NAT. CROAT. | VOL. 7 | No 4 | 307–319 | ZAGREB | December 31, 1998

ISSN 1330-0520
UDK 574.583:556.54:581.93/.54(497.5)

TAXONOMIC COMPOSITION AND SEASONAL DISTRIBUTION OF MICROPHYTOPLANKTON IN THE KRKA RIVER ESTUARY

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Bakran-Petricioli, T., Petricioli, D. & Viličić, D.: Taxonomic composition and seasonal distribution of microphytoplankton in the Krka River estuary, Nat. Croat., Vol. 7, No. 4., 307–319, 1998, Zagreb

Microphytoplankton taxonomic composition and cell density distribution were investigated at three representative stations along the highly stratified Krka River estuary on the eastern Adriatic coast. Samples were collected at approximately monthly intervals from March 1988 to April 1989. One hundred thirty six taxa were determined by light microscopy: 108 marine species (1 chrysophyte, 5 prymnesiophytes, 55 diatoms, 1 euglenophyte, 46 dinoflagellates) and 28 freshwater species (1 chrysophyte, 21 diatoms, 1 dinoflagellate, 3 chlorophytes, 2 cyanophytes). The seasonal distribution of microphytoplankton cell densities is influenced by the freshwater inflow through the Krka River and the ecological properties of the karstic salt-wedge-stratified estuary. Anthropogenic influence is notable in the lower reach of the estuary, around Šibenik.

Key words: Stratified estuary, phytoplankton, taxonomy, distribution, Adriatic Sea

Bakran-Petricioli, T., Petricioli, D. & Viličić, D.: Taksonomski sastav i sezonska raspodjela mikrofitoplanktona u estuariju rijeke Krke, Nat. Croat., Vol. 7, No. 4., 307–319, 1998, Zagreb

U radu je prikazan taksonomski sastav i raspodjela gustoće stanica mikrofitoplanktona na tri reprezentativne postaje u visoko stratificiranom estuariju rijeke Krke. Uzorci su sakupljeni u mjesečnim intervalima od ožujka 1988. do travnja 1989. godine. Svjetlosnim je mikroskopom određeno stotinu trideset i šest mikrofitoplanktonskih vrsta: 108 morskih (1 krizoficeja, 5 primneziophyceja, 55 dijatomeja, 1 euglenoficeja, 46 dinoflagelata) i 28 slatkovodnih vrsta (1 krizoficeja, 21 dijatomeja, 1 dinoflagelat, 3 kloroficeje, 2 cijanoficeje). Na sezonsku raspodjelu gustoće stanica mikrofitoplanktona utječe dotok vode rijeke Krke i ekološki uvjeti u estuariju. Utjecaj čovjeka vidljiv je u donjem dijelu estuarija, oko Šibenika.

Ključne riječi: Stratificirani estuarij, fitoplankton, taksonomija, distribucija, Jadransko more

INTRODUCTION

Phytoplankton is an important component contributing to the biogeochemical processes in a salt-wedge-stratified estuary such as the Krka River estuary on the eastern coast of Adriatic Sea. The sinking and decomposition of freshwater phytoplankton which develops in Visovac Lake and flows over the calcium tuffa barriers into the estuary, can cause eutrophication in the upper reaches of the estuary (LEGOVIĆ *et al.*, 1994, LEGOVIĆ *et al.*, 1996), occasional hypoxic/anoxic conditions and benthic mortality (PETRICIOLI *et al.*, 1996). The majority of the freshwater phytoplankton accumulates at the brackish-seawater interface (BSI), dies and decomposes in the upper and middle reaches of the estuary, and becomes the main source of dissolved and particulate organic matter (VILIČIĆ *et al.*, 1989). In the middle reach of the estuary (Prokljan), in autumn, marine phytoplankton blooms can contribute to hypoxia and subsequent benthic mortality (PETRICIOLI *et al.*, 1990; LEGOVIĆ *et al.*, 1991a).

Although the importance of certain taxa of the phytoplankton in the biogeochemical processes in Krka estuary has been discussed in the mentioned papers, the taxonomic composition has not been presented. VILIČIĆ *et al.* (1990) showed seasonal distribution and taxonomic composition of microphytoplankton for only one station in the middle reach of the estuary, in Prokljan. In this paper we present microphytoplankton taxonomic composition and seasonal cell density distribution at three representative stations along the Krka estuary. Ecological conditions in the highly stratified estuary differ from those in the coastal and offshore waters of the Adriatic Sea. Data about the taxonomic composition of phytoplankton in the Adriatic are scarce (VILIČIĆ, 1998). The aim of this paper is to present a check-list of microphytoplankton in the Krka estuary.

Scientific research into this area was interrupted in 1991by the war. Only recently has it been renewed, although (due to economic circumstances) it is now not as intense as it was before the war.

