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Taxonomic composition and abundance of phytoplankton in the middle reach of the karstic Zrmanja Estuary (Croatia)

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The taxonomic composition and abundance of phytoplankton were analyzed in relation to thermohaline and hydrological conditions in the middle reach of the karstic river Zrmanja Estuary, eastern Adriatic coast, Croatia, in the period December 1981 to November 1982, and June 1998 to June 1999. General trophic interrelations were characterized by the spring–summer development of marine phytoplankton (mainly diatoms) and autumn–winter development of small herbivores (copepods, nauplii, copepodites). Two maxima of naked ciliates indirectly indicated the regeneration of alochtonous organic matter in winter, and autochtonous organic matter in late summer. In general, dominant phytoplankton species provided seasonal recurrent assemblages. Freshwater phytoplankton above the halocline is less abundant in the lower than in the upper reach of the estuary. Instead of freshwater phytoplankton, the brackish diatom *Thalassiosira* (a short-chained, small-celled species) was abundant above the halocline during the winter–spring period.

Key words: Phytoplankton, microzooplankton, seasonal distribution, karstic, stratified, estuary, river discharge, Adriatic Sea

Introduction

There are several small karstic rivers that discharge into the eastern Adriatic Sea, forming highly stratified estuaries that have not been adequately investigated. High stratification is maintained in areas where a high volume of river discharge is combined with low tides (Dyer 1991). Estuaries are highly productive habitats, providing ecologically and economically valuable fish-larvae and shellfish refugia, nurseries (Steele 1974), and dynamic nutrient transformation zones at the interface between freshwater and marine environments (Nixon 1995). Temporal and spatial distribution of phytoplankton in an estuary is regulated by the dilution of river flow, light and mixing processes (Cloern 1996). The in-

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creased primary production in estuaries is influenced by nutrients brought by the river discharge (MALONE et al. 1988).

Highly stratified estuaries are characterized by an accumulation of microphytoplankton (VILIČIĆ et al. 1989), nanophytoplankton (DENANT et al. 1991, AHEL et al. 1996), bacteria (FUKS et al. 1991), dissolved organic matter and detritic particles (ŽUTIĆ and LEGOVIĆ 1987, CAUWET 1991), and pollutants (MIKAC et al. 1989) along the sharp halocline.

The scope of this paper is to present a fragment of the interdisciplinary research in the Zrmanja Estuary that was carried out extensively in both 1981/1982 and 1998/1999. We present the seasonal distribution of thermohaline characteristics, phytoplankton and microzooplankton in the middle reach of the Zrmanja Estuary. The results may give some information valuable for further ecological research.

Investigated area

The Zrmanja River is a small karstic river that discharges into the eastern Adriatic Sea. It is 69 km long, from its source in the Dinaric karst region to the mouth in the Velebit Channel. The estuary and the adjacent coastal sea are westerly oriented between the Velebit Mountain ridge on the north, and large North-Dalmatian plateau to the south and east (FRIGANOVIĆ 1961). The 14 km long upper reach (Fig. 1) extends from the Jankovića buk waterfalls to the wider portion of the estuary (Novigradsko more). The steep banks of the upper portion of the estuary are strongly eroded, making the estuarine bed relatively shallow (mostly about 5 m deep).The middle reach consists of Novigradsko and the southeasterly extension of Karinsko more. The lower reach consists of the narrow strait (Novsko ždrilo), as a conection between Novigradsko more and the Velebit Channel. The lower reach is up to 40 m deep. In Novsko ždrilo strait there is a 19-m deep sill. The influence of this sill on overall circulation in the estuary is not defined to this day.

The tides in the area are rather weak: M2 amplitudes are below 10 cm, and K1 amplitudes are close to 13 cm (e. g. KASUMOVIĆ 1960).

The average outflow (calculated for the period 1953 –1990) equals 38 m^3/s, but may be as high as 456 m^3/s (December 1959) and as low as 0.09 m^3/s (June 1986). There is a complex water circulation in the karst system in the Zrmanja River catchment area (BONACCI 1999). The numerous permanent and temporary springs along the river are connected with swallow holes (»ponors«) in the hinterland. Underwater springs (»vruljas«) in the estuary discharge water during rainy (October-December) and snow melting periods (March-May).

The surrounding area is without considerable anthropogenic influence, resulting in moderate phytoplankton abundance (indicating natural eutrophication; VILIČIĆ 1989), low chlorophyll *a* and nutrient concentrations, as well as a well-oxygenated water column (Tab. 1).

Materials and methods

Water samples for the analyses of phytoplankton were collected at station N1 (Fig. 1), at monthly intervals, in the period December 1981 to November 1982, and June 1998 to June 1999. The water column at Station N1 is 20 m deep. Phytoplankton was sampled using 5-liter Niskin bottles, mostly at 0, 2, 4 and 10 m depths. Samples were preserved in a 2

Tab. 1. Range (MAX, MIN) and average (AVG) values of physical, chemical and phytoplankton parameters at Station N1 in the middle reach of the Zrmanja estuary, in the period 1981–1982 and 1998–1999.

