastrum, Chaetoceros, Thalassiosira, Nitzschia, Rhizosolenia* and *Skeletonema.* The species *B. delicatulum* was most abundant. It occurred in associations with *Ch. affinis* var. *willei, Ch. affinis* and *Ch. compresus.* Of genus *Rhizosolenia* which is predominant in summer species *Rh. alata f. gracillima* was dominant at the surface and *Rh. alata* at 30 m depth. *N. delicatissima* was most important of pennates. *Calyptrosphaera, Pontosphaera* and *Rhabdosphaera* genera were responsible for the numerical abundance of coccolitophorids with the dominant species *Calyptrosphaera sphaeroidea.* In spring when »microflagellates« were relatively best represented, *Chlamydomonas piriformis* and *Hilleax fusiformis* species were predominant.

Diatoms dominated the phytoplankton of this area except in April and July 1979. The highest relative diatom abundance was recorded in spring 1980, constituting 90.75% of the total counts. They were followed by coccolitophorids which accounted for 55% of the total counts in April 1979. They were also well represented in July (38.32%). Dinoflagellates contributed more significantly to phytoplankton only in July (20.42%), and »microflagellates« reached maximum relative abundance of 16.04% the same month. It was observed that the numbers of diatoms were inversely related to the number of coccolitophorids, that is the decline in diatom numbers coincided with the coccolitophorid numbers increase. This may be easily understood in light of the dominance of these two groups. This relationship is given in Fig. 2.

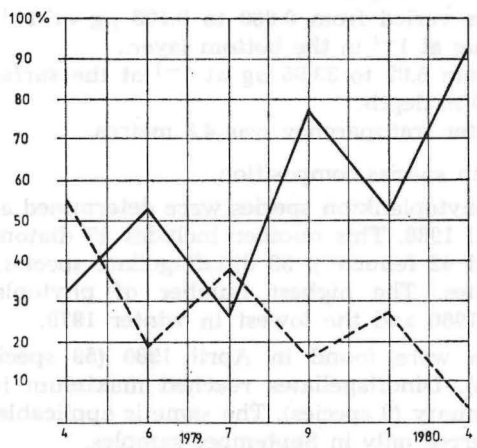

Fig. 2. Seasonal fluctuations of relative diatom abundance (unbroken line) and coccolitophorids (dashed line) for the 0—30 m at Z_1 station

e) Vertical density distribution of the total phytoplankton

The vertical distribution of phytoplankton density for the period of our study is shown in Fig. 3 and Table 1.

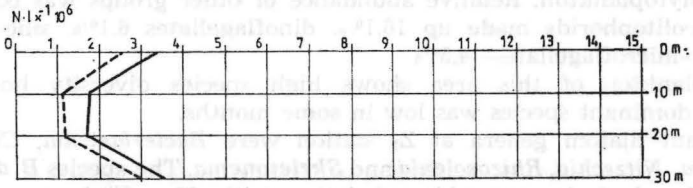

Fig. 3. Mean density distribution of the total phytoplankton (unbroken line) and diatoms (dashed line) at Z_1 station for the time of investigations

Mean phytoplankton density values show that vertical distribution has surface and bottom maxima. Dominance of diatoms is evident in the case of vertical distribution as well (Fig. 5).

Šibenik area — $Š_1$ station

a) Hydrography

Station $Š_1$ (43°44'0"N; 15°53'5"E) of 32 metres depth is strongly affected by the adjacent land and freshwater inflows. This is shown by physical and chemical parameters, particularly by their marked seasonal fluctuations, strong vertical temperature and salinity gradients and low transparency.

Temperature ranged from 9.7 to 25.31°C at the surface and from 13.04 to 17.12°C at 30 m depth.

Salinity varied from 4.67 to 31.86‰ at the surface and from 38.05 to 38.65‰ at 30 m depth.

pH ranged from 8.17 to 8.28.

Nitrates varied from 0.51 to 9.69 μg at 1^{-1} at the surface and from 0.75 to 2.27 μg at 1^{-1} at 30 m depth.

Phosphate levels varied from 0.060 to 0.128 μg at 1^{-1} at the surface and from 0.060 to 0.081 μg at 1^{-1} in the bottom layer..

Silica ranged from 6.07 to 33.95 μg at 1^{-1} at the surface and from 5.07 to 11.14 μg at 1^{-1} at 30 m depth.

Average sea water transparency was 4.8 metres.

b) Phytoplankton species composition

A total of 134 phytoplankton species were determined at station $Š_1$ between June 1979 and April 1980. This number includes 82 diatom species (40 species of centric forms and 42 fenuctes), 33 dinoflagellate species, 17 coccolitophorids and 2 silicoflagellates. The highest number of phytoplankton species was recorded in spring 1980 and the lowest in winter 1979.

Diatom maxima were found in April 1980 (59 species) and minima in January (21 species). Dinoflagellates reached maximum in June (20 species) and minimum in January (9 species). The same is applicable to coccolitophorids. Silicoflagellates occurred only in September samples.

Diatoms are quantitatively principal phytoplankton group. Neritic forms are predominant, and the presence of benthic forms is also significant as well as that of brackish and fresh water species.

The following diatom species occurred in every month of sampling: *Leptocylindrus danicus, Skeletonema costatum, Thalassiosira sp., Chaetoceros affinis* and *Rhizosolenia alata f. gracillima* of centric forms and *Thalassiothrix frauenfeldi, Nitzschia seriata, N. delicatissima* and genera *Synedra, Cocconeis* and *Navicula* of pennates.

Diatom species *Dactyliosolen mediterraneus, Hemiaulus haucki, Cerataulina bergoni, Chaetoceros compressus, Rhizosolenia alata, Rh. calcar-avis, Synedra pulchella, Thalassionema nitzschioides, Licmophora sp.,* and *Pleurosigma elongatum* occurred only in samples collected during the warmer part of the year.

The species *Coscinodiscus lineatus, Chaetoceros lorenzianus, Striatella unipunctata* and *Navicula distans* were recorded only in winter.

The following dinoflagellate species were recorded in every month of sampling: *Exuviaella sp., Amphidinium acutissimum* and *Gyrodinium fusiforme.*

The species *Amphidinium crassum, Gymnodinium agiliforme, G. obtusum, Glenodinium sp.* and *Oxytoxum laticeps* occurred only during the warmer part of the year. The following coccolitophorids were recorded every month: *Coccolithus huxley* and genera *Syracosphaera* and *Rabdosphaera.*

The »microflagellates« *Chlamydomonas* and *Carteria* occurred throughout the period of investigations and *Euglena* and *Chloromonas* only during the warmer period.

c) Seasonal fluctuations of the total phytoplankton and density of phytoplankton groups

Mean phytoplankton density, determined for the 0, 10, 20 and 30 m layers, varied from 311×10^3 cells per liter to 238×10^3 cells per liter.

Seasonal phytoplankton density fluctuations were modest at this station thus that minimum to maximum ratio was 1 : 7.66. Mean phytoplankton density was 1270×10^3 cells per liter. Seasonal phytoplankton density fluctuations at $\check{S}_1$ station are given in Table 3.