STUDY AREA

The estuary of the karstic Krka River is located in the central part of the eastern Adriatic coast (Fig. 1). This is a typical salt-wedge-stratified estuary. The largest part of its freshwater inflow comes from Visovac Lake over the calcium tuffa barriers of Skradinski buk waterfalls. Seawater enters the estuary as a compensating bottom current. The annual nutrient inflow into the estuary is considered to be low: 55×10^{6} mol N, 1.8×10^{6} mol P and $36{,}4\times10^{6}$ mol SiO_4 (GRŽETIĆ *et al.*, 1991). Growth of phytoplankton in the estuary is primarily P-limited except for the Šibenik harbour area which is under strong anthropogenic influence (LEGOVIĆ *et al.*, 1994). The residence time of the lower, seawater layer in the estuary is estimated to be long: from 50 to 100 days in winter and up to 250 days in summer (LEGOVIĆ, 1991).

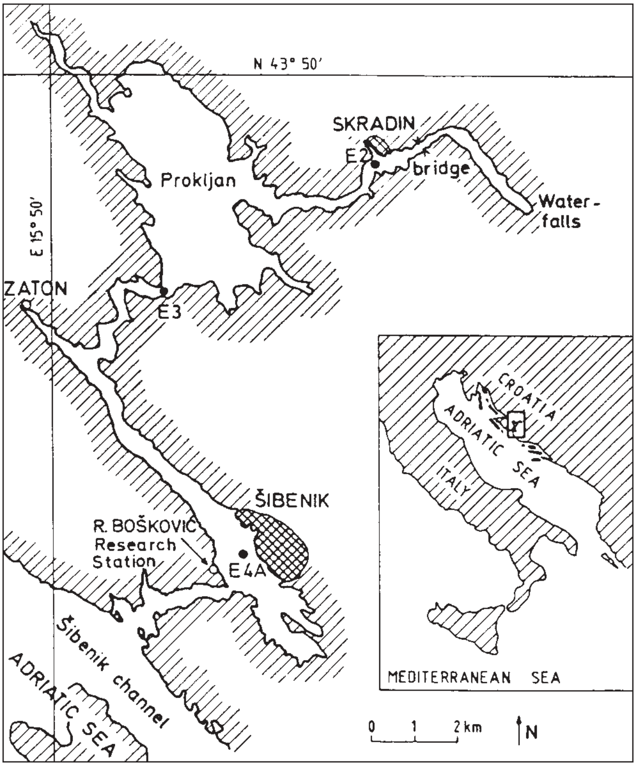

Fig. 1. Location of sampling stations (E2, E3, E4A) in the Krka River estuary (central part of the eastern coast of the Adriatic Sea).

METHODS

Water samples for phytoplankton cell counts and taxonomic determination were collected by SCUBA divers with horizontally placed Niskin bottles (5 l, General Oceanics) at approximately monthly intervals from March 1988 to April 1989. Three sampling stations were chosen: E2 (depth 8 m) – representing the upper reach of the estuary; E3 (depth 23 m) – representing the middle reach of the estuary; E4A (depth 40 m) – representing the lower reach of the estuary (Fig. 1). At each station, samples were taken at the surface; 0.5 m above the visible brackish-seawater interface; at the brackish-seawater interface (BSI); 0.5 m below the BSI; and in the seawater layer at 6.0 m and at 20.0 m (at E3 and E4A). Samples were preserved in a 2% (final concentration) neutralised formaldehyde solution. Phytoplankton cell counts were obtained by the inverted microscope method (UTHERMÖHL, 1958). Subsamples of 25 ml were analysed microscopically after sedimentation for 24 h. Determination of species was done under 200 × magnification.

Temperature (0.2C) and salinity (0.65 PSU) were measured with a YSI 53 probe.

RESULTS AND DISCUSSION

At three sampling stations: E2, E3 and E4A in the Krka River estuary, 136 taxa of microphytoplankton were identified: 108 marine species (1 chrysophyte, 5 prymnesiophytes, 55 diatoms, 1 euglenophyte, 46 dinoflagellates) and 28 freshwater species (1 chrysophyte, 21 diatoms, 1 dinoflagellate, 3 chlorophytes, 2 cyanophytes).

Frequency of findings and maximum population densities of each species, as well as sampling station, depth and date when maximum population density was recorded, are shown in Table 1. The most frequent (F>20%) marine diatoms were: *Cerataulina pelagica*, *Leptocylindrus danicus*, *Licmophora* sp., *Pseudonitzschia* spp., *Tha-*

Table 1. List of microphytoplankton species in the Krka River estuary in the period from March 1988 to April 1989. F – frequency of findings; F(%) – relative frequency of findings; Max – maximum of population density (cells l^{-1}); Stat – sampling station; $D_{(max)}$ – depth in meters where population density maximum was recorded; $Date_{(max)}$ – date when maximum of population density was recorded.