Parameter	AVG	MAX	MIN	n
Temperature (°C)	15.19	25.90	4.60	77
Salinity (PSU)	28.81	37.94	3.46	77
Transparency (Secchi, m)	7.8	9.5	5.5	77
Total microphytoplankton (cells l^{-1})	265700	1843700	1500	77
Diatoms (cells l^{-1})	243900	1843600	1320	77
Dinoflagellates (cells l^{-1})	17900	538000	0	77
Coccolithophorids (cells l^{-1})	2500	34400	0	77
Chlorophyll *a* ($\mu g\ l^{-1}$)*	0.33	0.82	0.04	37
NO_3 ($\mu mol\ l^{-1}$)*	7.03	15.75	0.44	37
NO_2 ($\mu mol\ l^{-1}$)*	0.31	0.71	0.11	37
NH_4 ($\mu mol\ l^{-1}$)*	0.47	1.07	0.17	37
Total inorganic nitrogen ($\mu mol\ l^{-1}$)*	7.81	16.93	1.33	37
PO_4 ($\mu mol\ l^{-1}$)*	0.06	0.07	0.06	37
SiO_4 ($\mu mol\ l^{-1}$)*	16.42	27.83	8.16	37
Oxygen saturation (%)*	100	108	91	37

* Chlorophyll *a* and nutrient concentrations were determined by N. JASPRICA and M. CARIĆ (VILIČIĆ et al. 1999).

per cent (final concentration) neutralized formaldehyde solution. The cell counts were obtained by the inverted microscope method (UTERMOHL 1958). Subsamples of 50 ml were analyzed microscopically, after a sedimentation time of 24 h, within one month after the cruise. Cells longer than 20 µm were designated as microphytoplankton, cells 2–20 µm long as nanoplankton. Cells were counted at a magnification of 400 × (1 transect) and 200 × (transects along the rest of the counting chamber base plate). Recognizable nanoplankton cells were counted in 20 randomly selected fields of vision along the counting chamber base plate, at a magnification of 400 ×. The precision of the counting method is ±10%.

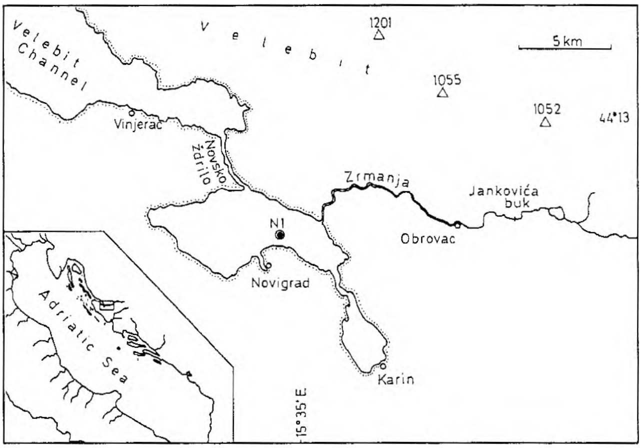

Fig. 1. Position of Station N1 in the middle reach of the Zrmanja River Estuary.

Samples for the analysis of microzooplankton were collected using 5-liter Niskin bottle samplers, fixed in 2.5 per cent neutralized formaldehyde and allowed to settle twice for 24 hours in plastic containers and glass cylinders, reducing the original volume of 5 l to a few milliliters. Counts were done at a magnification of 100 × (water immersion objective) using a self-designed chamber (75 × 45 mm, bottom glass 1 mm thick) (KRŠINIĆ 1980).

Salinity was determined using a Beckman RS5–3 salinometer, and by argentometric titration. Temperature was measured by Beckman sond and a reversing thermometer.

Results

Rainfall and river water discharge determined thermohaline characteristics in the estuary. Higher river discharge (Fig. 2) induced the formation of an about 4 m thick surface brackish layer (salinity 3.46–30 PSU) at Station N1 in January, May and November 1982 (Fig. 3). The salinity in the marine layer (below the halocline) ranged from 30 to 37.94 PSU. During the strong stratification, a vertical salinity gradient of up to 21.77 PSU was registered in the 2–4 m layer (= 10.88 PSU m^{-1}). A similar hydrological regime was evident during 1998/1999. Similar termohaline conditions were detected by CTD multisond during current research in 2000.

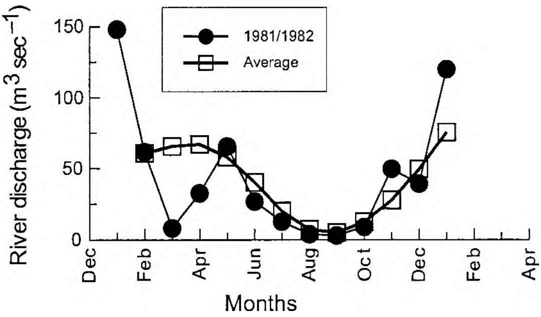

Fig. 2. Monthly river discharge during 1981/82 and average values for the 1958–1970 period compared

Thermic stratification in summer provided temperatures 22–26 °C above 8 m depth, and a thermic gradient of 5 °C in the 4–10 m layer (= 0.83 °C m^{-1}). Inverted stratification was detected in winter (December–March), with temperatures below than 8 °C in the 0 – 5 m layer. A short appearance of surface ice was detected between samplings in January 1999. Isothermic conditions were determined in April and October.

