Population structure and abundance of zooplankton along the Krka river estuary in spring 2006

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The zooplankton assemblage was investigated in April 2006 at 9 stations along, and in front of, the highly stratified salt-wedge Krka river estuary, using 53- and 125-µm mesh Nansen nets. Tintinnids, copepods and their developmental stages and mollusc larvae dominated the zooplankton community, with 28 tintinnid and 41 copepod taxa recorded in the investigated area. Both tintinnid and copepod communities showed a general decrease in abundance and increase in species number from the head to the mouth of estuary, with a clear dominance of estuarine-neritic species. The most abundant tintinnids were Tintinnopsis campanula *and* Favella ehrenbergii. *Small cyclopoid copepod* Oithona nana *dominated in the upper reaches, presumably feeding opportunistically on abundant organic matter accumulated at the permanent halocline. The contribution of calanoids intensified towards marine stations, except in the eutrophicated Šibenik harbour area in the middle reaches, where cyclopoid* Oithona nana *again proliferated. An assessment of the sampling performances of the 53- and 125-µm nets and data on zooplankton population structure indicated that the 125-µm mesh size plankton net in combination with Niskin bottles would give the optimal insight into the ecology of all zooplankton components in future investigations of this and similar highly stratified estuaries.*

Key words: zooplankton, tintinnids, copepods, Krka estuary

INTRODUCTION

Due to its unique characteristics, the physical and chemical properties of the karstic river Krka estuary have been studied extensively for more than 20 years (ŽUTIĆ & LEGOVIĆ, 1987; GRŽETIĆ *et al*., 1991; LEGOVIĆ *et al*., 1994, 2003). Several investigations on phytoplankton composition, distribution and vertical flux of biogenic matter were also published (VILIČIĆ *et al*., 1990; BAKRAN-

PETRICIOLI *et al*., 1999; CETINIĆ *et al*., 2006; SVENSEN *et al*., 2007). However, few detailed studies have been conducted on the zooplankton assemblage, particularly in the upper reaches of the estuary. Published results on the microzooplankton community date back to samples collected in 1909 (LAACKMANN, 1913) and 1981/82 (KRŠINIĆ, 1987, 1990; MUŠIN, 1990), and a more detailed account of the long-term microzooplankton distribution in the lower reaches was recently published

by KRŠINIĆ (2007). Some mesozooplankton data are available through environmental monitoring motivated by the occurrence of eutrophication in the Šibenik harbour area (REGNER, 1977, 1986) and carbon flux measurement in the lower estuary (SVENSEN et al., 2007).

Several studies have shown that the variability of the estuarine environment is reflected in the diversity and dynamics of biological populations, particularly if combined with eutrophication effects (SOETAERT & VAN RIJSWIJK, 1993; URIARTE & VILLATE, 2005; MARQUES COTRIM et al., 2006). Salinity is often the key factor in controlling species development and distribution. Therefore we aimed to study the variability in zooplankton abundance and taxonomic composition along the horizontal salinity gradient in the Krka estuary. In addition, sampling performances of the 53- and 125-μm mesh size plankton nets were assessed in order to determine possible future sampling strategies in this and similar estuarine areas.

MATERIAL AND METHODS

Study area

The Krka estuary is located in the middle part of the eastern Adriatic coast (Fig. 1). The estuary receives freshwater mainly from Visovac Lake, followed by a series of travertine barriers and waterfalls. It is approximately 25 km long and relatively narrow, except in Prokljan Lake and Šibenik harbour, with depth gradually increasing from 2 m below the waterfalls to 42 m near the estuarine mouth. The largest part is a pristine environment situated within the borders of a National Park, but the estuary's middle reaches near the city of Šibenik is affected by anthropogenic eutrophication (GRŽETIĆ et al., 1991; LEGOVIĆ et al., 1994). This salt wedge estuary is highly stratified throughout the year due to a low tidal range (20-40 cm on average). The upper freshwater and the lower saltwater layers are separated by a narrow interfacial boundary situated at the halocline which contains an organic film formed mainly by the accumulation of plankton-derived organic material (ŽUTIĆ &
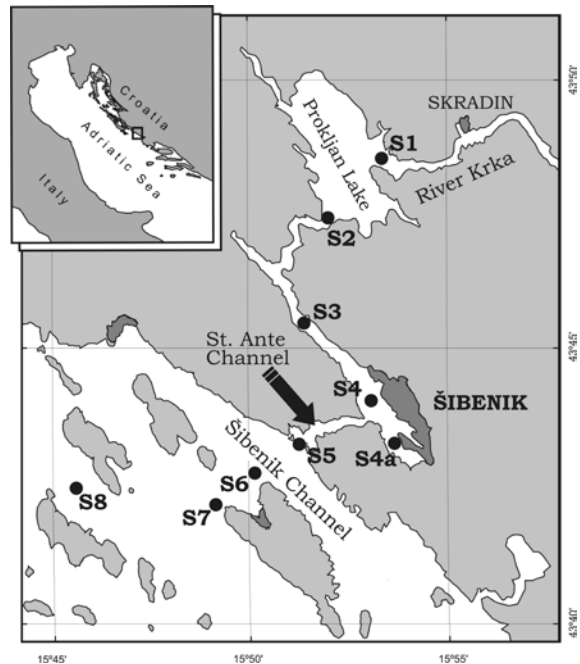

Fig. 1. Map of the Krka estuary with nine sampling stations

LEGOVIĆ, 1987). Both layers are characterized by suspended matter concentrations which do not exceed 10 mg l^{-1} (LEGOVIĆ et al., 1994).

Sampling methods

Zooplankton sampling was performed in April 2006 at 9 stations along the estuary and in coastal waters off the estuary mouth (Fig. 1). The stations were selected to represent the upper (S1 and S2), middle (S3 and S4) and lower (S5) estuary. The additional stations are in the vicinity of the sewage outfalls of the city of Šibenik (S4a) and those representing a marine reference (S6, S7 and S8). The total depths of the stations as well as sampling depths are presented in Table 1. Samples were collected with a 53-μm mesh Nansen net (45 cm diameter, total length 2.5 m) and a 125-μm mesh Nansen net (57 cm diameter, total length 2.5 m) by consecutive vertical hauls from near-bottom to the surface. Net collections were preserved in 2.5% formaldehyde-seawater solution, previously buffered with $CaCO_3$. Counting and species identification were performed using inverted microscopes (Olympus). Abundances were expressed as the

Table 1. Bottom depth and sampling depth of the nvestigated stations

STATION	Bottom depth (m)	Sampling depth (m)
S1	12	8
S2	20	16
S3	33	30
S4	39	35
S4a	25	21
S5	12	8
S6	8	4
S7	32	28
S8	60	56

number of individuals per cubic meter (ind. m^{-3}). Adult copepods and copepodids were counted separately. Taxonomic identification was performed to the species level.