Table 3. Numerical abundance of the total phytoplankton at $\check{S}_1$ station (expressed as the number of cells per liter of sea water)

	1979			1980	
Depth (m)	June	July	September	January	April
0	568680	662760	3118080	5355000	7063560
10	296520	175560	374640	198240	1368360
20	769440	93240	—	—	581280
30	559440	—	205800	73920	517440
Mean	548520	310520	1232840	1875720	2382660

The results obtained show that seasonal fluctuations of phytoplankton density are best marked at the surface (1 : 12.4).

Seasonal fluctuations of density of phytoplankton groups in water column are given in Table 4.

Table 4. Numerical abundance of individual phytoplankton groups in water column (0—30 m) at $\check{S}_1$ station (expressed as the number of cells per liter of sea water)

Year	Month	Diat.	Dinofl.	Cocc.	Sil	»Microfl.«
1979	June	1459920	155400	188160	—	390600
	July	443520	99120	194880	840	193200
	September	3308760	199920	152040	3360	34440
1980	January	1704360	42840	3819480	—	60480
	April	9061920	112560	158760	—	197400
Mean		3195696	121968	902664	840	175224

Judging from the seasonal occurrences of phytoplankton groups it is apparent that diatoms reach maximum quantities in spring and »microflagellates« is spring-summer. These both group minima were recorded in summer. Dinoflagellates reach maximum in summer and minimum in winter, and coccolitophorids minimum in summer and maximum in winter. Diatoms are the principal phytoplankton group as to the quantity. Seasonal phytoplankton density fluctuations are dependent on diatom quantities.

d) Interrelations between phytoplankton groups and dominant speices

Diatoms dominated the total phytoplankton contributing an average of 72.68%. Relative proportion of other phytoplankton groups was much lower; coccolitophorids constituted 20.53%, »microflagellates« 3.89% dinoflagellates 2.77% and silicoflagellates 0.02%.

It was observed that *Leptocylindrus adriaticus, Chaetoceros compressus* and species of genus *Nitzschia* were predominant in deeper layers of the water column, particularly at 20 m depth. They were either fully absent or occurred in low numbers at the surface. However, *Skeletonema costatum, Chaetoceros simplex, Guinardia flaccida, Thalassiosira,* sp. and *Dactyliosolen mediterraneus* species were quantitatively most significant at the surface and they were responsible for the numerical abundance of phytoplankton at this station. Diatom *Skeletonema costatum* was the most dominant species the quantity of which was 6384×10^3 cells per liter, and relative abundance 70.4% in April 1980. This is the greatest »bloom« recorded during »Vir-Konavle« investigations.

The species *Prorocentrum aporum* was most abundant of dinoflagellates, *Coccolithus huxley* of coccolithophorids. This species was predominant throughout the water column in January with the average density of 3683×10^3 cells per liter.

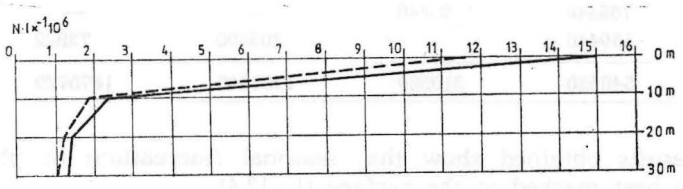

Fig. 4. Mean vertical distribution of the total phytoplankton density (unbroken line) and diatoms (dashed line) at $\check{S}_1$ station between June 1979 and April 1980

e) Vertical distribution of the total phytoplankton density

It may be concluded that at this station phytoplankton is mainly concentrated at the surface. The only exception was recorded in June 1979 when vertical distribution did not show any regular pattern.

Vertical distribution of the total phytoplankton and diatom densities at $\check{S}_1$ station for the period of investigations is given in Fig. 4.

Split area — S_1 station

a) Hydrography

S_1 station representative of the Split area (43°30'0"N; 16°26'3"E), of 36 m depth, is characterized by the following physical and chemical parameters:

Surface temperature varied from 12.2 to 24.48°C and bottom temperature from 12.28 to 17.01°C.

Surface salinity ranged from 32.57 to 37.25‰ and in the bottom layer from 37.83 to 38.65‰.

pH range was 8.19—8.26.

Nitrates varied at the surface between 0.45 and 0.68 μg at 1^{-1} of the sea water and in the bottom layer between 0.45 and 0.68 μg at 1^{-1}.

Phosphates varied within the 0.006—0.111 μg at 1^{-1} range at the surface and within 0.40—0.111 μg at 1^{-1} in the bottom layer.

Silica varied from 2.71 to 6.07 μg at 1^{-1} at the surface and from 4.82 to 12.86 μg at 1^{-1} at 30 m depth.

Average sea water transparency was 11.5 m.

b) Phytoplankton species composition

A total of 115 species were determined at S_1 station of which 66 diatoms (37 centric forms and 29 pennates), 33 dinoflagellates, 14 coccolitophorids and 1 silicoflagellate, as well as a larger number of unidentified »microflagellate« species. The highest number of phytoplankton species was recorded in spring 1980 and the lowest in winter.

Diatoms varied from 23 species in January 1980 to 42 species in April 1980. Centric forms were predominant, except in January 1980 when 10 centric species and 13 pennates were recorded. Dinoflagellates reached maximum in spring 1980 (33 species) and minimum in winter (12 species). Coccolitophorids maximum was recorded in spring and minimum in summer. Of silicoflagellates *Dictyocha fibula* was recorded only in April 1979 and January 1980. Neritic diatoms dominated the phytoplankton species composition while oceanic forms were restricted to the spring period.

The following diatom species were recorded every month: *Leptocylindrus danicus, Thalassiosira* sp., *Hemiaulus haucki, Cerataulina bergoni, Chaetoceros affinis, Thalassiothrix frauenfeldi, Navicula* sp., *Nitzschia closterium, N. seriata* and *N. delicatissima.*

During the warmer part of the year the following diatoms occurred: *Coscinodiseus* sp., *Chaetoceros compressus, Bacteriastrum delicatulum, Rhizosolenia alata, Rh. alata, f. gracillima, Rh. stolterfothi, Rh. delicatula, Guinardia flaccida* and *Thalassionema nitzschioides.*

There is no record of species from this station restricted exclusively to winter.

The following dinoflagellates occurred every season: *Prorocentrum micans, Amphidinium lissae* and *Gymnodinium sp.*

Gymnodinium grammaticum was recorded only in summer and *Goniaulax sp.* only in winter.

Coccolitophorids *Calyptrosphaera sphaeroidea* and *Rabdosphaera sp.* were found throughout the period of investigations and *Syracosphaera cornus* and *Calyptrosphaera pirus* only during the warmer part of the year.

Microflagellate genera *Chlamydomonas, Hillea* and *Carteria* were recorded in all months of investigations.