Secchi disc transparency varied between 5.5 and 7.8 m (Tab. 1).

Increased abundances of microphytoplankton (values higher than 10^6 cells l^{-1}) were detected in winter–spring, with maximum of 1.8 × 10^6 cells l^{-1} in April 1999 (Fig. 4). Freshwater phytoplankton did not provide more abundant population above the halocline at Station N1. Instead of freshwater species, the still unidentified, small-celled centric diatom *Thalassiosira* sp. provided dense population in the brackish layer (above the halocline) in January – May 1982 and 1999.

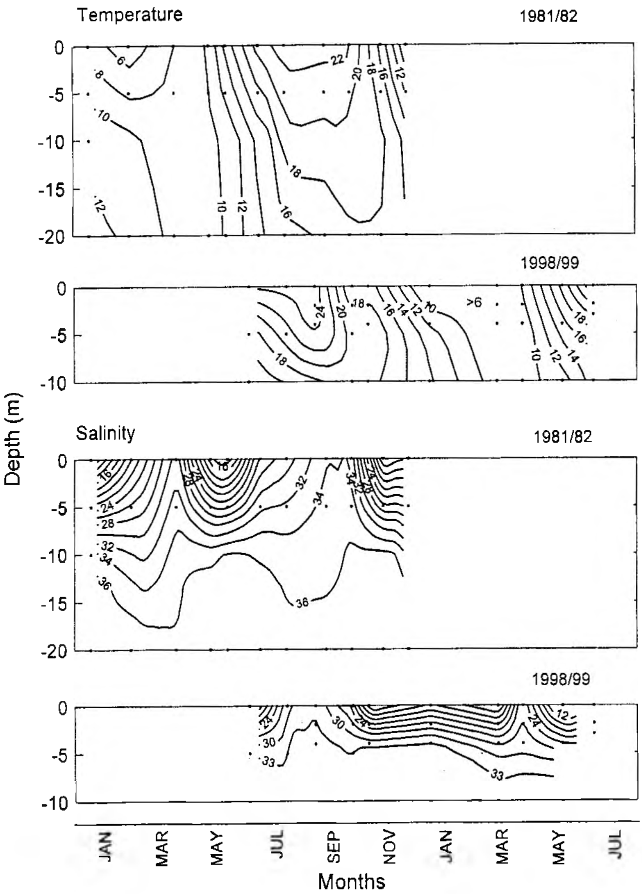

Fig. 3. Distribution of temperature and salinity in the middle reach of the estuary (Station N1) during 1981/82 and 1998/99.

Marine diatoms and dinoflagellates provided the dominant phytoplankton groups throughout the year. During the intensive development of phytoplankton in spring, diatoms were most important group, as indicated by the ratio between abundance of diatoms and dinoflagellates (Fig. 5). Dinoflagellates dominated in winter and summer.

Seasonal variations of phytoplankton taxa provided evidence of relatively recurrent assemblages in the estuary (Tab. 2). There were several diatoms with maximum abundance in winter–spring period, such as: *Pseudo–nitzschia* spp., *Rhizosolenia stolterfothii*, *Thalassiosira* (brackish, unidentified species), and *Bacteriastrum delicatulum*. The diatom *Leptocilindrus danicus* was abundant during summer. Among abundant dinoflagellates, several naked and thecate nanoplanktonic species (10–20 µm size fraction) appeared in summer. Among larger prymnesiophites, an abundant population of *Syracosphaera* was registered in summer–autumn.

Due to the taxonomic composition, microphytoplankton was composed of 72 diatoms (26 pennatae, 46 centric diatoms), 43 dinoflagellates, 7 prymnesiophytes, 3 chryso-