Vertical temperature and salinity profiles were measured with a Sea Bird SBE-25 CTD probe. For determination of phytoplankton biomass water was sampled with Nansen bottles at 0 m at all stations, at 0, 5 and 10 m at S1 and 0, 5, 10 and 23 m at S4a. Aliquots of 500 ml were filtered onto GF/F filters, and chlorophyll *a* measurements were performed on a Turner 112 fluorometer following acetone extraction (STRICKLAND & PARSONS, 1972).

Statistical data analysis

Differences in the sampling performances of two plankton nets were tested by paired t-test, using the statistical package STATISTICA for Windows (StatSoft Inc., 2000, version 5.5; http://www.statsoft.com).

Shannon diversity index (H') was used to analyze spatial diversity changes in tintinnid and copepod communities. Hierarchical cluster analysis (CA) and 2-dimensional MDS ordination were used to illustrate relationships between stations. The analyses were performed using the statistical package Primer 5 (version 5.2.9; CLARKE & GORLEY, 2001).

RESULTS

Environmental parameters

Temperature values ranged from 12.9 to 14.7°C (Figs. 2A and 2C). At stations S1–S3 sub-surface maximum values were recorded at 4.5 m depth as a result of freshwater input in the area. At the remaining stations temperature maxima were recorded at the surface. The highest surface temperature was recorded at station S4.

A large horizontal salinity gradient was recorded along the estuary in the 0-5 m layer. A surface layer of brackish water was evident at stations S1–S4a, with surface salinity ranging from 1.9 (S2) to 7.7 (S4). At 5 m depth salinity increased to >30.0 (Fig. 2B). At stations S5–S8 the vertical salinity gradient was far less pronounced (Fig. 2D). The influence of the freshwater at those stations was evident in somewhat reduced surface salinity values, although those were generally >32.0. Deeper layers with salinities >36.5 were influenced by the advection of marine water.

Surface chlorophyll *a* concentrations ranged from 0.25-19.38 mg m^{-3}. Increased values were recorded at the middle estuarine stations S4 and S4a (2.3 and 19.4 mg m^{-3}, respectively). At the upper estuarine stations surface concentrations also increased to >1.0 mg m^{-3}. The lowest values were recorded at the marine stations S7 and S8 (<0.25 mg m^{-3}).

Zooplankton population structure, distribution and abundance

Fig. 3 shows the spatial variation in the abundance of total zooplankton and main zooplankton groups in the 53- and 125-μm taxocenosis. Total abundances estimated by the two nets showed similar trends in the upper and middle reaches of the estuary, but differed in the lower reaches. On average, the abundance estimated with the 53-μm mesh net was 4.7 times higher than in the 125-μm taxocenosis and the difference was significant (P=0.005).

Data for the tintinnid community, rotifers and copepod nauplii derived from the 53-μm mesh net exclusively. Overlapping occurred in
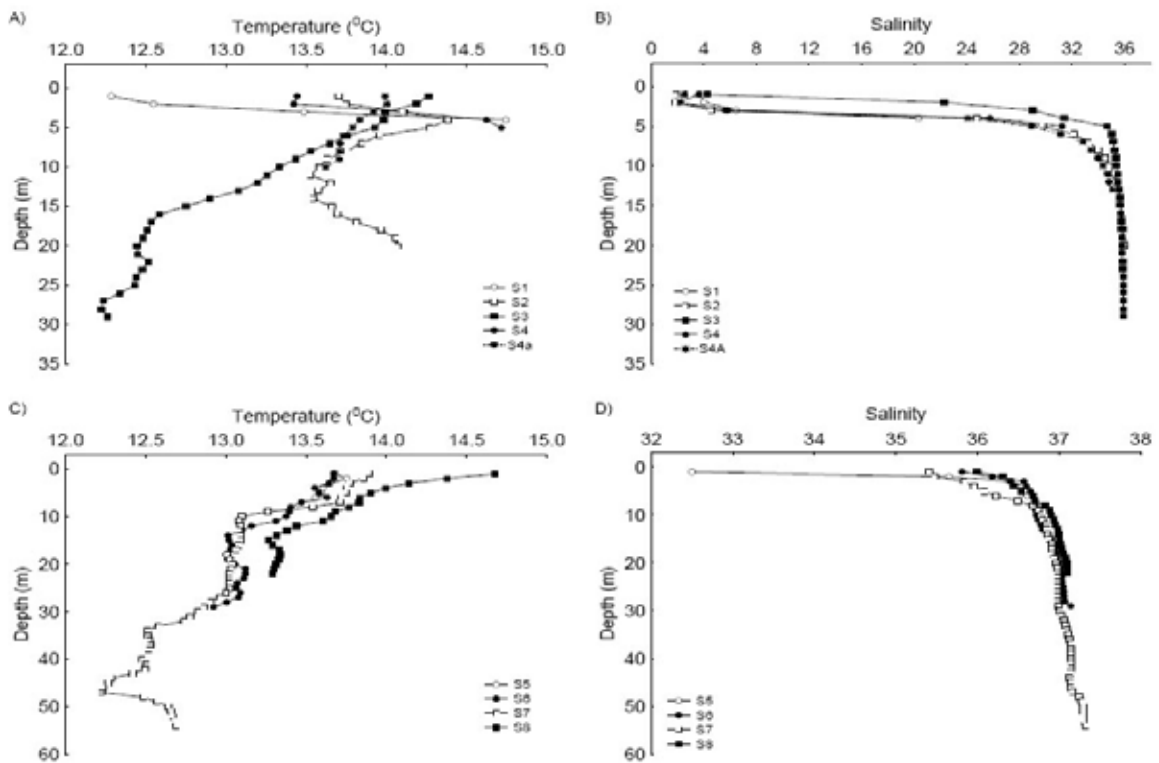
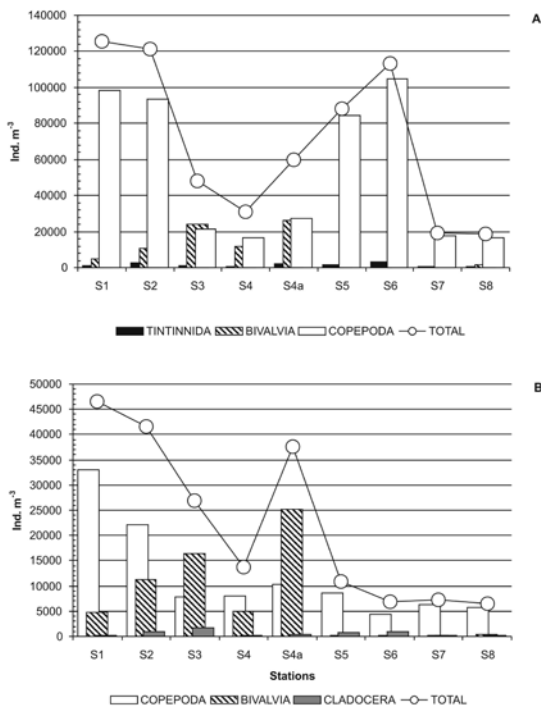Fig. 2.   Vertical changes in temperature (A, C) and salinity (B, D) at the investigated stations