Total number of samples	182	100(%)				
MARINE SPECIES	F	F(%)	Max	Stat	$D_{(max)}$	$Date_{(max)}$
CHRYSOPHYCEAE						
Dictyocha fibula Ehrenb.	21	11.5	10224	E3	6	Mar-88
PRYMNESIOPHYCEAE						
Anoplosolenia brasiliensis (Lohm.) Gerl.	23	12.6	18220	E4A	2	Sep-88
Calciosolenia murrayii Gran	8	4.4	7328	E4A	20	Aug-88
Ophiaster hydroideus (Gran)	1	0.5	11840	E2	6	Sep-88
Rhabdosphaera tignifer Schiller	32	17.6	14576	E4A	1	Oct-88
Syracosphaera pulchra Lohm.	58	31.9	38340	E2	3.4	May-88
BACILLARIOPHYCEAE						
Achnanthes brevipes Agardh	14	7.7	20448	E4A	20	May-88
Amphiprora decussata (Grun.) Cleve	1	0.5	40	E3	2	Jun-88
Amphora ostrearia Breb.	8	4.4	5112	E3	2	Apr-88
Asteromphalus heptactis (Breb.) Ralfs	19	10.4	10932	E4A	3	Sep-88
Bacteriastrum delicatulum Cleve	16	8.8	66456	E2	4.5	Mar-88
Bacteriastrum hyalinum Lauder	14	7.7	102032	E4A	0.5	Mar-89
Bacteriastrum mediterraneum Pav.	5	2.7	7328	E2	2	Dec-88
Bacteriastrum sp.	1	0.5	20448	E3	3.4	Mar-88
Cerataulina pelagica (Cleve) Hendey	37	20.3	211864	E4A	3	Oct-88
Chaetoceros affinis Laud.	16	8.8	30672	E2	6	Apr-88
Chaetoceros convolutus Castr.	23	12.6	123896	E3	1	Dec-88
Chaetoceros curvisetus Cleve	23	12.6	98388	E4A	3	Dec-88
Chaetoceros danicus Cleve	5	2.7	5112	E2	4.5	Mar-88
Chaetoceros decipiens Cleve	24	13.2	125244	E4A	6	Mar-88
Chaetoceros delicatulum Ostenf.	2	1.1	17892	E2	3.5	Apr-88
Chaetoceros didymus Ehrenb.	9	4.9	153084	E4A	3	Dec-88

Total number of samples	182	100(%)				
MARINE SPECIES	F	F(%)	Max	Stat	$D_{(max)}$	$Date_{(max)}$
Chaetoceros diversus Cleve	8	4.4	14576	E4A	3	Dec-88
Chaetoceros laciniosus Schuett	1	0.5	3195	E2	2.5	Mar-88
Chaetoceros lorenzianus Grun.	7	3.8	38340	E3	20	Mar-88
Chaetoceros rostratus Laud.	1	0.5	1368	E3	20	Oct-88
Chaetoceros simplex Ostenf.	2	1.1	10224	E2	2	Jun-88
Chaetoceros tetrastichon Cleve	1	0.5	80	E3	2	Sep-88
Chaetoceros vixvisibilis Schiller	2	1.1	186588	E4A	20	Apr-88
Chaetoceros sp.	10	5.5	54660	E4A	3.7	Aug-88
Cocconeis scutellum Ehrenb.	35	19.2	10224	E2	0.5	Apr-88
Coscinodiscus perforatus Ehrenb.	23	12.6	10224	E2	0.5	Jun-88
Coscinodiscus stellaris Roper	1	0.5	321	E3	20	Apr-88
Diploneis sp.	20	11	5112	E3	6	Mar-88
Grammatophora sp.	8	4.4	3556	E2	0.5	Jun-88
Guinardia flaccida (Castr.) Perag.	15	8.2	5112	E4A	20	Jun-88
Gyrosigma sp.	19	10.4	7668	E4A	20	Apr-88
Hemiaulus hauckii Grun.	30	16.5	33228	E3	4.4	Mar-88
Hemiaulus sinensis Grev.	6	3.3	2556	E2	3.4	Mar-88
Leptocylindrus adriaticus Schroeder	20	11	258724	E4A	0.8	Jan-89
Leptocylindrus danicus Cleve	55	30.2	284232	E4A	3	Dec-88
Leptocylindrus minimus Gran	8	4.4	295164	E4A	6	Jan-89
Licmophora sp.	43	23.6	12780	E3	6	Jun-88
Melosira moniliformis (Mull.) Agardh.	1	0.5	40	E2	3.4	Mar-88
Melosira nummuloides Agardh.	5	2.7	2556	E3	0.5	Mar-88
Nitzschia longissima (Breb.) Ralfs	11	6	32796	E4A	6	Dec-88
Orthoneis sp.	18	9.9	12780	E2	0.5	Jun-88
Pleurosigma angulatum (Quekett) W. Smith	5	2.7	2733	E3	6	Jan-89
Pseudonitzschia spp.	61	33.5	255600	E4A	4.5	Mar-88
Rhizosolenia alata f. gracillima (Cleve) Grun.	21	11.5	15336	E4A	2.5	Jun-88
Rhizosolenia calcar-avis Schultze	14	7.7	3644	E4A	6	Apr-89
Rhizosolenia delicatula Cleve	1	0.5	25560	E3	20	Mar-88
Rhizosolenia fragilissima Berg.	2	1.1	2730	E2	1	Sep-88
Rhizosolenia imbricata Brightw.	8	4.4	7668	E4A	20	Mar-88
Rhizosolenia stolterfothii Perag.	11	6	17892	E4A	20	Mar-88
Rhizosolenia sp.	1	0.5	5112	E2	6	Apr-88
Skeletonema costatum (Grev.) Cleve	23	12.6	1019844	E2	4.5	Mar-88
Striatella unipunctata (Lyngb.) Agardh.	4	2.2	8960	E4A	6	Mar-88
Surirella sp.	1	0.5	80	E2	3.4	Mar-88
Thalassionema nitzschioides Grun.	96	52.7	243462	E4A	2.5	Apr-88
Thalassiosira sp.	45	24.7	76524	E4A	1	Dec-88
EUGLENOPHYCEAE						
Eutreptia lanowii Steuer	22	12.1	427259	E4A	3.2	Aug-88