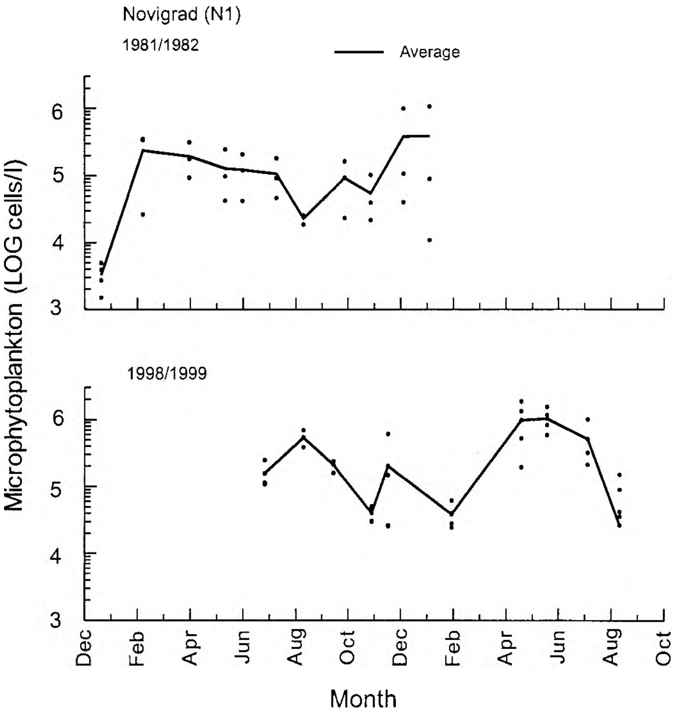

Fig. 4. Seasonal distribution of microphytoplankton in the lower reach of the Zrmanja Estuary during 1981/82 and 1998/99.

phyceae, and 1 euglenophyte (Tab. 3). The following diatoms provided maximum abundance greater than 5 × 10^6 cells l^{-1}: *Chaetoceros compressus, Ch. tortissimus, Pseudo–nitzschia sp., Thalassiosira* sp., while the most abundant dinoflagellates were gymnodinoid cells and *Prorocentrum micans.*

Discussion

Due to the rather weak tides in the area, the Zrmanja River may be expected to create a highly stratified estuary, at least during episodes of strong river outflow. The measurements performed in the Zrmanja Estuary indicated that the river influenced the stratification and dynamics not only in the middle reach of the estuary (Station N1) but in the Velebit Channel as well (VILIČIĆ et al. 1999).

Vertical temperature profiles are also of interest (Fig. 3). The thermocline was mostly observed close to the halocline. A subsurface temperature maximum was detected in October 1998 and February 1999. It could be interpreted in terms of a combined effect of radiative heating and reduced heat exchange at the halocline level. Moreover, the accumulation of suspended matter close to the halocline and selective absorption of solar radiation might contribute to its occurrence. The same phenomena have previously been observed in some other east Adriatic estuaries - the Krka Estuary (LEGOVIĆ et al. 1991; ORLIĆ et al. 1991) and the Ombla Estuary (VILIČIĆ et al. 1995).

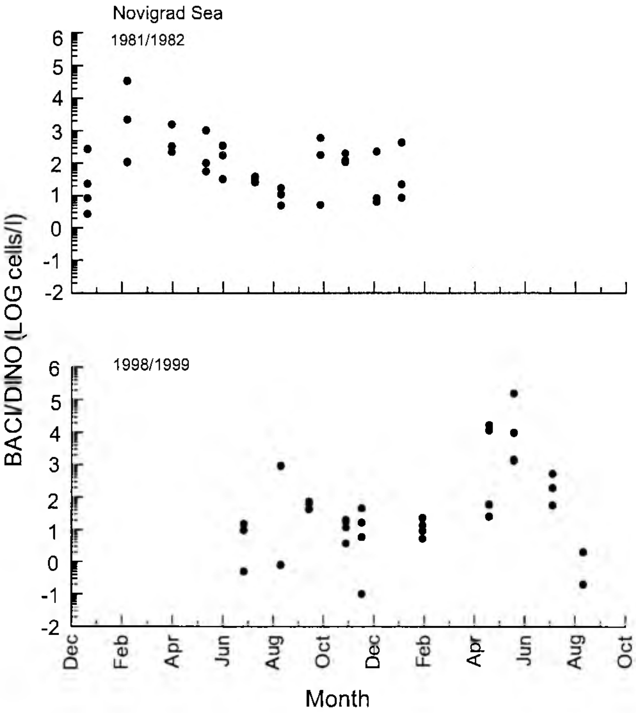

Fig. 5. Seasonal variations in the ratio between abundance of diatoms (BACI) and dinoflagellates (DINO) during 1981/82 and 1998/99. Distribution of ortophosphates, silicates, nitrates and ammonia along the investigated profile in October 1998.

Freshwater phytoplankton species in the Zrmanja Estuary were scarce, in contrast to the estuary of the River Krka, where freshwater phytoplankton develops in the relatively large freshwater accumulation in front of the estuary (VILIČIĆ et al. 1989). The freshwater phytoplankton, mostly composed of chrysophyte *Dinobryon* and numerous freshwater, pennate diatoms, sink to the halocline and die due to the osmotic shock, resulting in a decrease of cell density seaward.

The fact that marine phytoplankton accumulates just below the halocline is due to the more favorable nutritive and light conditions, as well as the more stable conditions below the outflowing surface brackish layer.

Marine phytoplankton below the halocline is attractive food for herbivores in the lower reach of the estuary. According to RUIZ et al. (1998) microzooplankton grazing is more responsible for phytoplankton distribution along the salinity gradient in the outer than in inner zone of estuaries. Among heterotrophic plankton in the pelagic community, small copepods and larval stages of copepods (nauplii) accumulated in and below the halocline at N1. Seasonal variations of nauplii, copepodites and small adult copepods run parallel, with maximum development in winter (October–Februray)(Fig. 6). Naked ciliates (10 – 30 µm size fraction) provided two maxima; one in winter, and another in summer. Maximum abundance of ciliates was observed below the halocline in summer, and above the halocline in winter (Fig. 7).