Euglena dand *Eutreptiella* genera were found in the samples from the warmer part of the year. They were not recorded in winter.

c) Seasonal fluctuations of the total phytoplankton and density of phytoplankton groups

Mean phytoplankton density was determined from the 0, 10, 20 and 35 m layers at S_1 station. It ranged from 161×10^3 cells per liter to 786×10^3 cells 1^{-1}. Monthly means show that phytoplankton of this area has no marked seasonal pattern of fluctuations. Thus minimum values to maximum values ratio of this parameter is 1 : 4.88 (Table 5). Annual phytoplankton density mean is 435×10^3 cells 1^{-1}.

The deepest layer showed the highest seasonal fluctuations (1 : 16.2).

Table 5. Numerical abundance of the total phytoplankton at S_1 station (expressed as the number of cells per liter of sea water)

	1979			1980		
Depth (m)	April	June	July	September	January	April
0	400680	571200	1310400	613200	231840	379680
10	393960	340200	372960	447720	132720	298200
20	737840	547680	66360	—	—	345240
35	1611960	419160	99960	116780	117600	326760
Mean	785610	469560	462420	392600	160720	337470

Table 6. Numerical abundance of individual phytoplankton groups in the water column (0—35 m) at S_1 station (expressed as the number of cells per liter of sea water)

Year	Month	Diat.	Dinofl.	Cocc.	Sil.	»Microfl.«
1979	April	2682120	64680	378000	1680	15960
	June	1320480	202440	57120	—	298200
	July	1534680	96600	162960	—	55400
	September	834980	59640	267120	—	15960
1980	January	226800	50400	79800	840	124320
	April	1128960	50400	71400	—	99120
Mean		1288003	87360	169400	420	101493

Diatom and dinoflagellate quantities reached maximum in spring and minimum in winter. Coccolitophorids maximum as well as minimum occurred in spring (April and June respectively). Maximum of dinoflagellates was recorded in June and minimum in January and April 1980.

Diatoms were the most important phytoplankton group affecting the dynamics of the total phytoplankton. Coccolitophorids, »microflagellate« and dinoflagellate quantities followed the dinoflagellates.

d) Interrelations between phytoplankton groups and dominant species

Diatoms dominated the phytoplankton and formed between 47.03 and 85.35% with an average of 78.21%, followed by coccolitophorids with 10.28%, »microflagellates« with 6.16%, dinoflagellates with 5.3% and silicoflagellates with 0.025% of the total phytoplankton.

Nitzschia seriata was the dominant phytoplankton species for the thorough period of investigations. This species density increased with depth in spring thus that minimum to maximum density ratio was 1 : 23.46 in April. Its »bloom« exceeded the blooms of other species. It came in association with *N. delicatissima* and species of genus *Chaetoceros (Ch. affinis, Ch. compressus* and Ch. sp.).

In September both the absolute density and relative proportions of *Skeletonema costatum* in association with *Leptocylindrus minimus* were highest in the entire water column.

Coccolithus huxley and genera *Rabdosphaera* and *Syracosphaera* were responsible for the numerical abundance of coccolitophorids.

e) Vertical distribution of the total phytoplankton density.

The main characteristic of the vertical phytoplankton density distribution at Split station is that the majority of phytoplankton is concentrated in the surface and bottom layers while density is lower in the intermediate layers (Fig. 5).

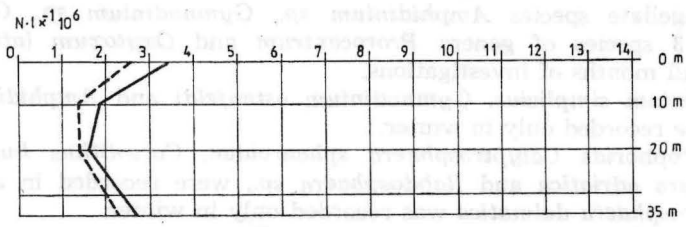

Fig. 5. Mean vertical distribution of the total phytoplankton (unbroken line) and diatoms (dashed line) at S_1 station from April 1979 to April 1980

Kardeljevo area — P_1 station

a) Hydrography

P_1 station (43°01'0"N; 17°05'0"E) of 20 m depth is characterized by the following physical and chemical parameters:

Temperature ranged from 12.80 to 22.84°C at the surface and from 12.98 to 21.35°C at 20 m depth.

Salinity varied from 25.07 to 35.97‰ at the surface and from 37.70 to 38.61‰ at 20 m depth.

pH range was 8.08—8.26.

Nitrates varied from 0.57 to 0.89 μg at l^{-1} at the surface and from 0.38 to 0.58 μg at l^{-1} at 20 m depth.

Phosphate levels ranged from 0.047 to 0.100 μg at l^{-1} at the surface and from 0.060 to 0.100 μg at l^{-1} at 20 m depth.

Silica concentrations varied between 5.54 and 12.86 μg at l^{-1} at the surface and between 5.54 and 9.10 μg at l^{-1} at 20 m depth.

Average sea water transparency was 10.3.

b) Phytoplankton species composition

A total of 126 phytoplankton species were determined at P_1 station during our investigations, of which 83 diatoms (35 centric forms and 48 pennates), 29 dinoflagellates and 14 coccolitophorids. The highest number of phytoplankton species was recorded in spring 1980 and the lowest in summer 1979.

Diatoms reached maximum in April 1979 and minimum in September of the same year. Dinoflagellate maximum occurred in April 1980 and minimum in July 1979. The highest numbers of coccolitophorids were recorded in April and the lowest in January 1980. Diatoms were predominant phytoplankton group, particularly pennates.

The presence of freshwater and brackishwater diatom genera and their species is particularly significant. Freshwater species of genera *Achanthes, Cocconeis, Pleurosigma, Synedra* and some others occurred at P_1 station.

Diatom species: *Thalassiosira sp., Chaetoceros affinis* and *Nitzchia seriata* were present in all months.

The following species were recorded only during the warmer period: *Chaetoceros compressus, Bacteriastrum delicatum,* 4 species of *Rhizosolenia* genus of centric forms, as well as *Thalassiothrix frauenfeldi, Navicula bicapitata, N. aglica, Pleurosigma elongatum, Amphora cymbifera, N. longissima* and *N. sigma* of pennates.

The species *Grammatophora, Navicula rhynocephala, Nitzschia bilobata* and *N. paradoxa* occurred only in winter.

Dinoflagellate species *Amphidinium sp., Gymnodinium sp., Gyrodinium fusiforme,* 3 species of genera *Prorocentrum* and *Oxytoxum laticeps* were present in all months of investigations.

Protodinium simplicius, Gymnodinium ostenfeldi and *Amphidinium stigmatum* were recorded only in winter.

Coccolitophorids *Calyptrosphaera sphaeroidae, Coccolithus huxley, Lohmannosphaera adriatica* and *Rabdosphaera sp.,* were recorded in all seasons, *Calyptrosphaera dalmatica* was recorded only in winter.

»Microflagellate« genera *Carteria* and *Chlamydomonas* occurred in all months and the *Euglena* genus during the warmer part of our investigations.