Total number of samples	182	100(%)				
MARINE SPECIES	F	F(%)	Max	Stat	$D_{(max)}$	$Date_{(max)}$
DINOPHYCEAE + DESMOPHYCEAE						
Ebria sp.	18	9.9	14576	E4A	6	Dec-88
Ceratium buceros Zacharias	1	0.5	321	E4A	3.5	Mar-88
Ceratium candelabrum Ehrenb.	1	0.5	80	E2	1	Dec-88
Ceratium furca (Ehrenb.) Clap. et Lachm.	35	19.2	3644	E3	1	Oct-88
Ceratium fusus (Ehrenb.) Dujardin	22	12.1	2556	E4A	2.5	Mar-88
Ceratium longirostrum Gourr.	9	4.9	963	E3	6	May-88
Ceratium massiliense (Gourr.) Karsten	2	1.1	2556	E3	6	May-88
Ceratium trichoceros (Ehrenb.) Kof.	5	2.7	642	E3	20	Mar-88
Ceratium tripos (Muell.) Nitzsch	62	34.1	21864	E2	2.4	Apr-89
Ceratium sp.	1	0.5	40	E4A	20	Jun-88
Dinophysis acuminata Clap. et Lachm.	22	12.1	10932	E2	1.5	Oct-88
Dinophysis acuta Ehrenb.	1	0.5	40	E3	3.4	Mar-88
Dinophysis caudata Seville-Kent	16	8.8	2730	E3	6	Sep-88
Dinophysis fortii Pav.	9	4.9	5433	E3	3.5	May-88
Dinophysis rotundata (Clap. et Lachm.) Abe	5	2.7	1822	E2	1	Dec-88
Dinophysis tripos Gourr.	8	4.4	2733	E3	6	Dec-88
Dinophysis sp.	1	0.5	321	E3	20	Apr-88
Gonyaulax digitale (Pouchet) Kof.	3	1.6	20448	E2	3.4	Mar-88
Gonyaulax hyalina Ostenf. et Schm.	2	1.1	631	E3	2.5	Jun-88
Gonyaulax polyedra Stein	12	6.6	29152	E3	6	Oct-88
Gonyaulax polygramma Stein	2	1.1	631	E3	2.5	Jun-88
Gonyaulax sp.	32	17.6	23004	E2	2.5	Jun-88
Gymnodinium "simplex" (Lohm.) Kof. et Sw.	29	15.9	306720	E3	2.5	Jun-88
Gymnodinium sp.	10	5.5	7300	E2	1.5	Sep-88
Gyrodinium sp.	21	11.5	29152	E2	1.5	Oct-88
Noctiluca scintilans (Macartney) Ehrenb.	2	1.1	80	E4A	6	Mar-88
Oxytoxum sceptrum (Stein) Schroeder	1	0.5	160	E3	6	Apr-88
Oxytoxum scolopax Stein	17	9.3	7328	E4A	3	Oct-88
Podolampas elegans Schuett	4	2.2	640	E3	4.4	Mar-88
Podolampas palmipes Stein	1	0.5	40	E3	6	Sep-88
Podolampas sp.	1	0.5	456	E3	3	Oct-88
Prorocentrum micans Ehrenb.	87	47.8	218640	E3	1	Jan-89
Prorocentrum minimum (Pav.) Schiller	10	5.5	36440	E2	3	Apr-89
Prorocentrum redfieldii Bursa	119	65.4	1741832	E2	7	Apr-89
Prorocentrum scutellum Schroeder	46	25.3	163980	E3	0.5	Oct-88
Protoperidinium crassipes (Kof.) Bal.	14	7.7	15336	E3	2	Jun-88
Protoperidinium depressum (Bailey) Bal.	1	0.5	321	E2	1.4	May-88
Protoperidinium divergens (Ehrenb.) Bal.	23	12.6	10932	E3	3	Mar-89
Protoperidinium globulus (Stein) Bal.	10	5.5	7668	E3	6	Mar-88
Protoperidinium leonis (Pav.) Bal.	7	3.8	5112	E3	2.5	May-88