Tab. 2. Seasonal variations of abundance (water column average) of dominant phytoplankton species in the middle reach of the Zrmanja Estuary (at Station N1), during 1981/82 and 1998/99.

	Syr pul 81/82	Syr pul 98/99	Bact del 81/82	Bact del 98/99	Lept dan 81/82	Lept dan 98/99	Pseudo 81/82	Pseudo 98/99	Gui stri 81/82	Gui stri 98/99	Thal 81/82	Thal 98/99	NANODINO 98/99
DEC	0		0		0		80		30		0		
JAN	0		0		320		0		600		135300		
MAR	210		1100		2200		640		113300		13600		
APR	0		4700		10		430		430		7800		
MAY	0		4793		640		0		0		7700		
JUN	0	0	300	900	0	12700	0	19000	0		15300	12900	0
JUL	0	0	300	0	0	2900	0	3000	0	0	1200	0	8500
AUG	0	3100	700	0	230	103500	130	6700	0	270	0	5300	1100
SEP	0	1000	0	0	9000	6300	430	5300	0	500	900	6400	16000
OCT	0	5100	1900	0	1800	1100	33230	1900	100	0	11900	27200	13800
NOV	42200		400		430		19800		130		32700		
DEC	0			100		0		6600		1320		1420	1200
JAN													
FEB	0			20		610		678000		28000		234600	2000
MAR	0			0		100		291000		28300		689000	0
APR													
MAY	0			0		0		10700		3600		414000	0
JUN	0			0		100		11400		0		11500	400

Legend: Syr pul	*Syracosphaera pulchra*
Bact del	*Bacteriastrum delicatulum*
Lept dan	*Leptocylindrus danicus*
Pseudo	*Pseudo-nitzschia sp.*
Gui stri	*Guinardia striata*
Thal	*Thalassiossira sp.* (small cells)
NANODINO	Small dinoflagellates (cells 10-20 μm)

Nanoplankton accumulation around the halocline is due to the accumulation and degradation of organic matter (ŽUTIĆ and LEGOVIĆ 1987), and physico-chemical transformations of organic matter (EISMA et al. 1991). At Station N1 nanoplanktonic dinoflagellates accumulated around the halocline (Fig. 8). These cells 2–10 μm in size probably belong to mixotrophs, participating in the processes of microbial transformation and degradation of organic matter. In summer, ciliates play an important role in the degradation of autochthonous organic matter below the halocline (Fig 7). On the other hand, in winter, during the increased river discharge, these microorganisms probably participated in regeneration of allochthonous organic matter, above the halocline.

Low concentrations of orthophosphates and nitrates (VILIČIĆ and STOJANOSKI 1987, VILIČIĆ et al. 1999, Tab 1), a phytoplankton abundance with the most frequent values between 10^5 and 10^6 cells l^{-1} (without any extremely high values), as well as an oxygenated and transparent water column, indicate a moderate eutrophication of the Zrmanja Estuary (VILIČIĆ 1989). Data on seasonal variations of nutrient concentrations are still not available. According to some personal observations, sporadic phytoplankton blooms in April usually induce short macroaggregate formations in the research area.

Tab. 3. List of phytoplankton and some heterotrophic species with abundance greater than 40 cells l^{-1} in the middle reach of the Zrmanja Estuary (at Station N1), during 1981/82 and 1998/99. Number of samples analyzed (n) = 127. Fr% – relative frequency, Max – maximum abundance (cells l^{-1}), Avg – average abundance (cells l^{-1}), Std – standard deviation. CHR – chrysophyceae, PRY – prymnesiophytes, P – penatae diatoms, C – centric diatoms, DIN – dinoflagellates, EUG – euglenophytes, CY – cyanobacteria, IC – incertae sedis