Fig. 3.   Spatial variability of total zooplankton and most abundant zooplankton groups in the 53-μm taxocenosis (A) and 125-μm taxocenosis (B)

all other zooplankton groups, particularly in the copepod community and meroplankton larvae. Total copepod abundances (nauplii excluded) were on average 1.2 times higher in the 53-μm taxocenosis and the difference in the abundance estimates by the two nets was significant (P<0.05). Significant differences (P<0.005) were determined in the calanoid community, with the 125-μm mesh netting retaining on average 2.4 times more organisms and a more diverse assemblage. Although the 53-μm mesh size retained on average 1.8 times more cyclopoids than the 125-μm mesh size, the differences were not significant either for total cyclopoids, *Oithona nana* adults or *Oithona* spp. copepodids. The cyclopoid assemblage also showed higher diversity in the 125-μm taxocenosis, with the exception of *Oncaea zernovi*, a very small species which appeared only in 53-μm catches at stations S4, S4a, S6 and S8. Mollusc larvae were 2.3 times more abundant in the 53-μm taxocenosis, and the differences in abundance estimates between the two nets were significant (P<0.05).

Tintinnids

Tintinnid abundances ranged from 360 ind. m^{-3} at S4 to 3271 ind. m^{-3} at S6 (Fig. 4A), representing on average 2.2% of the total zooplankton in the 53-μm taxocenosis. A total of 28 tintinnid species was determined in the investigated area, with an increasing trend of species number along the estuary. The list of the registered taxa is presented in Table 2.

At the upper estuarine stations the tintinnid community was characterized by low biodiversity and the dominance of estuarine-neritic species (Fig. 4), with *Tintinnopsis campanula* representing >70.0% of the total tintinnid number. In Šibenik harbour and the St. Ante Channel estuarine-neritic species contributed between 55.0 and 67.0% to total tintinnids. *Favella ehrenbergii* represented almost 50.0% of the total tintinnid population. At stations S5, S7

Table 2. List of the registered tintinnid taxa at the investigated stations (+, present; blank, absent)

| STATION:	S 1	S 2	S 3	S 4	S 4a	S 5	S 6	S 7	S 8
TINTINNIDA									
Tintinnopsis sp.							+	+	
Tintinnopsis fracta Brandt, 1906							+		+
Tintinnopsis campanula (Ehrenberg) Daday, 1887	+	+	+	+	+		+		+
T. campanula var. *buetschlii* Daday, 1887	+	+							
Tintinnopsis beroidea Stein, 1867			+						
Tintinnopsis radix (Imhof) Brandt, 1907	+	+				+	+		+
Tintinnopsis levigata Kofoid & Campbell, 1929				+	+				
Tintinnopsis lobiancoi Daday, 1887						+	+		
Tintinnopsis compressa (Daday) Laackmann, 1913	+								
Tintinnopsis fennica Kofoid & Campbell, 1929	+	+							
Tintinnopsis angulata Daday, 1887	+								
Tintinnopsis cylindrica Daday, 1887	+								
Codonella aspera Kofoid & Campbell, 1929				+	+	+		+	+
Codonellopsis schabi (Brandt) Kofoid & Campbell, 1929			+	+				+	+
Stenosemella nivalis (Meunier) Kofoid & Campbell, 1929									+
Stenosemella ventricosa (Claparède & Lachmann) Jörgensen, 1924			+	+	+	+	+	+	+
Favella ehrenbergii (Claparède & Lachmann) Jörgensen, 1924	+	+	+	+	+	+	+	+	
Favella campanula (Schmidt) Kofoid & Campbell, 1929		+	+		+				
Cyttarocylis cassis (Haeckel) Fol, 1881									+
Undella claparedei (Entz) Daday, 1887									+
Undella hyalina Daday, 1887									+
Steenstrupiella steenstrupii (Claparède & Lachmann) Kofoid & Campbell, 1929			+			+	+	+	+
Amphorides amphora (Claparède & Lachmann) Kofoid & Campbell, 1929									+
Amphorides quadrilineata var. *minor* Jörgensen, 1924			+					+	+
Eutintinnus tubulosus (Ostenfeld) Kofoid & Campbell, 1939						+	+	+	+
Eutintinnus lusus-undae (Entz) Kofoid & Campbell, 1939			+	+	+			+	+
Eutintinnus apertus Kofoid & Campbell, 1929						+			
Eutintinnus fraknoi (Daday) Kofoid & Campbell, 1939		+	+			+	+	+	+
Salpingella sp.						+			
Salpingella glockentoegeri (Brandt) Kofoid & Campbell, 1929			+						
Dadayiella ganymedes (Entz) Kofoid & Campbell, 1929				+					
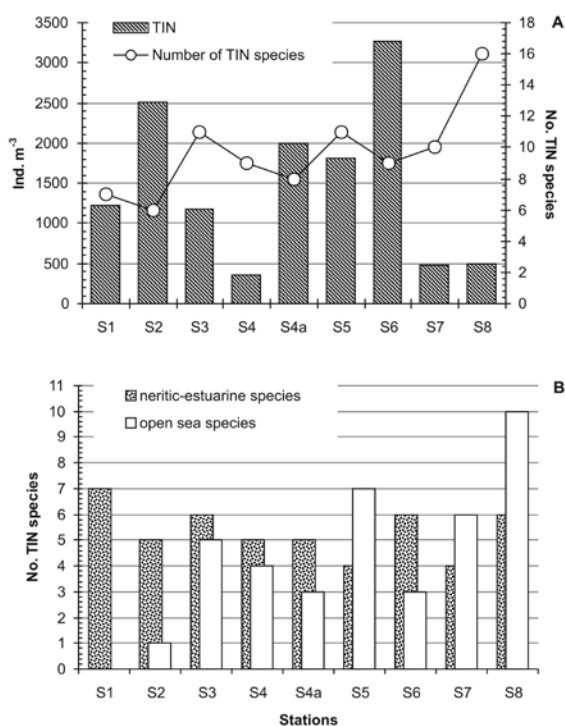
Fig. 4. Spatial distribution of abundance and number of tintinnid (TIN) species along the Krka estuary

and S8 the dominance of open-sea species was recorded (Fig. 4B), with a large contribution by *Eutintinnus fraknoi*. Spatial variability of the Shannon diversity index (H') in the tintinnid community is presented in Fig. 5.