Species composition at P_1 station is given in Appendix (Table 1).

c) Seasonal fluctuations of the total phytoplankton and density of phytoplankton groups

Phytoplankton density determined at 0, 10 and 20 m at P_1 station in the area of Kardeljevo ranged between 147×10^3 to 1533×10^3 cells l^{-1}. Minimum to maximum density ratio was 1 : 10.4, and annual mean phytoplankton density was 1474×10^3 cells per liter.

Seasonal phytoplankton density values are given in Table 7.

Table 7. Numerical abundance of the total phytoplankton at P_1 station (expressed as the number of cells per liter)

	1979			1980		
Depth (m)	April	June	July	September	January	April
0	698880	801360	1557360	499800	183960	361200
10	125160	248640	2875320	38640	156240	341040
20	182280	165480	167160	173880	101640	162960
Mean	335440	405160	1533280	237440	147280	288400

Table 8. Numerical abundance of individual phytoplankon groups in the water column (0—20 m) at P_1 station (expressed as the number of cells per liter)

Year	Month	Diat.	Dinofl.	Cocc.	Silic.	»Microfl.«
1979	April	810600	36120	144480	—	15120
	June	1015560	65520	94080	—	40320
	July	4506600	20160	46200	—	26880
	September	483840	50400	154560	—	23520
1980	January	194880	74400	84000	—	91560
	April	545160	39480	47040	—	233520
Mean		1259440	47180	95060	—	71820

Dominant diatom genera at P_1 station for the time of investigations were *Nitzschia and Chaetoceros* with the species *N. delicatissima, Ch. affinis, Ch, compressus* and *Ch. curvisetus.* The species *Lauderia borealis* was prominent in winter.

Of dinoflagellates *Prorocentrum micans* was predominant and of coccolitophorids *Coccolithus huxley* and *Calyptrosphaera sphaeroidea.*

e) Vertical distribution of the total phytoplankton density

It is characteristic for this station that, on the average, the highest densities were recorded at the surface and minimum densities at 20 m. Vertical distribution of diatoms significantly affects the vertical distribution of the total phytoplankton. (Fig. 6.).

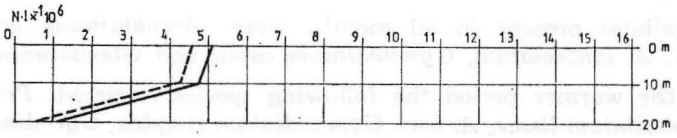

Fig. 6. Vertical distribution of density of the total phytoplankton (unbroken line) and diatoms (dashed line) at P_1 station for the time of investigations

Dubrovnik area — D_1 station

a) Hydrography

D_1 station (42°40'3"N; 18°04'2"E) of 36 m depth showed the following physical and chemical properties:

Temperature varied from 12.7 to 22.28°C at the surface and from 13.69 to 16.87°C at 35 depth.

Salinity ranged from 35.41 to 36.87‰ at the surface and from 37.95 to 39.12‰ at 35 m depth.

pH varied between 8.19 and 8.24.

Nitrates were present in 0.49 to 0.85 μg at l^{-1} concentrations at the surface and in 0.58 to 0.73 μg at l^{-1} at 35 m depth.

Phosphates ranged from 0.047 to 0.094 μg at l^{-1} at the surface and from 0.068 to 0.100 μg at l^{-1} at 35 m depth.

Silica varied within the 4.00 to 9.94μg at l^{-1} range at the surface and 4.28 to 12.22 μg at l^{-1} at 35 m depth.

Sea water transparency averaged 13.83 m.

b) Phytoplankton species composition

A total of 109 phytoplankton species were determined for the time of investigations, of which 55 diatom species (31 centric forms and 24 pennates), 33 dinoflagellate species, 20 coccolitophorids and 1 silicoflagellate species. The highest number of phytoplankton species were recorded in spring and the lowest in summer 1979. Diatoms reached maximum in spring 1980 and minimum in summer 1979. Maximum dinoflagellate and coccolitophorid numbers were recorded in summer 1979 and minimum in winter. The only silicoflagellate species *Dictyocha fibula* was recorded in January.

Diatoms were prevalent throughout the period of investigations, particularly neritic forms. Brackish and freshwater species were also noted.

The following diatom species were recorded in all seasons: *Thalassiosira sp., Leptocylindrus danicus, L. minimus, Thallasionema nitzschioides, Navicula sp., Rhizosolenia alata, f. gracillima, Nitzschia delicatissima, N. seriata, N. closterium* and *Pleurosigma elongatum.*

The species *Hemiaulus haucki, Cerataulina bergoni, Chaetoceros compressus, Ch. curvisetus, Ch. danicus, Ch. decipiens, Bacteriastrum delicatulum, B. hyalinum, Rhizosolenia alata, Rh. fragillissima, Rh. stolterfothi, Achnanthes longipes* and *Cocconeis sp.* were recorded only during the warmer months.

The species *Cyclotella sp., Rhizosolenia alata f. indica, Navicula smithi* and *Nitzschia panduriformis* were recorded only in winter.

Dinoflagellates present in all months were: *Amphidinium acutissimum, A. curvatum, A. lanceolatum, Gymnodinium caput* and *Glenodinium sp.*

During the warmer period the following species occurred: *Prorocentrum micans, Amphidinium lissae, A. cori, Gymnodinium simplex, Gyrodinium pingue* and *Oxytoxum laticeps.*

Prorocentrum aporum species was recorded only in winter.

Coccolitophorids *Coccolithus huxleyi, Syracosphaera spinosa* and *Calyptrosphaera sp.* occurred in all months and *C. gracillima, Lohmannosphaera adriatica* and *Calciosolenia grani* only during warmer months.

»Microflagellate« species *Chlamydomonas piriformis, Hillea fusiformis* and genus *Carteria* were present in all months and *Euglena* and *Eutreptiaella* genera only during warmer months.

c) Seasonal fluctuations of the total phytoplankton and density of phytoplankton groups

Phytoplankton density, determined at D_1 station at 0, 10, 20 and 35 m depth, is shown in Table 9.

Seasonal phytoplankton density variations were not considerable at this station. Minimum density was recorded in January 1980, and maximum in June 1979, with values of 108×10^3 to 434×10^3 cells per liter, that is the 1:4 ratio. Annual mean phytoplankton density was 982×10^3 cells per liter of sea water.

Table 9. Numerical abundance of the total phytoplankton at D_1 station (expressed as the number of cells per liter)

	1979			1980		
Depth (m)	April	June	July	September	January	April
0	444360	1198680	1302840	420000	140280	188160
10	237720	232680	203280	84000	123480	198240
20	133560	153720	61320	—	—	246960
35	89880	150360	86520	64000	61320	73920
Mean	226380	433860	413490	189000	108360	176820

The greatest phytoplankton density fluctuations were recorded at the surface and the lowest at 30 m depth.

Mean numerical abundance of individual phytoplankton groups for the time of investigations is given in Table 10.