Total number of samples	182	100(%)				
MARINE SPECIES	F	F(%)	Max	Stat	$D_{(max)}$	$Date_{(max)}$
Protoperidinium steinii (Joerg.) Bal.	14	7.7	30672	E2	2.5	Jun-88
Protoperidinium tubum (Schiller) Bal.	67	36.8	25600	E2	3.5	Apr-88
Protoperidinium sp.	8	4.4	3644	E3	2	Mar-89
Pseliodinium vaubanii Sournia	15	8.2	1822	E3	2.7	Apr-89
Scrippsiella sp.	3	1.6	10930	E2	1.5	Sep-88
Spatulodinium pseudonoctiluca (Pouchet) Cachon et Cachon	2	1.1	80	E2	2.4	Apr-89
FRESHWATER SPECIES	F	F(%)	MAX	Stat	$D_{(max)}$	$Date_{(max)}$
CHRYSOPHYCEAE						
Dinobryon sertularia Ehrenb.	35	19.2	746352	E3	1.5	Jun-88
BACILLARIOPHYCEAE						
Achnanthes nodosa A. Cl.	1	0.5	2556	E4A	0.5	Jun-88
Achnanthes sp.	19	10.4	7668	E2	0.5	Apr-88
Asterionella formosa Hassall	84	46.1	115020	E3	2	Apr-88
Cocconeis placentula Ehrenb.	6	3.3	5112	E4A	0.5	Apr-88
Cocconeis sp.	3	1.6	3644	E2	0.5	Jan-89
Cyclotella ocellata Pantocsek	111	61	702900	E2	0.5	Apr-88
Cyclotella sp.	96	52.7	1814105	E3	2.4	Mar-88
Cymbella sp.	38	20.9	23004	E3	2	Apr-88
Diatoma elongatum (Lyngb.) Agardh.	17	9.3	153360	E3	0.5	Mar-88
Diatoma vulgare Bory	7	3.8	10932	E2	2	Dec-88
Fragillaria capucina Desm.	3	1.6	30672	E2	3	Apr-88
Fragillaria crotonensis Kitt.	27	14.8	63900	E3	3.4	Mar-88
Gomphonema sp.	6	3.3	1280	E3	2.4	Mar-88
Melosira sp.	1	0.5	320	E2	6	Apr-88
Melosira varians Agardh.	9	4.9	7296	E4A	0.5	Jan-89
Meridion circulare Agardh.	2	1.1	15336	E2	0.5	Mar-88
Rhoicosphaenia curvata (Kuetz.) Grun.	1	0.5	160	E3	0.5	May-88
Rhoicosphaenia sp.	16	8.8	5112	E3	0.5	Apr-88
Synedra acus Kuetz.	118	64.8	3062088	E3	2	Jun-88
Synedra sp.	24	13.2	10930	E2	1	Sep-88
Synedra ulna (Nitzsch) Ehrenb.	2	1.1	1262	E3	1.5	Jun-88
DINOPHYCEAE						
Ceratium hirundinella (O.F. Muell.) Schrank	7	3.8	912	E2	1.5	Dec-88
CHLOROPHYCEAE						
Ankistrodesmus sp.	2	1.1	2556	E2	3.4	Mar-88
Scenedesmus acuminatus (Lagerh.) Chod.	1	0.5	1824	E2	1.3	Aug-88
Scenedesmus quadricauda (Turp.) Breb.	3	1.6	2556	E4A	0.5	Mar-88
CYANOPHYCEAE						
Merismopedia sp.	2	1.1	30672	E2	2.4	May-88
Oscillatoria sp.	3	1.6	14400	E2	3	Apr-88

lassionema nitzschioides, *Thalassiosira* sp. The most frequent marine dinoflagellates were: *Ceratium tripos*, *Prorocentrum micans*, *Prorocentrum redfieldii*, *Prorocentrum scutellum*, *Protoperidinium tubum*. Among coccolithophorids *Syracosphaera pulchra* was found in more than 20% of samples. Among freshwater species, the diatoms *Asterionella formosa*, *Cyclotella ocellata*, *Cyclotella* sp., *Cymbella* sp. and *Synedra acus* were present in more than 20% of samples while the freshwater chrysophyte *Dinobryon sertularia* was present in 19.2% of samples.

Skeletonema costatum and *Prorocentrum redfieldii* were the most abundant marine species with cell density maxima of 1.2×10^6 cells l^{-1} in March 1988 and 1.7×10^6 cells l^{-1} in April 1989, respectively. The most abundant freshwater species were *Dinobryon sertularia* (7×10^5 cells l^{-1} in June 1988), *Cyclotella ocellata* (7×10^5 cells l^{-1} in April 1988), *Cyclotella* sp. (1.8×10^6 cells l^{-1} in March 1988) and *Synedra acus* (3×10^6 cells l^{-1} in June 1988).

The microphytoplankton genera with the greatest number of species were two diatom genera *Chaetoceros* (15 species) and *Rhizosolenia* (7 species), and three dinoflagellates *Ceratium* (9 species), *Dinophysis* (7 species) and *Protoperidinium* (7 species). These genera also provided a great number of species in the offshore southern Adriatic (VILIČIĆ, 1998).