Rotifers

Rotifers were recorded at all stations except S5, S6 and S7. The highest abundances were determined at station S1 in Prokljan Lake (2365 ind. m^{-3}) and S4a in the Šibenik harbour area (2147 ind. m^{-3}), while the other stations showed far lower abundances (<600 ind. m^{-3}). The majority of the rotifers belonged to the genera *Synchaeta*, *Keratella* and *Trichocerca*.

Copepod nauplii and copepodids

Copepod nauplii dominated the copepod population in the 53-µm taxocenosis (Fig. 6). Their spatial distribution along the estuary was irregular, with the highest abundances at stations S5 and S6 (73266 and 91381 ind. m^{-3}, respectively), and station S2 (~50000 ind. m^{-3}).
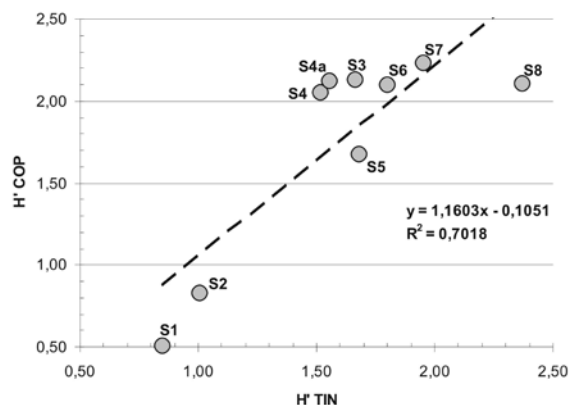

Fig. 5. Scatterplot of tintinnid and copepod Shannon diversity indices (H') for the nine investigated stations

High copepodid abundances recorded at stations S1 and S2 (69945 and 34017 ind. m^{-3}, respectively) decreased to <10000 ind. m^{-3} in the rest of the investigated area (Fig. 6). *Oithona* spp. copepodids dominated this category (92%) in the 53-µm taxocenosis, with the maximal abundance of 64661 ind. m^{-3} recorded at station S1 (Fig. 7A). The proportion of cyclopoid and calanoid copepodids along the estuary was remarkably similar in the 53- and 125-µm taxocenoses (Fig. 7). Cyclopoid copepodids constituted >80.0% of total copepodids in the upper estuary, while calanoid copepodids dominated at all other stations, with the exception of S4a where both orders contributed almost equally to this category.
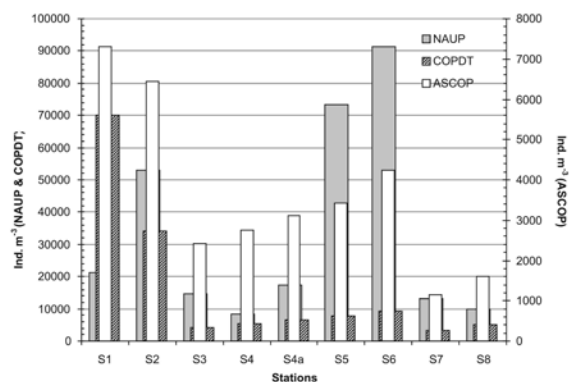

Fig. 6. Spatial distribution of abundance of copepod nauplii (NAUP), copepodids (COPDT) and adult small copepods (ASCOP) in the 53-µm taxocenosis
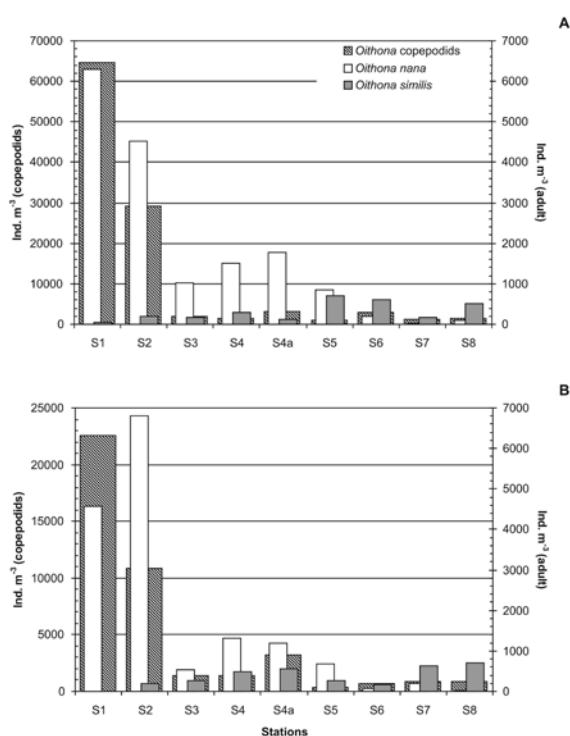
Fig. 7. Comparative abundances of Oithona spp. *adults and copepodids in the 53-μm taxocenosis (A) and 125-μm taxocenosis (B)*

Fig. 8. Percentage contribution of the copepod orders to total copepod abundance in the 125-μm taxocenosis

Adult copepods

A total of 40 copepod taxa was determined in the 125-μm taxocenosis (Table 3). Spatial variability of the Shannon diversity index (H') in the copepod community is presented in Fig. 5.

Cyclopoids in general and *Oithona nana* in particular dominated the copepod assemblage at the upper estuarine stations S1 and S2 (Figs. 7 and 8). The dominance of calanoids intensified towards the estuary mouth and marine stations (Fig. 8), with the exception of S4a where oithonids attained abundances similar to total calanoids. The calanoid assemblage was dominated by the neritic species *Paracalanus parvus* and *Acartia clausi*, particularly at stations S1 and S2, where their combined abundances constituted 97.8 and 85.4% of total calanoids, respectively. This percentage decreased towards the estuarine mouth, but generally remained higher than 30.0%. Other regularly-occurring calanoids at all stations were *Centropages typicus* and *Ctenocalanus vanus*, while *Temora longi-*
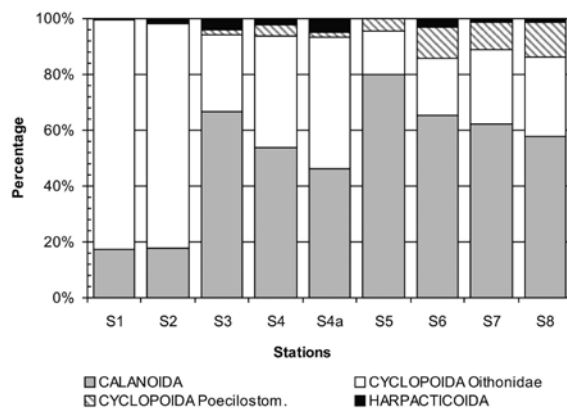
cornis and *Diaixis pygmoea* showed somewhat increased abundances at stations S3 and S4.