Table 10. Numerical abundance of individual phytoplankton groups in the water column (0—35 m) at D_1 station (expressed as the number of cells per liter)

Year	Month	Diat.	Dinofl.	Cocc.	Silic.	»Microfl.«
1979	April	346560	217560	294000		29400
	June	143640	1275960	188160		127680
	July	1349880	104160	121800		78120
	September	183960	201600	76440		105000
	January	157080	53760	68040	5040	41160
1980	April	450000	75600	39480		142800
Mean		441520	321440	131320	840	87360

Diatom quantities mainly exceeded the quantities of other phytoplankton groups except in June and September when dinoflagellates were predominant. This ih shown in Fig. 7.

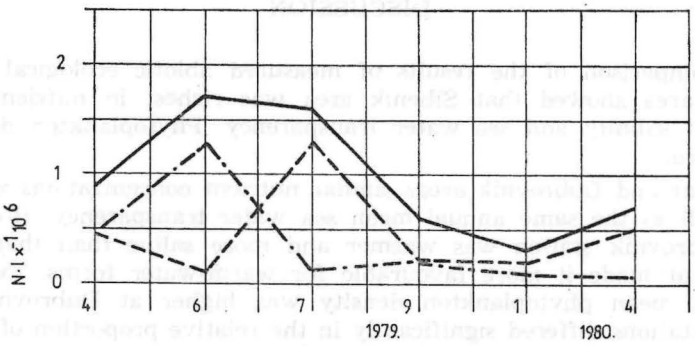

Fig. 7. Seasonal fluctuations of density of the total phytoplankton (unbroken line), diatoms (dashed line) and dinoflagellates (dash-dotted line) at D_1 station (expressed as the number of cells per liter of sea water)

d) Interrelations between individual phytoplankton groups and dominant species

Diatoms constituted on the average 44.93% of the total phytoplankton, dinoflagellates 32.71%, coccolitophorids 13.36%, »microflagellates« 8.89% and silicoflagellates 0,09%.

Dominant diatoms were *Skeletonema costatum, Bacteriastrum delicatulum, Leptocylindrus danicus, Nitzschia delicatissima, Thalassiosira* sp. and *Thalassiothrix frauenfeldi.* During highest phytoplankton density in June dinoflagellates were predominant (73.52%) and *Prorocentrum micans* species (992×10^3 cells per liter) accounted for the total phytoplankton density in association with the species of genus *Gymnodinium.*

Dominant coccolitophorid genera were *Coccolithus, Rhabdosphaera* and *Syracosphaera,* with dominant species *Coccolithus huxleyi.*

e) Vertical distribution of the total phytoplankton density

The highest phytoplankton density at this station was recorded from the surface. It decreased with depth. Diatoms were evenly distributed in the water column (Fig. 8.).

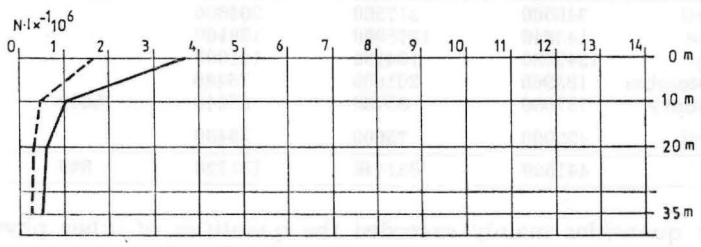

Fig. 8. Vertical distribution of the total phytoplankton density (unbroken line) and diatoms (dashed line) at D_1 station for the time of investigations

DISCUSSION

The comparison of the results of measured abiotic ecological factors in the study area showed that Šibenik area was richest in nutrients, coldest, with lowest salinity and sea water transparency. Phytoplankton density was highest there.

In Zadar and Dubrovnik areas similar nutrient concentrations were recorded, as well as the same annual mean sea water transparency. However, the sea at Dubrovnik station was warmer and more saline than that at Zadar station, what made it more favourable for warm-water forms. Even though the annual mean phytoplankton density was higher at Dubrovnik station, these two stations differed significantly in the relative proportion of individual phytoplankton groups. Namely, dinoflagellates were predominant at Dubrovnik station during the warmer part of the year as distinct from Zadar station where besides predominant dinoflagellates coccolitophorids occurred in considerable quantites.

Quantities of nutrients at Split station were similar to those at Zadar and Dubrovnik stations. Phytoplankton density was lower than at these two station while percentage proportion of diatoms exceeded that at these two stations.

Mean phosphate and nitrate levels were lowest at P_1 station near Kardeljevo, while temperature was, on the average, highest for the whole study area. Even though the average phytoplankton density was highest at this station this is not absolutely true since only one bloom of *Chaetoceros* genus (July) at this station changed the common quantitative relations between this and other stations. This was also proved by the results of some earlier »Vir—Konavle« investigations (Institut za oceanografiju i ribarstvo, Split, 1978b, 1979, 1980, 1981a).

The analysis of species composition at the »Vir—Konavle« profile showed a total of 216 phytoplankton species, of which 128 diatoms (56 centric and 72 pennates), 55 dinoflagellates, 2 silicoflagellates and 31 coccolitophorids. Larger number of »microflagellates« was also determined. However, due to the fact that this heterogeneous group of organisms could not be precisely determined, they were determined to the level of genus. A total of seven »microflagellate« genera were determined.

Even though the number of samplings was relatively low large number of phytoplankton species was recorded since the study area is wide and ecologically diverse. We tried to compare our data with some earlier ones from the Adriatic.

Pucher-Petković (1966) reported 120 diatom species, 83 centric diatoms and 37 pennates for the wider area of the middle Adriatic. Considerably higher number of centric diatoms recorded is due to the fact that these researches were carried out predominantly in deeper waters. Homen (1979) recorded 81 diatom species, 56 centric diatoms and 25 pennates from the Kaštela Bay. The records of 65 diatoms (31 centric and 24 pennates) were reported for the area of Rijeka Dubrovačka (Institut za oceanografiju i ribarstvo, Split, 1978), as well as 140 phytoplankton species for the area of Šibenik (Institut za oceanografiju i ribarstvo, Split, 1974).

A total of 62 phytoplankton species were recorded from the study area as a whole. These species were predominantly neritic and of wide ecological valence.

Of diatoms, 36 species were recorded from all the stations. Since they were mainly recorded from more shallow areas larger number of tychopelagic species were noted among them.

Unarmoured forms (*Gymnodiniales* genus) had the widest spatial distribution of all dinoflagellates. Thus, as much as 12 different forms belonged only to the *Amphidinium* and *Gymnodinium* genera. A total of 19 dinoflagellate species occurred all over the study area. It may be of interest to mention that *Miracanthodinium bacilliferum* (Schiller, Deflandre, 1937) species determined at S_1 station had not been recorded from the Adriatic ever since its first records (after the Catalogue of Species, Keržan and Štirn, 1976).

Seven coccolitophorid species and six »microflagellate« species occurred at all the stations.

Two silicoflagellate species were recorded, of which *Dictyocha fibula* was noted at all the stations except at P_1 station.

The highest number of species occurred at $Š_1$ station (134) and the lowest at D_1 (109). Diatoms were most numerous at all the statons. It was observed that centric diatoms were predominant at Z_1, S_1 and D_1 stations and pennates at $Š_1$ and P_1 which are affected by fresh waters. Dinoflagellates were evenly distributed all over the study area as well as coccolitophorids.