In the Krka estuary we found a high total microphytoplankton density, up to 1.7×10^6 cells l^{-1} for marine phytoplankton, which is approximately $20\times$ higher than the maximum recorded from open southern Adriatic samples (VILIČIĆ, 1998). Even higher total cell densities (up to 4×10^6 cells l^{-1}) were recorded for freshwater microphytoplankton originating from the freshwater Visovac Lake.

In the upper reach of the estuary the brackish upper layer was more pronounced throughout the year (Fig. 2). This layer became thinner at station E4A (lower reach of the estuary, Fig. 4). A subsurface temperature maximum was recorded during summer 1988 at stations E2 (Fig. 2) and E3 (Fig. 3). At station E4A it was not recorded (Fig. 4), due to deeper water at that station (40 m) and the influence of incoming compensating current from the surrounding coastal sea. That temperature maximum contributed to high water column stability/stratification and even to benthic mortality in the central part of the estuary, in Prokljan, later in the year, in October 1988 (PETRICIOLI *et al.*, 1990; LEGOVIĆ *et al.*, 1991a).

Freshwater microphytoplankton density along the estuary (FWMICRO on Fig. 2, Fig. 3 and Fig. 4) decreased downstream towards station E4A, where freshwater phytoplankton was present only in the upper brackish layer and at much lower densities than at stations E2 and E3. In March, April and June 1988, Krka River inflow into the estuary was high (up to 100 m^3 s^{-1}; LEGOVIĆ, 1991). This high freshwater inflow carried freshwater phytoplankton all the way downstream to station E4A (Figs. 2–4). In contrast, when inflow into the estuary was low the majority of the freshwater phytoplankton sank to the bottom even before reaching Prokljan (LEGOVIĆ *et al.*, 1996; PETRICIOLI *et al.*, 1996).

The most pronounced total marine phytoplankton cell density maxima were found at station E2 during the springs of 1988 and 1989 (Fig. 2). Another lower maximum was also observed at the same station in June 1988.