Poecilostomatoid cyclopoids from the families Oncaeidae, Corycaeidae and Sapphirinidae were also recorded in the investigated area and their abundances generally increased towards the marine stations. Harpacticoid densities were low, and mainly controlled by the variability of the most abundant species *Euterpina acutifrons*.

Mollusc larvae

Mollusc larvae were highly represented among total metazoans in the upper and middle estuary (Fig. 3). Higher abundances were recorded in the 53-μm taxocenosis, but taxonomic composition and the spatial distribution were similar in both nets. Bivalve larvae were the most abundant at stations S3, S4 and S4a, contributing on average >40.0% to the total metazoa. Gastropod larvae showed increased abundances at stations S1 and S2. The contribution of both groups decreased significantly at stations S5-S8, where they generally represented <1% of total metazoa.

Other groups

Cladoceran densities in the 125-μm taxocenosis exceeded 800 ind. m^{-3} at stations S2, S3, S5 and S6, with *Evadne nordmanni* as the highest contributor (Fig. 3B). Appendicularians were

Table 3. List of the registered copepod taxa at the investigated stations (+, present; blank, absent)

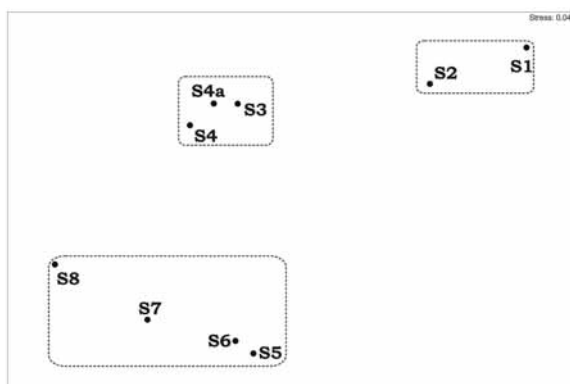| STATION:	S 1	S 2	S 3	S 4	S 4a	S 5	S 6	S 7	S 8
COPEPODA									
Calanus helgolandicus (Claus, 1863)	+	+	+	+	+	+			+
Paracalanus nanus Sars, 1907									+
Paracalanus parvus (Claus, 1863)	+	+	+	+	+	+	+	+	+
Calocalanus pavoninus Farran, 1936			+	+		+	+	+	+
Calocalanus contractus Farran, 1936				+				+	+
Calocalanus styliremis Giesbrecht, 1888			+		+		+		
Mecynocera clausi J. C. Thompson, 1888				+	+	+	+		+
Clausocalanus arcuicornis (Dana, 1849)				+	+				+
Clausocalanus jobei Frost & Fleminger, 1968							+		+
Ctenocalanus vanus Frost & Fleminger, 1968	+		+	+	+		+	+	+
Diaixis pygmoea (T. Scott, 1899)			+	+	+				+
Centropages typicus Krøyer, 1849	+	+	+	+	+	+	+	+	+
Centropages krøyeri Giesbrecht, 1892		+	+		+				
Isias clavipes Boeck,1865				+		+	+	+	
Temora stylifera (Dana, 1849)			+						
Temora longicornis (Müller, 1792)	+	+	+	+	+	+			+
Labidocera wollastoni (Lubbock, 1856)			+		+				
Candacia giesbrechti Grice &Lawson, 1977			+	+				+	+
Acartia clausi Giesbrecht, 1889	+	+	+	+	+	+	+	+	+
Pontella sp.							+		
Oithona similis Claus, 1866		+	+	+	+	+	+	+	+
Oithona nana Giesbrecht, 1892	+	+	+	+	+	+	+	+	+
Oithona plumifera Baird, 1843							+	+	+
Oithona atlantica Farran, 1908						+	+	+	+
Oncaea waldemari Bersano & Boxshall, 1994	+		+	+	+	+	+	+	+
Oncaea scottodicarloi Heron & Bradford-Grieve, 1995						+	+	+	+
Oncaea media Giesbrecht, 1891						+			
Oncaea mediterranea (Claus, 1863)									+
Monothula subtilis (Giesbrecht, 1892)		+	+	+	+	+	+	+	+
Triconia conifera (Giesbrecht, 1891)									+
Ditrichocorycaeus brehmi (Steuer, 1910)		+	+	+		+	+	+	+
Ditrichocorycaeus minimus indicus (M. Dahl, 1912)					+				+
Agetus typicus Krøyer, 1849					+			+	+
Farranula rostrata (Claus, 1863)	+				+			+	+
Onychocorycaeus giesbrechti (F. Dahl, 1894)								+	
Onychocorycaeus ovalis (Claus, 1863)			+						
Sapphirina nigromaculata Claus, 1863								+	
Goniopsyllus clausi Huys & Conroy-Dalton, 2000									+
Microsetella norvegica (Boeck, 1865)	+		+		+	+	+	+	+
Euterpina acutifrons (Dana, 1847)	+	+	+	+	+	+	+	+	+

Fig. 9. Non-metric multidimensional scaling (MDS) ordination of nine Krka river estuary stations based on Bray-Curtis similarities from the fourth root transformed abundance values of zooplankton. Dashed lines denote subgroups originating in the hierarchical cluster dendrogram at the similarity level of 70%

dominated by their juveniles. Other recorded groups included ostracods, pteropods, chaetognaths, thaliaceans and siphonophores and contributed <3% to the total mesozooplankton.

Data analysis

The result of the MDS ordination of the nine investigated stations shows the grouping of the stations based on their zooplankton composition and abundances (Fig. 9). The stations in Prokljan Lake (S1 and S2) are separated at the similarity level of 56.8%. The rest of the stations were further subdivided at the 64.6% similarity level in two groups, the first encompassing the middle estuarine stations S3, S4 and S4a; and the second containing station S5, situated at the estuary mouth, and marine stations S6, S7 and S8.

DISCUSSION

During this investigation a general decreasing trend of zooplankton abundance along the Krka estuary was observed. Exceptions were noted at stations S5 and S6 situated in Šibenik Channel, characterized by a high density of copepod nauplii, and at station S4a where rotifers and bivalve larvae were mainly responsible for the increase in total zooplankton. The pro-

liferation of copepod nauplii in Šibenik Channel is consistent with previous investigations demonstrating that copepod reproduction in the channel areas starts earlier than in adjacent estuaries and bays (BOJANIĆ, 2002). A long-term zooplankton study in the lower reaches of the Krka estuary confirmed that Šibenik Channel has characteristics typical for inside channels of the middle Adriatic Sea (KRŠINIĆ, 2007).