Sørensen's (1948) similarity index was used for the analysis of similarity of phytoplankton communities between stations. Only microplankton component of phytoplankton was taken into consideration since these forms were determined up to the level of species, while »microflagellates« and some coccolitophorids could not be determined but up to the level of genus. The results obtained indicate (Table 11) that phytoplankton species composition is similar at all the stations since similarity index ranged from 65.5 ($Š_1/P_1$) to 76.1% (S_1/D_1).

Table 11. Indices of similarity between microplankton communities at Vir-Konavle profile

	S (%)		S (%)
$Š_1/P_1$	65.5	$Š_1/D_1$	69.2
$Š_1/S_1$	65.7	Z_1/S_1	69.3
Z_1/P_1	66.9	P_1/D_1	71.2
$Z_1/Š_1$	67.9	Z_1/D_1	75.6
S_1/P_1	68.5	S_1/D_1	76.1

Maximum number of species was recorded from all the stations in spring, and niminum in winter (in the majority of cases). Qualitative maximum coincided with the quantitative maximum. This was also recorded earlier from some localities in the middle Adriatic (Pucher-Petković, 1966). The diversity index (Margalef, 1951) calculated for diatoms, was highest at all the stations in spring, and minimum diversity indices were recorded in different seasons. Global diversity index of diatoms was highest at most productive stations in the study area ($Š_1$ and P_1). The lowest diversity index of diatoms occurred at Zadar and Dubrovnik stations (Table 12).

Diatoms were better represented at $Š_1$ station at which salinity was lower and the levels of phosphates, nitrates and organic matter higher.

Table 12. Monthly and global diatom diversity index at Vir-Konavle stations in the period of investigations

	1979				1980		Global diatom
Station	April	June	July	September	January	April	diversity index
Z_1	2.14	2.12	1.67	1.90	1.86	3.15	3.91
$Š_1$	—	2.82	2.31	2.59	1.39	3.63	4.88
S_1	2.57	2.56	1.89	2.71	1.78	2.49	4.09
P_1	3.31	3.29	2.87	1.83	2.22	2.57	5.17
D_1	3.26	2.19	1.77	1.57	1.84	2.59	3.92

Dinoflagellates were most numerous at Dubrovnik station. Global species diversity index (Table 13), was highest in this area. This might be expected since this is the southernmost station where dinoflagellates, as warm-water organisms, find most favourable conditions for their development. As found in the literature, the number of diatoms decreases in these waters and dinoflagellates are significant constituent of phytoplankton community.

Table 13. Mean dinoflagellate density, number of species and global diversity index at Vir-Konavle stations in the period of investigations

Station	Z_1	$Š_1$	S_1	P_1	D_1
Mean dinoflagellate density	649320	609840	524160	283080	928640
Number of species	30	33	33	29	33
Global diversity index	2.17	2.40	2.42	2.23	2.69

Coccolitophorids were most numerous at Šibenik station and least numerous at P_1 station. This is surprising since these are the organisms which prefer warmer sea waters. Thus, for example, coccolitophorid density at Šibenik station was eight times that at Kadeljevo station. It may be said that, in general, the number of coccolitophorids was higher at more northern stations than at the southern ones.

Even though silicoflagellates occurred in quite insignificant quantities, they were best represented at Dubrovnik station, while their number was lower at Zadar station.

»Microflagellate« numbers were highest at Šibenik station even though their proportion in relation to other phytoplankton organisms was lowest.

With respect to the long time intervals between samplings and relatively short time of investigations the succession of species at individual stations could not be established. Species succession depends on a seriers of factors, such as sea water temperature, light intensity in different seasons, composition and concentrations of nutrients. Mutual effects of coastal and open sea waters, surface and deep water exchanges (Johnston, 1963), land freshwater effects, trace metals and vitamines (Fogg, 1966) play also an outstanding role.

Dominant phytoplankton genera and species by individual stations during the period of investigations are given in Table 14.

Phytoplankton density fluctuations were highest at Z_1 station and lowest at D_1 station. At these stations seasonal phytoplankton density fluctuations were highest in both the surface and bottom layer. This is characteristic for shallow coastal stations.

It was observed that the occurrence of maximum phytoplankton density coincided at Z_1, $Š_1$ and S_1 stations in spring and at southern P_1 and D_1 stations in summer. Minimum density was recorded from all the stations in winter except from $Š_1$ station where it was recorded in summer. Diatoms showed the same seasonal dynamics. However, owing to the long time intervals between individual samplings no real picture of seasonal dynamics could be obtained. Since each sampling did not last longer than few days the obtained results are indicative of the more or less synchronic seasonal rhythm of phytoplankton along the eastern Adriatic coast. This conclusion may be proved by some earlier investigations carried out in the same area (Institut za oceanografiju i ribarstvo, Split, 1978b).

Highest diatom percentage presence in phytoplankton community was found at Kardeljevo (85.47%) and Split (78.81%) stations, and the lowest one in the area of Dubrovnik (44.93%). These values range within common limits for this group of organisms in the middle coastal Adriatic (Pucher-Petković, 1979).

Table 14. Dominant phytoplankton species in the study area

Station	1979				1980	
Month	April	June	July	September	January	April
Z_1	*Thalassiosira sp.*	*Rhizosolenia alata* *Nitzschia delicatissima*	*Rhizosolenia alata*	*Rhizosolenia alata f. gracillima*	*Chaetoceros affinis* *Nitzschia seriata*	*Bacteriastrum delicatulum* *B. hyalinum* *Chaetoceros affinis*
$Š_1$		*Leptocylindrus adriaticus* *Nitzschia delicatissima*	*Leptocylindrus adriaticus* *Chaetoceros sp.*	*Chaetoceros sp.* *Dactyliosolen mediterraneus*	*Thalassiosira sp.*	*Skeletonema costatum*
S_1	*Nitzschia seriata*	*Chaetoceros affinis* *Ch. compressus* *Ch. sp.* *Nitzschia delicatissima*	*Chaetoceros affinis* *Ch. compressus*	*Skeletonema costatum*	*Nitzschia delicatissima* *Chaetoceros sp.*	*Nitzschia seriata*
P_1	*Lauderia borealis*	*Chaetoceros affinis* *Ch. compressus* *Nitzschia seriata*	*Chaetoceros affinis* *Ch. compressus* *Ch. sp.*	*Chaetoceros affinis*	*Nitzschia delicatissima* *Chaetoceros curvisetus*	*Nitzschia seriata*
D_1	*Bacteriastrum delicatulum*	*Nitzschia delicatissima* *N. seriata*	*Skeletonema costatum* *Chaetoceros affinis*	*Melosira moniliformis*	*Nitzschia delicatissima*	*Bacteriastrum delicatulum*

Dinoflagellates constituted on the average 2.77% to 32.71% of the total phytoplankton. They were most poorly represented at Šibenik station and best represented in the Dubrovnik area. These values, however, exceed those recorded earlier from the coastal waters of the middle Adriatic (Pucher-Petković, op. cit.).