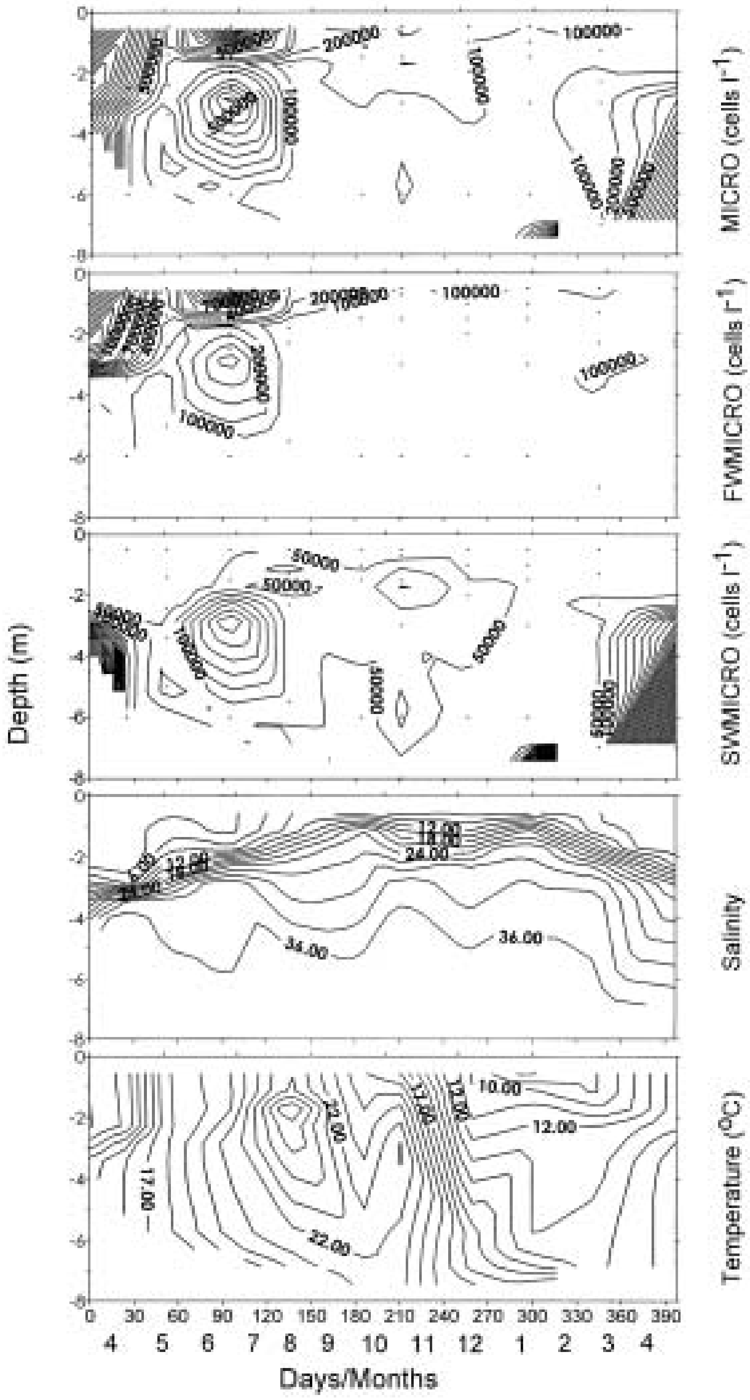

Fig. 2. Isopleth diagrams for microphytoplankton cell density distribution, salinity and temperature at sampling station E2 in the Krka estuary during the research period (from March 1988 to April 1989). MICRO – cell density distribution of total microphytoplankton; FWMICRO – cell density distribution of freshwater microphytoplankton; SWMICRO – cell density distribution of seawater microphytoplankton.

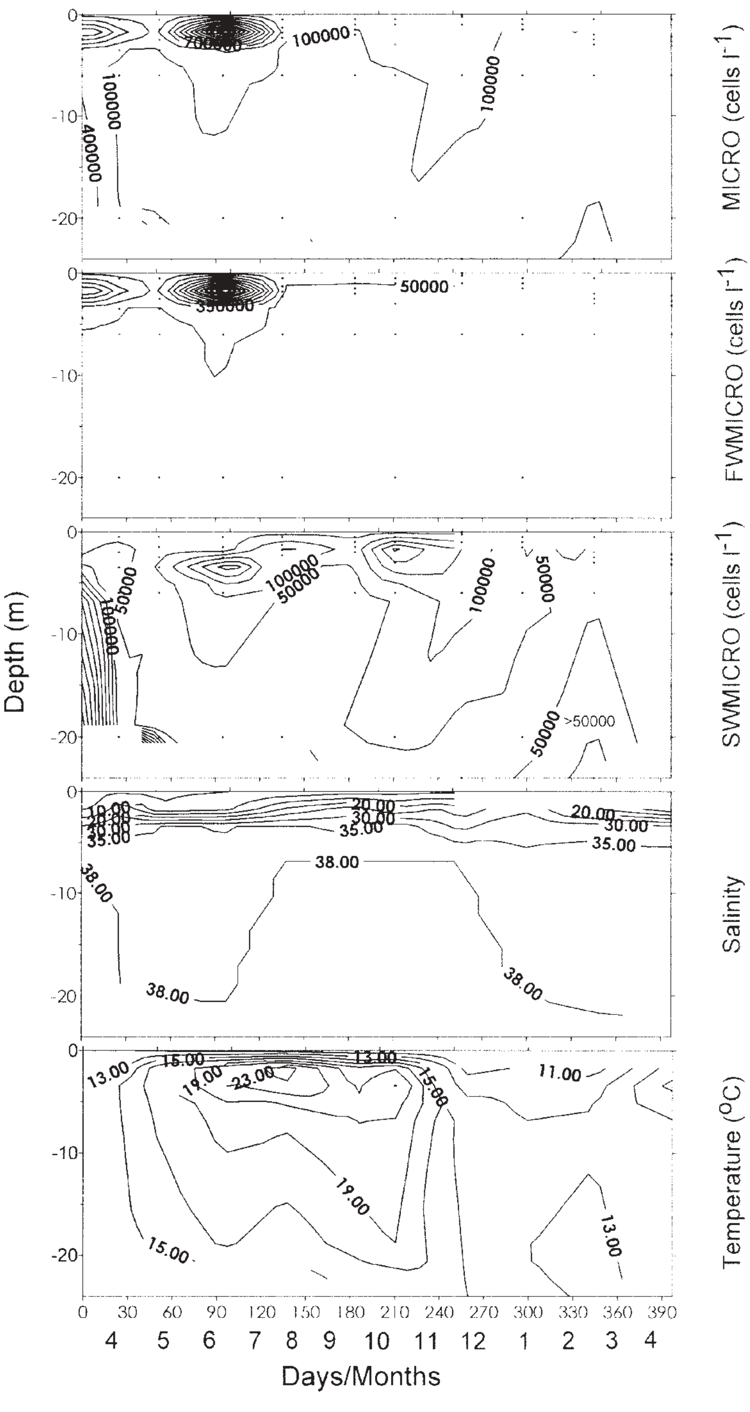

Fig. 3. Isopleth diagrams for microphytoplankton population density distribution, salinity and temperature at sampling station E3 in Krka estuary during the research period (from March 1988 to April 1989). MICRO – cell density distribution of total microphytoplankton; FWMICRO – cell density distribution of freshwater microphytoplankton; SWMICRO – cell density distribution of seawater microphytoplankton.