Spatial trends of tintinnid species numbers and values of the Shannon diversity index per station roughly paralleled each other. Although the differences in tintinnid abundances among stations were not significant, an increasing trend of the number of taxa along the salinity gradient was observed. The salinity distributions give evidence of the strong influence of the open sea and freshwater at stations in Šibenik harbour and Prokljan Lake (KRŠINIĆ, 1987). The lowest salinity surface waters have an outgoing drift of current, whereas in the deeper layers there is compensation through an inflowing high salinity current. Such water circulation in the estuary enhances the entering of open sea tintinnids, such as *Eutintinnus fraknoi*, as far as Prokljan Lake (S2) and the large contribution of neritic species, including *Tintinnopsis* spp., *Stenosemella* spp. and *Codonellopsis schabi*, at marine station S8.

During the 1981/82 investigations in Šibenik harbour and Prokljan Lake, 19 and 20 tintinnid species, respectively, were recorded (KRŠINIĆ, 1987). Recently, the same author completed a tintinnid list from the harbour station with 11 new species (KRŠINIĆ, 2007). The majority of the tintinnid community consists of neritic and estuarine species that can form cysts under unfavourable environmental conditions (KRŠINIĆ, 1990). The excystment of tintinnids at the bottom probably plays an important role in forming new tintinnid populations in the water column (PARANJAPE, 1987). According to KRŠINIĆ (1990), tintinnid fauna in the river Krka estuary is impoverished during the winter-spring period, which could partly explain the low tintinnid biodiversity during our investigation. Nevertheless, we determined nine tintinnid species in Prokljan Lake (S1 and S2) and Šibenik harbour (S4),

three additional species *Tintinnopsis fennica*, *T. angulata* and *Favella campanula* in the upper estuary, and two additional species *T. levigata and Codonella aspera* at the harbour station.

As distinct from other neritic areas along the Adriatic coast, the representatives of the main microzooplankton groups in the lower reaches of the Krka estuary show extreme abundances. The exceptionally high density was recorded in Šibenik harbour for nonloricate ciliates, reaching 10770 ind.l[-1] (KRŠINIĆ & NJIRE, 2001). A detailed review of their abundances in other marine regions was given earlier in BOJANIĆ *et al.,* 2006. Copepod nauplii were recorded as the most numerous metazoans in Šibenik Bay, with the highest abundance of 1139 ind.l[-1] (KRŠINIĆ & NJIRE, 1996). Those values in other Adriatic neritic areas, such as the Bay of Mali Ston and the central part of Kaštela Bay, were approximately twice as low (RUDENJAK-LUKE-NDA, 1985; BOJANIĆ, 2002). Lower tintinnid and copepod nauplii abundances recorded during our research, apart from the seasonal influence, could be attributed to a decreasing trend of anthropogenic influence in the Šibenik area that has been observed since 2005 (KRŠINIĆ, 2006).

Despite the low surface salinity in the estuary's upper and middle reaches, the copepod community was essentially marine, dominated by estuarine-neritic species. Even in the upper reaches the brackish layer was relatively thin, allowing marine species to inhabit the waters below 5 m depth. MUŠIN (1990) has determined that most of the copepodites and adult small copepods in Prokljan Lake and Šibenik harbour are found at 5 and 10 m depths, respectively.

Copepod diversity increased towards the estuary's end, and the dominance of oithonids in the upper reaches was evident in both taxocenoses, with *Oithona nana* as the most abundant species. The clear dominance and high abundances of this small copepod and its developmental stages is mainly responsible for the separation of upper estuarine stations S1 and S2, illustrated by the MDS ordination. Due to its wide tolerance to temperature and salinity and opportunistic diet (LAMPITT & GAMBLE, 1982; WILLIAMS & MUXAGATA, 2006), *O. nana* is well

adapted for the utilization of food resources in stratified environments. In the upper reaches of the Krka estuary decomposing freshwater phytoplankton from Visovac Lake situated above the waterfalls is the main nutrient source (VILIČIĆ *et al.*, 1989; LEGOVIĆ *et al.*, 1996). The organic-rich layer formed by accumulation of decaying freshwater micro- and nanophytoplankton cells and detrital particles at the permanent halocline (SVENSEN *et al.*, 2007) presents a suitable environment for the proliferation of a passive planktonic raptor such as *O. nana* (LAMPITT & GAMBLE, 1982; GONZÁLES & SMETACEK, 1994). An earlier investigation of the copepod community in Prokljan lake has recorded *Oithona* sp. in very low numbers (REGNER, 1977), but that could be related to the selectivity of the 330-μm mesh size and extensive loss of these small organisms through the meshes (VIDJAK 1998; GALLIENNE & ROBINS, 2001).

Similar respective contributions of calanoids and oithonids, and high abundances of *Oithona* spp. (~ 4900 ind. m[-3]) were recorded in the Šibenik harbour area (stations S4 and S4a). Nutrient enrichment in this area comes from natural (Krka river) and anthropogenic sources (local sewage), contributing to the high Chl *a* values recorded at the surface. Despite a recently evidenced decrease in anthropogenic input of sewage and domestic waste waters, this is still one of the most productive coastal areas on the eastern Adriatic coast (KUŠPILIĆ et al., 2007). The first signals of the changes in the copepod community of this area triggered by the eutrophication process were detected in the 1973-1974 period (REGNER, 1977), although the use of a coarse mesh size (330-μm) probably led to an underestimation of total copepod abundances, as well as the role of younger stages and smaller taxa. SVENSEN *et al.* recorded the dominance of small copepods in the lower part of the Krka estuary using a 180-μm mesh plankton net (SVENSEN *et al.*, 2007). Proliferation of the small copepod *O. nana* is often associated with polluted and eutrophic enclosed coastal areas (JAMET *et al.*, 2001; VIDJAK *et al.*, 2006). Nonloricate ciliates, an important food source for small copepods (GISMERVIK & ANDERSEN, 1997),

are abundant in Šibenik harbour throughout the year (KRŠINIĆ, 1990, 2007). In addition, changes in the phytoplankton composition towards smaller algae can favour the replacement of larger copepod species by the smaller ones (UYE, 1994). The results of the recent phytoplankton monitoring in Šibenik harbour have shown a high contribution of small gymnodinial dinoflagellates, chain-forming small diatoms and microflagellates (MARASOVIĆ *et al.*, 2007). The dominant calanoids *Acartia clausi* and *Paracalanus parvus* are also known to feed on the mixed diets of phytoplankton and microzooplankton, with *A. clausi* regularly switching between algal and ciliate foods (GISMERVIK & ANDERSEN, 1997) and *P. parvus* including heterotrophic dinoflagellates, besides autotrophic phytoplankton, in its diet (SUZUKI *et al.*, 1999).