Maximum density of this group was recorded at surface of D_1 station in June (108×10^3 cells per liter). It was due to the »bloom« of *Prorocentrum micans,* known as cosmopolitan eurythermal and euryhaline species.

On the average, the proportion of coccolitophorids varied from 6.45 in the area of Kardeljevo to 20.53% in the area of Šibenik. These percentages are higher than those reported by Pucher-Petković (op. cit.), who found the values of 3 to 8% in the coastal area of the middle Adriatic. The highest coccolitophorid density was recorded from the surface layer of $Š_1$ station in winter (3819×10^3 cells per liter) constituting 71.3% of the total phytoplankton. Only *Coccolithus huxleyi* species accounted for 68.78% of the coccolitophorid density at sea water temperature of 9.7°C and 4.6‰ salinity.

»Microflagellates« varied on the average from 4.5 to 8.89% along the eastern Adriatic coast. These values are lower than those found by Pucher-Petković (1979). They are mainly better represented during the warmer part of the year. The same was found during some earlier investigations as well.

Silicoflagellates ranged between 0.02 and 0.51% which somewhat exceed earlier reported values from Vir—Konavle.

On the basis of the observations of quantitative structure of phytoplankton from the Vir—Konavle study area taken as a whole, it may be concluded that diatoms are responsible for phytoplankton density along the eastern coast of the middle Adriatic. The most abundant is *Skeletonema costatum* species. After this species the species *Chaetoceros affinis, Nitzschia seriata, Thalassiosira sp., N. delicatissima, Ch. compressus* and *Leptocylindrus adriaticus* are numerically best represented.

Owing to the prominent dominance of diatoms all over the study area, some earlier results on this phytoplankton group are brought out.

Many authors dealt with the distribution of the species *Skeletonema costatum* as well as with its annual fluctuations, such as Riley (1952), Conover (1956), Smayda (1957), Curl and McLeod (1961), Revelante (1975), Homen (1979), Pucher-Petković and Marasović (1980).

Some authors described its euryhaline and eurythermal character (Smayda, 1957; De Pauw *et al.,* 1980; Goldman and Ryther, 1976). *Skeletonema costatum* seems to be the species recorded whenever the phytoplankton was studied in the coastal areas except in arctic and antarctic waters (Curl and Mc Leod, 1961).

This species occurred at Šibenik station in all sampling months. Maximum densities were recorded during spring boom in April 1980 (689×10^3 cells l^{-1} at sea surface). *Skeletonema costatum* was alternatively predominant with *Thalassiosira* sp. at $Š_1$ station with the codomination of *Nitzschia seriata.* Maximum of *Skeletonema costatum* was recorded from S_1 in September and from D_1 in July. It may be of interest to mention that this species was recorded from P_1 station on only two occasions, in November 1978 and June

1980. Its densty did not exceed 12×10^3 cells l^{-1}, even though these stations have been studied ever since 1976.

Physical and chemical properties of the sea water in the study area showed that in the Šibenik area the conditions were most favourable for the development of *Skeletonema costatum*. Thus, the highest nutrient levels were recorded from the surface of this station. These salts were manily carried by the Krka river what was proved by the marked vertical gradient of their concentrations. The decrease of *Skeletonema costatum* density with depth may be accounted for by the poorer light penetration to greater depths. Namely, during bloom in April 1980 the sea water transparency was only 5 m at $Š_1$ station. At the same time the sea water temperature of 11.14°C and salinity of 11.74‰ were obviously favourable for its development.

Lower nutrient levels at S_1 and D_1 stations were probably the cause of its poorer development.

Data on basic physical and chemical properties of the sea water at stations at which *Skeletonema costatum* reached maximum are given in Table 15.

Table 15. Maximum density of *Skeletonema costatum* and physical and chemical properties of the sea at $Š_1$, S_1 and D_1 stations

Station	Depth (m)	T°C	Sali. ‰	NO_3—N µgat/l	PO_4—P µgat/l	SiO_2—Si µgat/l	*Skeletonema costatum* Nl^{-1}
$Š_1$	0	11,14	11,74	4,03	0,119	33,95	6384×10^3
(April	20	13,05	37,65	1,80	0,060	5,07	64×10^3
1980)	30	13,04	38,05	0,75	0,051	5,54	53×10^3
S_1	0	22,28	36,24	0,49	0,094	5,54	911×10^3
(June	20	17,02	38,62	0,69	0,081	5,07	—
1979)	30	15,78	38,71	0,56	0,077	4,57	—
D_1	0	21,12	37,25	0,68	0,085	4,57	163×10^3
(July	20	21,31	38,19	0,61	0,081	3,42	—
1979)	30	17,01	38,65	0,82	0,077	7,10	33×10^3

It is also of interest to mention that *Skeletonema costatum* bloom was recorded from Šibenik area in February 1974 with the value of 4687×10^3 cells l^{-1} at 10.75°C temperature and 3.48‰ salinity (Institut za oceanografiju i ribarstvo, Split, 1974). This is another proof of its eurythermal and euryhaline character.

The second important species is *Nitzschia seriata*. Ercegović (1936) reported small quantities of this species from the waters in the vicinity of Split in winter. However, due to the eutrophication processes this species has gradually become one of the quantitatively most important species of these waters (Pucher-Petković, and Marasović, 1980).

The same was recorded for the *Leptocylindrus* genus, the small quantities of which were recorded by Ercegović (1936) in summer and somewhat higher quantities in winter. It has occurred in larger quantities in the Kaštela Bay from 1978 on and has become one of the most abundant genera (Pucher-Petković and Marasović, 1980).

This genus reached maximum density at all the stations in summer. It constituted 45.7 and 48.9% respectively of $Š_1$ station diatoms in June and July. This genus vas found to be one of the most dominant genera

together with the *Skeletonema costatum* species at $Š_1$ station by some earlier investigations in this study area(Institut za oceanografiju i ribarstvo, Split, 1974). Namely, the bloom of *Leptocylindrus adriaticus* with the value of 4255×10^3 cells l^{-1} was observed at the sea surface in summer 1973.

In addition to vertical mixing by which the surface sea layer is enriched in nutrients, coastal belt enrichment is also due to municipal wastes. This is particularly applicable to Šibenik and Split (Kaštela Bay) areas. Large number of earlier papers dealt with the gradual eutrophication and its effects on the development of coastal phytoplankton, from those published ten years ago (Pucher-Petković, 1975) to the recent ones (Pucher-Petković and Marasović, 1980). At the beginning, the eutrophication positively affects the phytoplankton development, but afterwards it gradually affects selectively the organims. Thus, *Skeletonema costatum* was not mentioned to occur in the waters of the middle Adriatic in the papers by Ercegović (1936) and Rampi (1940).

However, its mass occurrence has been recorded (Pucher-Petković, 1975; Homen, 1979; Pucher-Petković and Marasović, 1980).

Vertical distribution of phytoplankton density shows the same characteristics at Split and Zadar stations. Phytoplankton is concentrated at the surface and at 30 m depth, with maximum densites at the surface. At $Š_1$, P_1 and D_1 stations phytoplankton density decreases with depth. This vertical gradient of the total phytoplankton density is affected by diatoms which are responsible for the numerical abundance of phytoplankton at all the stations.