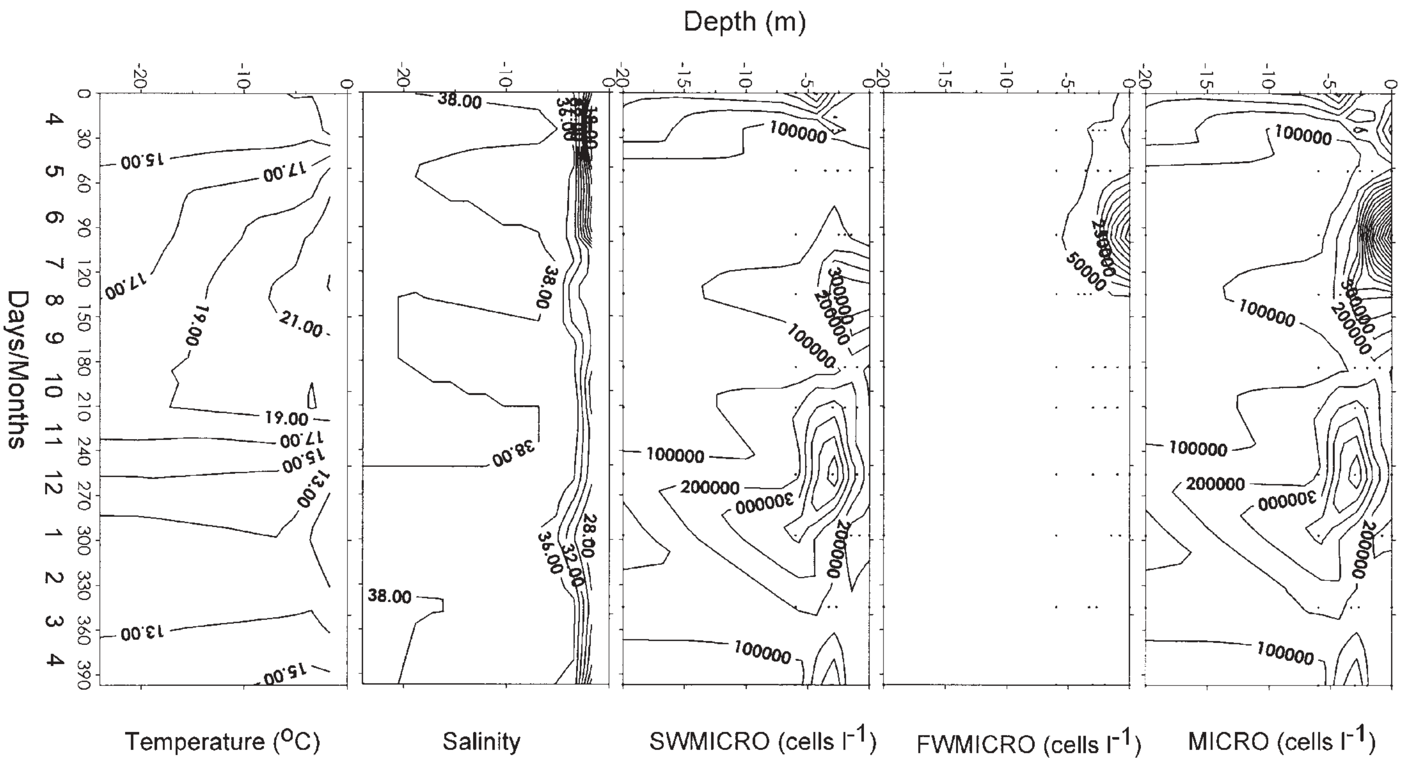

Fig. 4. Isopleth diagrams for microphytoplankton population density distribution, salinity and temperature at sampling station E4A in the Krka estuary during the research period (from March 1988 to April 1989). MICRO – cell density distribution of total microphytoplankton; FWMICRO – cell density distribution of freshwater microphytoplankton; SWMICRO – cell density distribution of seawater microphytoplankton.

At station E3 cell density maxima of marine microphytoplankton were recorded in spring 1988, during early summer 1988 and in autumn 1988 (Fig. 3). A subsurface bloom of *Gonyaulax polyedra* (6×10^5 cells l^{-1}) which was recorded in the central part of Prokljan in October 1988 (LEGOVIĆ *et al.*, 1991b) extended towards station E3, with a population density of up to 3×10^4 cells l^{-1}. This may be due to slow seawater movement (nearly stagnant marine layer) in the wider part of the estuary (Prokljan). LEGOVIĆ *et al*. (1994) pointed out that such events in the upper reach of the estuary were not the consequence of local anthropogenic nutrient sources.

The anthropogenic influence from the city of Šibenik is evident at station E4A, where cell density values of marine microphytoplankton were permanently high, with peaks in spring (March-April 1988) and summer (August 1988).

In conclusion, these results indicate that in the research period, the seasonal distribution of microphytoplankton cell densities was influenced by the freshwater inflow through the Krka River and the ecological properties of the karstic salt-wedge-stratified estuary. In addition, anthropogenic influence was notable in the lower reach of the estuary, around Šibenik.

ACKNOWLEDGEMENTS

This work was part of an extensive research project (MED POL – Phase II) undertaken by the Centre for Marine Research of Ruđer Bošković Institute Zagreb under the co-ordination of Dr. Vera Žutić.

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