The abundance of bivalve larvae in this area also indicates the availability of small phytoplankton and animal prey, such as ciliates and heterotrophic flagellates, that are important for the nutrition of the metazoan filtering community (KRŠINIĆ, 2007).

This preliminary investigation may be helpful when proposing future zooplankton sampling strategies in the Krka estuary or other highly stratified estuaries. The differences between zooplankton abundances obtained with the 53- and 125-μm mesh plankton nets confirm that the use of only one mesh size may lead to significant bias in the abundance of main zooplankton groups (MARQUES COTRIM *et al.*, 2006). The dominance of small-sized copepods and their developmental stages in the zooplankton community along the estuary emphasizes the need for using fine plankton nets (<200 μm) in zooplankton sampling. However, net samples do not give an insight into fluctuations of the nonloricate component of the protozoan community, which also acts as an important factor in the regulation of primary production (VERITY *et al.*, 1993), bacterial production and nanoflagellates abundances (ŠOLIĆ & KRSTULOVIĆ, 1995; URRUTXURTU *et al.*, 2003), or potentially numerous small tintinnid species which could pass through the 53-μm mesh. In future investigations, we propose the use of a 125-μm net in combination with Niskin bottles which would give more information on the protozooplankton community structure, as well as on their vertical distribution. Furthermore, high sampling frequency is essential for a better understanding of trophic relationships within the zooplankton community on the spatial and temporal scales in this and similar higly stratified estuaries.

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REFERENCES

BAKRAN-PETRICIOLI, T., D. PETRICIOLI & D. VILIČIĆ. 1999. Taxonomic composition and seasonal distribution of microphytoplankton in the Krka River estuary. Nat. Croat., 7(4): 307-319.

BOJANIĆ, N. 2002. Ecology of protozoa and micrometazoa in Kaštela Bay (in Croatian). Ph.D. Thesis. University of Zagreb, 148 pp.

BOJANIĆ, N., O. VIDJAK & I. BRAUTOVIĆ. 2006. Spatial and temporal variability in abundance and biomass of oligotrich ciliates in the Kaštela Bay (Middle Adriatic Sea). Acta Adriat., 47(2): 93-109.

CETINIĆ, I., D. VILIČIĆ, Z. BURIĆ & G. OLUJIĆ. 2006. Phytoplankton seasonality in a highly stratified karstic estuary (Krka, Adriatic Sea). Hydrobiologia, 555: 31-40.

CLARKE, K.R. & R.N. GORLEY. 2001. PRIMER v5: User Manual/Tutorial. PRIMER-E: Plymouth.

GALLIENNE, C.P. & D.B ROBINS. 2001. Is *Oithona* the most important copepod in the world's oceans? J. Plankton Res., 23: 1421-1432.

GISMERVIK, I. & T. ANDERSEN. 1997. Prey switching by *Acartia clausi*: experimental evidence and implications of intraguild predation assessed by a model. Mar. Ecol. Prog. Ser., 157: 247-259.

GONZÁLES, H.E. & V. SMETACEK. 1994. The possible role of cyclopoid copepod *Oithona* in retarding vertical flux of zooplankton faecal material. Mar. Ecol. Prog. Ser., 113: 233-246.

GRŽETIĆ, Z., R. PRECALI, D. DEGGOBIS & A. ŠKRIVANIĆ. 1991. Nutrient enrichment and phytoplankton response in an Adriatic karstic estuary. Mar. Chem., 32: 313-331.

JAMET, J.-L., G. BOGÈ, S. RICHARD, C. GENEYS & D. JAMET. 2001. The zooplankton community in bays of Toulon area (northwest Mediterranean sea, France). Hydrobiologia, 457: 155-165.

KRŠINIĆ, F. 1987. Tintinnines (Ciliophora, Oligotrichida, Tinntinnina) in Eastern Adriatic Bays. Est. Coast. Shelf Sci., 24: 527-538.

KRŠINIĆ, F. 1990. Planktonic ciliates in the lower reach of Krka river estuary. In: National park Krka, status of research and problems of ecosystem protection (in Croatian). Croatian Ecological Society, Zagreb, pp. 259-270.

KRŠINIĆ, F. 2006. Microzooplankton. In: Coastal sea quality assessment (Project Vir-Konavle), (in Croatian). Institute of Oceanography and Fisheries, Split, 269: 82-89.

KRŠINIĆ, F. 2007. Zooplankton population structure in the lower reach of the Krka estuary. In: D. Marguš (Editor). Simpozij rijeka Krka i Nacionalni park Krka (in Croatian). Prirodna i kulturna baština, zaštita i održivi razvitak. Šibenik, pp. 469-480.

KRŠINIĆ, F. & J. NJIRE. 1996. Microzooplankton. In: Coastal sea quality assessment (Project Vir-Konavle), (in Croatian). Institute of Oceanography and Fisheries, Split, 202: 55-62.

KRŠINIĆ, F. & J. NJIRE. 2001. Microzooplankton. In: Coastal sea quality assessment (Project Vir-Konavle), 223: 65-69 (in Croatian).

Institute of Oceanography and Fisheries, Split.

KUŠPILIĆ, G., S. MATIJEVIĆ, L. STOJANOSKI & I. PEZO. 2007. Chemical parameters. In: Coastal sea quality assessment (Project Pag-Konavle), (in Croatian). Institute of Oceanography and Fisheries, Split, 276: 57-70.

LAACKMANN, H. 1913. Adriatische Tintinnoiden; Sitzungberichte der Matematisch-Naturwissenschaftlischen Klasse der Kaiserlichen Akademie der Wissenschaften (Adriatic tintinnids: Reports of the Natural Sciences Department of the Royal Scientific Academy). 122: 1-45.

LAMPITT, R.S. & J.C. GAMBLE. 1982. Diet and respiration of the small planktonic marine copepod *Oithona nana*. Mar. Biol., 66: 185-190.

LEGOVIĆ, T., V. ŽUTIĆ, Z. GRŽETIĆ, G. CAUWET & R. PRECALI. 1994. Eutrophication in the Krka river estuary. Mar. Chem., 46: 203-215.

LEGOVIĆ, T., V. ŽUTIĆ, D. VILIČIĆ & Z. GRŽETIĆ. 1996. Transport of silica in a stratified estuary. Mar. Chem., 53: 69-80.

LEGOVIĆ, T., I. JANEKOVIĆ, D. VILIČIĆ, D. PETRICIOLI & Z. SMOLJAN. 2003. Effects of freshwater release to a marine bay. J. Environ. Sci. Health., A, 38: 1411-1420.