	Taxa	Fr%	Max	Avg	Std
PRY	*Acanthoica quatraspina* Lohm.	1.08	3200	76.2	333.6
PRY	*Anoplosolenia brasiliensis* (Lohm.) Gerl.	1.08	800	19.0	83.4
PRY	*Calyptrosphaera oblonga* Lohm.	1.08	27200	647.6	2835.8
CHR	*Dictyocha fibula* Ehrenb.	2.15	400	19.0	58.7
CHR	*Dictyocha speculum* Ehrenb.	3.23	6400	276.2	791.0
PRY	*Emiliania huxleyii* (Lohm.) Hay et Mohler	2.15	3200	114.3	371.4
PRY	*Ophiaster formosus* Gran	1.08	1200	28.6	125.1
PRY	*Rhabdosphaera tignifer* Schiller	4.30	1600	123.8	275.5
PRY	*Syracosphaera pulchra* Lohm.	5.38	123970	800.0	2163.1
CHR	*Dinobryon* sp.	23.66	251856	10073.7	26670.0
P	*Achnanthes longipes* Agardh	2.90	40	0.0	3.6
P	*Amphiprora decussata* (Grun.) Cleve	1.08	800	6.3	83.4
P	*Amphiprora sulcata* O'Meara	1.08	1600	12.6	166.8
P	*Amphiprora* sp.	4.30	800	18.9	130.0
C	*Asterolampra marylandica* Ehrenb.	1.08	400	3.1	41.7
C	*Asteromphalus flabellatus* (Breb.) Greville	1.08	400	3.1	41.7
C	*Asteromphalus heptactis* (Breb.) Ralfs.	2.53	80	1.6	10.6
C	*Bacteriastrum delicatulum* Cleve	27.43	9585	408.7	1405.4
C	*Bacteriastrum hyalinum* Lauder	2.95	4473	38.1	767.7
C	*Bacteriastrum mediterraneum* Pav.	5.90	5112	65.5	917.7
C	*Cerataulina pelagica* (Cleve) Hendey	40.61	17600	684.5	1787.3
C	*Chaetoceros affinis* Laud.	9.50	34500	612.0	4304.9
C	*Chaetoceros brevis* Schutt	7.35	65178	680.6	11488.5
C	*Chaetoceros compressus* Laud.	17.28	767969	8052.0	69126.8
C	*Chaetoceros convolutus* Castr.	9.50	3195	55.0	322.0
C	*Chaetoceros curvisetus* Cleve	13.10	222312	2012.6	19821.3
C	*Chaetoceros danicus* Cleve	13.79	8307	177.7	967.6
C	*Chaetoceros decipiens* Cleve	20.34	7668	212.5	921.8
C	*Chaetoceros diversus* Cleve	28.50	51120	1505.5	5969.7
C	*Chaetoceros lauderi* Ralfs	1.45	2556	20.1	438.4
C	*Chaetoceros perpusillus* Cleve	1.08	2400	24.6	260.4
C	*Chaetoceros rostratus* Laud.	2.95	2556	20.8	438.1
C	*Chaetoceros simplex* Ostenf.	10.31	46400	807.1	5168.0
C	*Chaetoceros socialis* Lauder	5.91	27200	1055.1	5311.4
C	*Chaetoceros tortissimus* Gran	10.30	749800	6258.2	128422.2
C	*Chaetoceros vixvisibilis* Schiller	15.24	97128	1480.3	9250.2
P	*Cocconeis scutellum* Ehrenb.	8.05	1600	29.7	171.0
C	*Coscinodiscus curvatulus* Grun.	1.45	1278	10.1	219.2
C	*Coscinodiscus gigas* Ehrenb.	4.40	80	1.3	16.4
C	*Coscinodiscus perforatus* Ehrenb.	4.40	80	1.9	23.0
C	*Dactyliosolen blavyanus* (Perag.)Hasle.	1.45	80	0.6	13.7
P	*Diatoma elongatum* (Lyngb.) Agardh.	3.23	12000	252.0	1636.1
P	*Diatoma* sp.	6.45	9600	192.1	1141.1
C	*Diploneis bombus* Ehrenb.	8.80	2556	39.7	478.7