CONCLUSIONS

The investigations of the basic characteristics of phytoplankton along the eastern Adriatic coast, from Zadar to Dubrovnik, showed the following:

1. The area shows high species richness. A total of 216 forms were determined, of which 128 diatom species (56 centric diatoms and 72 pennates). 55 dinoflagellates, 2 silicoflagellate species, 31 coccolitophorids and a number of »microflagellate« genera. The highest number of species was recorded from Šibenik station (134) and the lowest from Dubrovnik station (109).
2. Species composition showed similarity between stations. Similarity index of species composition varied from 65.5 to 76.1%.
3. Maximum number of species was recorded from all the stations in spring, and minimum in different seasons.
4. Qualitative maximum coincided with the quantitative maximum in the majority of cases.
5. Global diversity index for diatoms was highest at the most productive stations, $Š_1$ and P_1. The lowest diversity index was recorded from Z_1 and D_1 stations. However, the highest diversity index for dinoflagellates was recorded from D_1 station.
6. Diatom species were predominant at all the stations. This group was generally responsible for the phytoplankton numerical abundance. Quantitatively and qualitatively this group was best represented in areas of lower salinity and increased nutrient levels ($Š_1$ and P_1 stations).

7. Of diatoms, centric forms were predominant at Z_1, S_1 and D_1 stations, and pennates at $\check{S}_1$ and P_1 stations at which a larger number of brackish water and fresh water species were also recorded.
8. The most productive areas are Šibenik and Kardeljevo and the least productive Zadar and Split.
9. Maximum phytoplankton density was recorded from northern stations in spring and from the southern ones (P_1 and D_1) in summer. Minimum density occurred at these stations in winter except at $\check{S}_1$ station at which it was recorded in summer. Greatest seasonal fluctuations were recorded from Z_1 station and the lowest from D_1 station. The most significant fluctuations occurred in surface and bottom layers.
10. Phytoplankton blooms were due to the increase in density of one or more species of the same diatom genus or two genera, of which one was dominant and other accompanied it.
11. Diatoms constituted from 44.93% (D_1) to 78.21% (S_1) of the total phytoplankton density. Dinoflagellates contributed an average of 2.77—32.71% of the total phytoplankton, with the smallest proportion at S_1 station and the highest proportion at D_1 station. Percentage of coccolitophorids ranged from 6.45 (P_1) to 20.53 ($\check{S}_1$). »Microflagellates« constituted from 4.5 to 8.89%, and silicoflagellates from 0.02 to 0.51%.
12. Diatoms were mainly responsible for the phytoplankton density along the eastern Adriatic coast. Seven genera dominated: *Skeletonema, Nitzschia, Chaetoceros, Leptocylindrus, Thalassiosira, Rhizosolenia* and *Bacteriastrum. Skeletonema costatum* was quantitatively most significant species in the study area.
13. Of the species which are mainly responsible for the numerical abundance of phytoplankton of the study area, *N. seriata, N. delicatissima, N. closterium,* and species of genus *Leptocylindrus, Skeletonema costatum* and *Ch. affinis* are reported in the literature as opportunistic species, characteristic for the areas affected by river eutrophication and human pollution.

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KARAKTERISTIKE FITOPLANKTONA NEKIH LOKALITETA UZ ISTOČNU OBALU JADRANA

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KRATKI SADRŽAJ

Istraživanja fitoplanktona istočne obale srednjeg Jadrana na području od Zadra do Dubrovnika vršena su u sklopu opsežne oceanografske studije u razdoblju od travnja 1979. do travnja 1980. godine.

Uzorci fitoplanktona sakupljeni su sa tri odnosno četiri standardne dubine (0, 10, 20 i 30 m), ovisno o dubini postaje. Određivani su kvalitativni sastav, sezonske fluktuacije gustoće ukupnog fitoplanktona i njegovih grupa, međusobni odnosi fitoplanktonskih grupa i dominantnih vrsta te vertikalna distribucija fitoplanktona.

Analizom kvalitativnog sastava fitoplanktona na čitavom području istraživanja determinirano je ukupno 216 različitih vrsta. Najbogatija vrstama bila je šibenska postaja, a najsiromašnija dubrovačka. Indeks sličnosti među postajama kretao se od 65,5 do 76.1%.

Kvalitativni maksimum fitoplanktona nastupa na svim postajama u proljeće, a minimum u različito doba (zima, ljeto). Dijatomeje su po broju vrsta najzastupljenija fitoplanktonska grupa. Prevladavaju centrični oblici, dok su postaje koje su pod utjecajem slatke vode, bogatije penatama.

Srednjak gustoće fitoplanktona se na istraživanom području kretao u rasponu od 52600 st l^{-1}, koliko je iznosio zimi na zadarskoj postaji, do 2382660 st l^{-1}, na šibenskoj postaji u proljeće. Maksimalna gustoća fitoplanktona nastupa na sjevernijim postajama profila u proljeće, a na južnijim postajama ljeti. Pojava minimuma gustoće je sinhrona (zimi) za cijelo područje osim šibenske postaje gdje je minimum zabilježen ljeti.

Najveće sezonske fluktuacije fitoplanktona ima zadarsko, a najmanje dubrovačko područje. Sezonske fluktuacije gustoće fitoplanktona su na području Vir-Konavle najveće na površini mora i u pridnenom sloju.

Od svih postaja istraživanog profila najproduktivnije su bile postaje Kardeljeva i Šibenika, a najsiromašnija splitska. Zadarska i dubrovačka postaja su imale jednak godišnji srednjak gustoće fitoplanktona.

Fitoplanktonske zajednice područja Vir-Konavle i u kvantitativnom smislu karakterizira prevladavanje dijatomeja. Kao glavni nosioci numeričke abundancije dijatomeje utječu na godišnji hod ukupnog fitoplanktona te na sliku njegove vertikalne distribucije. Procentualna zastupljenost dijatomeja kretala se u rasponu od 44, 93 do 85, 47%. Na svim postajama, osim dubrovačke, po važnosti druga fitoplanktonska grupa bile su kokolitoforine, a na dubrovačkoj postaji dinoflagelati. Relativno učešće kokolitoforina na istraživanom području kretalo se od 6,45 do 20,53%, a dinoflagelata od 2,77 do 32,71%.

Na profilu Vir-Konavle zabilježeno je 7 dominantnih dijatomejskih rodova: *Skeletonema, Nitzschia, Chaetoceros, Leptocylindrus, Thalassiosira, Rhizosolenia* i *Bacteriastrum.* Vrsta *Skeletonema costatum* je kvantitativno najznačajnija na čitavom profilu.

U pogledu vertikalne distribucije fitoplanktona uočene su dvije pojave: na postajama Šibenika, Kardeljeva i Dubrovnika gustoća fitoplanktona opada s dubinom dok je na postajama Splita i Zadra fitoplankton koncentriran na površini i na dubini od 30 m.