MARASOVIĆ, I., Ž. NINČEVIĆ GLADAN & S. SKEJIĆ. 2007. Trophic status (Primary production). In: Coastal sea quality assessment (Project Pag-Konavle), (in Croatian). Institute of Oceanography and Fisheries, Split 276: 69-87.

MARQUES COTRIM, S., U. M. AZEITEIRO, J.C. MARQUES, J.M. NETO & M.A. PARDAL. 2006. Zooplankton and ichthyoplankton communities in a temperate estuary: spatial and temporal patterns. J. Plankton Res., 28: 297-312.

MUŠIN, D. 1990. Metazoan microzooplankton in the Krka river estuary. In: National park Krka, status of research and problems of ecosystem protection (in Croatian). Croatian Ecological Society, pp. 251-257.

PARANJAPE, M.A. 1987. The seasonal cycles and vertical distribution of tintinnines in Bedford Basin, Nova Scotia, Canada. Can. J. Zool., 65: 41-48.

REGNER, D. 1977. Investigations of copepods in the coastal areas of Split and Šibenik. Acta Adriat., 17(12): 1-19.

REGNER, D. 1986. Eutrophication effects on the copepod community of the eastern Adriatic coast. Rapp. Comm. int. Mer Médit., 30: p. 202.

RUDENJAK-LUKENDA, M. 1985. The vertical and seasonal distribution of microzooplankton in the Bay of Mali Ston (in Croatian). M.S. Thesis. University of Zagreb, 77 pp.

SOETAERT, K. & P. VAN RIJSWIJK. 1993. Spatial and temporal patterns of the zooplankton in the Westerschelde estuary. Mar. Ecol. Prog. Ser., 97: 47-59.

STRICKLAND, J.D.H. & T.R. PARSONS. 1972. A practical handbook of seawater analysis. Bull. Fish. Res. Bd. Can., 167: 1-310.

SUZUKI, K., Y. NAKAMURA & J. HIROMI. 1999. Feeding by the small calanoid copepod *Paracalanus* sp. on heterotrophic dinoflagellates and ciliates. Aquat. Microb. Ecol., 17: 99-103.

SVENSEN, C., D. VILIČIĆ, P. WASSMANN, E. ARASHKEVICH & T. RATKOVA. 2007. Plankton distribution and vertical flux of biogenic matter during high summer stratification in the Krka estuary. Est. Coast. Shelf Sci., 71: 381-390.

ŠOLIĆ, M. & N. KRSTULOVIĆ. 1995. Bacterial carbon flux through the microbial loop in the Kaštela Bay (Adriatic Sea). Ophelia, 41: 345-360.

URIARTE, I. & F. VILLATE. 2005. Differences in the abundance and distribution of copepods in two estuaries of the Basque coast (Bay of Biscay) in relation to pollution. J. Plankton Res., 27: 863-874.

URRUTXURTU, I., E. ORIVE & A. SOTA. 2003. Seasonal dynamics of ciliated protozoa and their potential food in an eutrophic estuary (Bay of Biscay). Est. Coast. Shelf Sci., 57: 1169-1182.

UYE, S.I. 1994. Replacement of large copepods by small ones with eutrophication of embayments: cause and consequence. Hydrobiologia, 292/293: 513-519.

VERITY, P.G., D.K. STOECKER, M.E. SIERACKI & J.R. NELSON. 1993. Grazing, growth and mortality of microzooplankton during the 1989 North Atlantic spring bloom at 47°N, 18°W. Deep-Sea Res. I, 40: 1793-1814.

VIDJAK, O. 1998. Comparative sampling of the mesozooplankton with 333 and 125 micrometer mesh size nets in the Kaštela Bay. Rapp. Comm. int. Mer Médit., 35: 504-505.

VIDJAK, O., N. BOJANIĆ, G. KUŠPILIĆ, I. MARASOVIĆ, Ž. NINČEVIĆ GLADAN & I. BRAUTOVIĆ. 2006. Annual variability and trophic relations of the mesozooplankton community in the eutrophicated coastal area (Vranjic Basin, eastern Adriatic Sea). J. Mar. Biol. Assoc. U. K., 86: 19-26.

VILIČIĆ, D., T. LEGOVIĆ & V. ŽUTIĆ. 1989. Vertical distribution of phytoplankton in a stratified estuary. Aquat. Sci., 51: 32-46.

VILIČIĆ, D., D. PETRICIOLI & N. JASPRICA. 1990. Seasonal phytoplankton distribution in the Krka estuary and Visovac lake. In: National park Krka, status of research and problems of ecosystem protection (in Croatian). Croatian Ecological Society, pp. 317-330.

WILLIAMS, J.A. & E. MUXAGATA. 2006. The seasonal abundance and production of *Oithona nana* (Copepoda: Cyclopoida) in Southampton Water. J. Plankton Res., 28(11): 1055-1065.

ŽUTIĆ, V. & T. LEGOVIĆ. 1987. A film of organic matter at the freshwater/seawater interface of an estuary. Nature, 328: 612-614.

Struktura populacije i brojnost zooplanktona u estuariju rijeke Krke u proljeće 2006-e godine

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SAŽETAK

Zooplanktonska zajednica je istraživana u travnju 2006. na devet postaja duž i ispred visoko-stratificiranog estuarija rijeke Krke, uporabom dviju planktonskih mreža Nansen tipa, opremljenih svilama finoće tkanja 53- i 125-μm. Tintinidi, kopepodni rakovi i njihovi razvojni stadiji te ličinke mekušaca su dominirale u zooplanktonu, a zabilježeno je 28 vrsta tintinida i 41 vrsta kopepoda. Kod tintinida i kopepoda zamijećen je pad brojnosti i porast broja vrsta prema ušću estuarija, uz izraženu dominaciju estuarsko-neritičkih vrsta. Najbrojniji tintinidi su bili *Tintinnopsis campanula* i *Favella ehrenbergii*. Mali ciklopoidni kopepod *Oithona nana* dominirao je u gornjem dijelu estuarija, vjerovatno se hraneći organskom tvari nakupljenoj na permanentnoj haloklini. Udio kalanoidnih kopepoda se povećavao prema postajama iza ušća, s iznimkom eutrofiziranog područja šibenske luke na kojem su ponovo zabilježene visoke brojnosti ciklopoida *Oithona nana*. Usporedba brojčanih podataka iz korištenih planktonskih mreža i sastav populacije zooplanktona ukazuju da bi kombinacija 125-μm planktonske mreže i Niskin crpca dala optimalne podatke o ekologiji zooplanktonske zajednice tijekom budućih istraživanja ovog i sličnih visokostratificiranih estuarija.

Ključne riječi: zooplankton, tintinidi, kopepodi, estuarij Krke