Tab. 3. – continued

	Taxa	Fr%	Max	Avg	Std
C	*Ditylum brightwellii* (West) Grun.	6.99	10800	188.3	1320.6
C	*Eucampia cornuta* (Cleve) Grun.	2.69	800	22.4	148.0
P	*Eunotia* sp.	2.69	8000	135.4	1021.0
C	*Guinardia delicatula* (Castr.) Perag.	0.54	1200	9.4	125.1
C	*Guinardia flaccida* (Castr.) Perag.	19.54	5112	77.7	467.9
C	*Guinardia striata* (Stolter.) Hasle.	29.22	196812	5135.1	22774.2
C	*Hemiaulus hauckii* Grun.	17.01	10224	141.9	957.4
C	*Hemiaulus sinensis* Grev.	20.24	6400	232.8	897.8
C	*Leptocylindrus danicus* Cleve	30.39	124800	3532.2	16328.3
C	*Leptocylindrus minimus* Gran	1.61	6400	90.2	788.9
P	*Licmophora flabellata* (Carm.) Agardh.	1.45	2556	20.1	438.4
P	*Licmophora* sp.	9.68	7200	226.9	993.3
C	*Melosira nummuloides* (Dillw.) Agardh.	0.54	3200	25.2	333.6
P	*Meridion circulare* (Grev.) Ag.	5.38	3200	129.1	661.3
P	*Nitzschia incerta* Grun.	5.90	80	1.6	17.4
P	*Nitzschia longissima* (Breb.) Ralfs.	38.34	19200	615.0	1951.2
P	*Nitzschia lorenziana* Grun.	0.54	200	1.6	20.9
P	*Nitzschia* sp.	3.23	3200	69.3	437.3
P	*Pleurosigma angulatum* (Quekett) W.Sm.	3.49	400	6.3	45.9
P	*Pleurosigma* sp.	4.30	3200	38.7	341.6
P	*Pseudonitzschia* sp.	41.04	1748940	74390.0	243647.3
C	*Proboscia alata* (Brightw.) Sundstr.	28.78	11200	460.6	1472.2
C	*Rhizosolenia alata* f. *indica* (H.Perag.) Ostenf.	3.49	1600	15.8	145.3
P	*Rhizosolenia calcar-avis* Schultze	3.06	1600	28.3	176.6
C	*Rhizosolenia fragilissima* Berg.	30.65	5112	428.2	973.6
C	*Rhizosolenia hebetata* Bailey	1.08	6800	53.9	708.9
C	*Rhizosolenia imbricata* Brightw.	50.63	230040	7570.0	29272.3
C	*Rhizosolenia robusta* Norm.	1.99	18400	145.2	1639.2
P	*Rhoicosphenia curvata* (Kg.) Grun..	0.54	800	6.3	83.4
P	*Surirella* sp.	1.08	800	9.4	92.8
P	*Synedra* sp.	16.13	19200	825.5	2881.8
P	*Synedra acus* Kg.	0.54	3200	25.2	333.6
P	*Synedra longissima* Sm.	0.54	800	6.3	83.4
P	*Synedra toxoneides* Castr.	0.54	800	6.3	83.4
P	*Thalassionema nitzschioides* Grun.	63.52	173196	5863.8	20213.5
C	*Thalassiosira* sp. (small cells)	69.61	2057976	111750.5	300621.9
C	*Thalassiosira* sp.	3.76	679011	6673.2	72459.1
DIN	*Ceratium extensum* (Gourr.) Cleve	3.06	80	1.9	11.2
DIN	*Ceratium furca* (Efrenb.) Clap. et Lachm.	22.33	800	27.7	103.0
DIN	*Ceratium fusus* (Ehrenb.) Dujardin.	22.49	800	29.6	103.9
DIN	*Ceratium horridum* (Cleve) Gran	13.25	240	6.6	59.1
DIN	*Ceratium longirostrum* Gourr.	4.40	160	2.8	38.5
DIN	*Ceratium trichoceros* (Ehrenb.) Kof.	1.08	120	1.3	13.1
DIN	*Ceratium tripos* (Muell.) Nitzsch.	25.71	533	629	47.8
DIN	*Dinophysis acuminata* Clap. et Lachm.	0.54	40	0.3	4.2
DIN	*Dinophysis acuta* Ehrenb.	1.61	200	2.5	22.7
DIN	*Dinophysis caudata* Seville-Kent	2.95	321	3.2	56.3
DIN	*Dinophysis sphaerica* Stein	6.98	800	9.2	72.8
DIN	*Dinophysis* sp.	3.60	639	12.3	75.7

Tab. 3. – continued

	Taxa	Fr%	Max	Avg	Std
DIN	*Diplopsalis* "complex"	2.69	1200	18.7	151.2
DIN	*Dissodinium elegans* Pav. (= Pyrocystis fusiformis)	1.61	200	2.5	22.7
DIN	*Gonyaulax diacantha* (Meunier) Schiller	1.99	1278	13.2	119.0
DIN	*Gonyaulax polygramma* Stein	0.54	400	3.1	41.7
DIN	*Gonyaulax* sp.	1.08	1200	15.7	149.6
DIN	*Gymnodinium simplex* (Lohm.) Kof. et Sw.	50.25	157728	2991.8	14434.5
DIN	*Gymnodinium* sp.	6.99	4800	162.2	749.4
DIN	*Gyrodinium fusiformis* Kof. et Sw.	2.15	400	10	50
DIN	*Gyrodinium* sp.	8.06	12800	196.9	1377.2
IC	*Hermesinum adriaticum* Zach.	1.08	800	8.0	86.0
DIN	*Kofoidinium velelloides* Pav.	1.99	400	3.5	35.8
DIN	*Mesoporos perforatus* (Gran) Lillick	0.54	210	1.7	21.9
DIN	*Oxytoxum adriaticum* Schiller	0.54	200	1.6	20.9
DIN	*Oxytoxum milneri* Murr. et Whitt.	0.54	400	3.1	41.7
DIN	*Oxytoxum scolopax* Stein	1.45	160	1.3	27.4
DIN	*Oxytoxum* sp.	2.15	1600	26.8	198.7
DIN	*Protoperidinium crassipes* (Kof.) Bal.	2.95	40	0.6	9.6
DIN	*Protoperidinium depressum* (Bailey) Bal.	1.99	80	0.9	7.9
DIN	*Protoperidinium divergens* (Ehrenb.) Bal.	9.34	640	8.5	58.9
DIN	*Protoperidinium globulus* (Stein) Bal.	0.54	800	6.3	83.4
DIN	*Protoperidinium oceanicum* (Vanhoeffen) Bal.	1.45	80	0.6	13.7
DIN	*Protoperidinium steinii* (Joerg.) Bal.	9.50	1280	18.1	121.1
DIN	*Protoperidinium tubum* (Schiller) Bal.	6.44	640	14.2	87.7
DIN	*Protoperidinium* sp.	4.84	1200	33.7	173.1
DIN	*Prorocentrum micans* Ehrenb.	44.63	109392	2749.2	12951.3
DIN	*Prorocentrum minimum* (Pav.) Schiller	13.82	70000	1646.9	8512.5
DIN	*Prorocentrum scutellum* Schroeder	11.67	2400	299.0	535.6
DIN	*Prorocentrum triestinum* Schiller	6.98	10224	126.6	949.0
DIN	*Pseliodinium vaubanii* Sournia	6.01	2400	25.2	217.1
DIN	*Pyrophacus horologicum* Stein	5.90	639	6.0	109.6
DIN	*Scrippsiella* spp. (?)	7.79	800	39.9	145.6
EUG	*Eutreptia lanowii* Steuer	6.44	1917	27.1	192.5
CY	*Merismopedia* sp.	2.15	27200	1161.9	3106.9

In the middle reach of the Zrmanja Estuary, the halocline divided two phytoplankton communities. Freshwater phytoplankton is transported to the estuary by the riverine water from the small freshwater accumulation in front of the estuary. As compared to data in the upper reach of the estuary, freshwater phytoplankton above the halocline is less abundant at Station N1. This might be due to the sinking of freshwater phytoplankton and decaying of cells along the halocline in the upper reach of the estuary, similarly as in the Krka Estuary (VILIČIĆ et al. 1989, LEGOVIĆ et al. 1996). Instead of freshwater phytoplankton above the halocline at N1, the abundant brackish diatom *Thalassiosira* sp. was detected. Marine phytoplankton accumulated below the halocline.

Research should be continued in the direction of defining the budget of nutrients and allochthonous organic matter, current system, limiting growth factors, as well as the seasonal production and regeneration processes in the estuary.

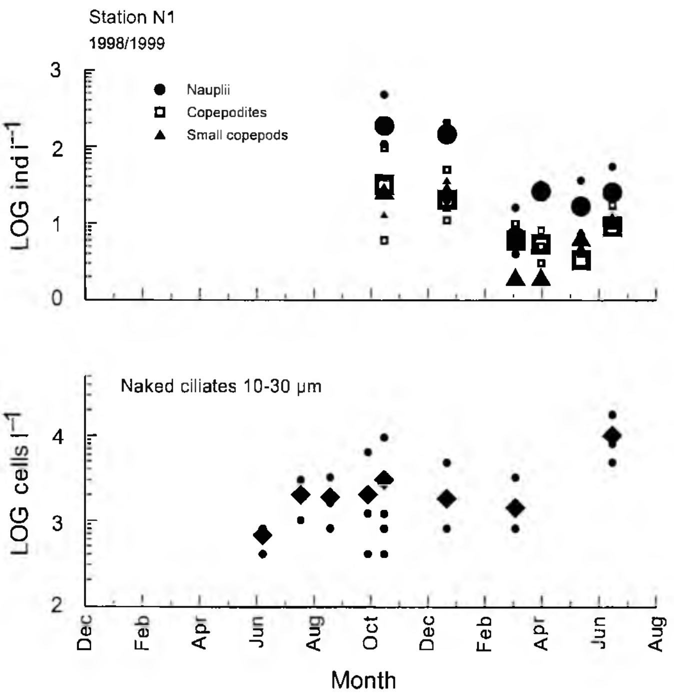

Fig. 6. Seasonal variations of microzooplankton in the lower reach of the Zrmanja Estuary (Station N1), during 1998/989. Bigger symbols indicate water column average.

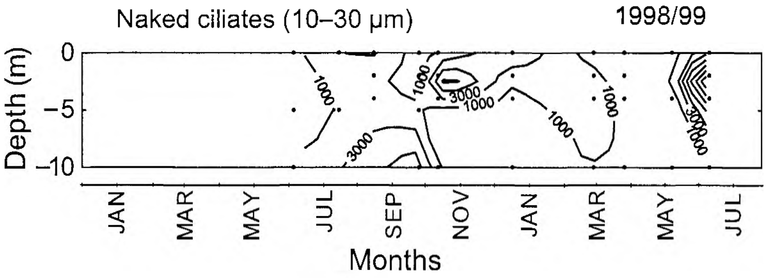

Fig. 7. Distribution of the abundance (cells l^{-1}) of naked ciliates at Station N1 during 1998/99.

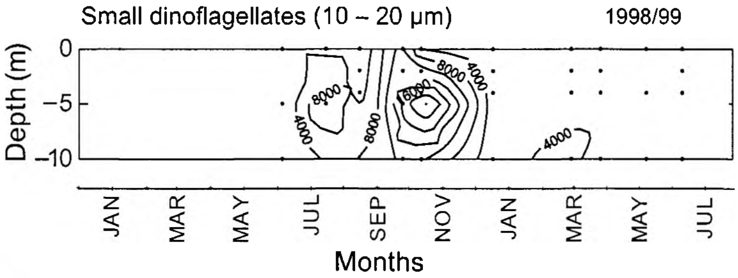

Fig. 8. Distribution of nanoplanktonic dinoflagellates at Station N1 during 1998/99.

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