MICROZOOPLANKTON IN THE KOTOR BAY (THE SOUTHERN ADRIATIC)

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Abstract

Vertical and temporal distribution of microzooplankton and phytoplankton are analyzed in the Kotor Bay.

Grazing of phytoplankton is increased mostly during the domination of ciliates, nauplii and small copepods.

Izvod

MIKROZOOPLANKTON U KOTORSKOM ZALJEVU (JUŽNI JADRAN)

Vertikalna i vremenska raspodjela mikrozooplanktona i fitoplanktona analizirana je u Kotorskom zaljevu.

Grazing fitoplanktona najčešće je povećan za vrijeme dominacije cilijata, naupliusa i malih kopepoda.

INTRODUCTION

On the basis of the scarce data on the Bokakotorska zooplankton fauna, Car (1896) characterized it as being poor. Among zooplankton species, only *Oithona nana* was registered in high numbers. Similar results were obtained by Gamulin (1938) on the basis of the sampling performed in November 1937 at five stations from the Cape of Oštro to the Bay of Kotor. A Nansen net supplied with a fine silk closing system was used, and the resultant data indicated a qualitative composition of small copepods which dominated at the outer as well as inner stations. Especially abundant were. *O. nana* and *Microsetella norvegica.* The plankton protozoans, tintinnines and the *Sticholonche zanclea* were numerically important in the inner part of the Bay. In investigations that followed, due to somewhat coarser mesh nets being used, the smallest zooplankton were omitted. Due to a mesh size of the nets used, marked differences in quantities of retained small copepods were observed to exist. For instance, Vukanić (1971), with a 250 μm mesh netting plankton net, found the copepod *O. nana* in the Kotor Bay to contribute 2.1% to total copepod numbers. On the other hand, by using the plankton net mesh netting 150 μm, Vukanić (1988) found that the *O. nana* contribution to the total copepods amounted to 45.2%.

This paper presents the first qualitative-quantitative data on plankton protozoans and micrometazoans on the basis of a one-year-long study at one station in the Kotor Bay.

MATERIALS AND METHODS

The microzooplankton and phytoplankton samples were taken at one station in the Kotor Bay (Fig. 1) at monthly intervals from December 1981 to December 1982.

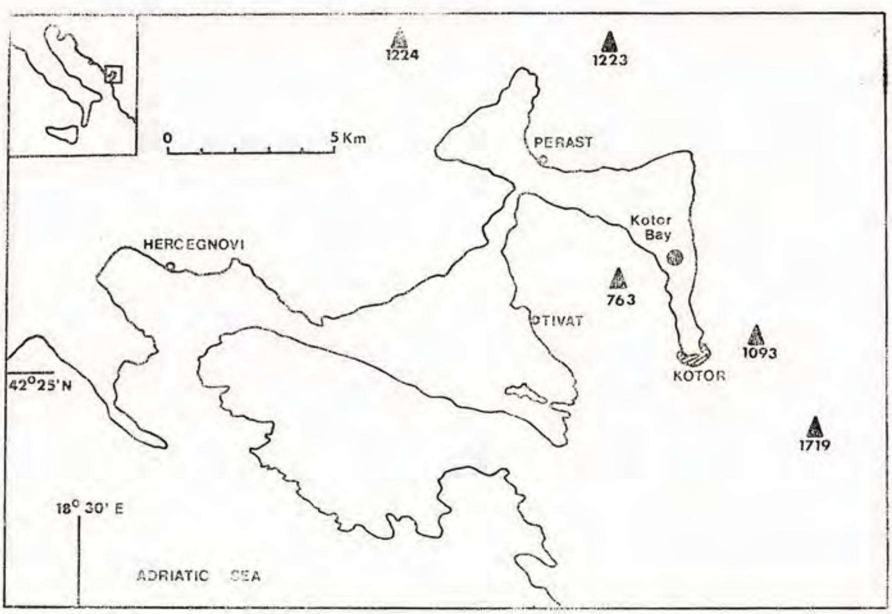

Fig. 1. Location of sampling station
Sl. 1. Položaj postaje

Qualitative microzooplankton sampling was performed by vertical tows from the 20 m depth to the surface with a 53 μm mesh-netting net, 45 cm in diameter. Samples for the quantitative analyses were taken with a 5 *l* Van Dorn sampler in 1, 5, 10 and 20 m layers. The 3 ml samples were obtained from the original sample volume by the sedimentation method. The microzooplankton samples were analysed and counted with a Wild binocular microscope at magnifications of 100 and 400 ×. Qualitative and quantitative results are contained in Table 3, where numerical values represent organismal density per 1 *l* volume.

The samples for the salinity measurements and quantitative analyses of phytoplankton were taken with a Nansen bottle at three layers (1, 5 and 20 m). The temperature was measured by a reversing thermometer. Salinity was determined by the argentometric titration or using a salinometer. The phytoplankton population density was determined by cell counting using a »Hydro-Bios« inverted microscope. The phytoplankton cells smaller than 20 μm were included with the nanoplankton, whereas those longer than 20 μm with the microphytoplankton. For a more detailed information on phytoplankton population analysis in the Kotor Bay, see Viličić (1986).

The plankton samples were preserved in 2.5% formaldehyde neutralized by $CaCO_3$.

RESULTS

Hydrography

The Kotor Bay is the innermost part of Boka Kotorska, one of the largest and the most indented bays on the eastern Adriatic coast. It is surrounded by relatively high mountains, which spread along the sea coast, rising directly out of the sea to the heights of 1888 m. The Boka Kotorska hinterland has been found to be the region of a most abundant rainfall in Europe, averaging 5000-5500 mm per year (Melik, 1956). The precipitation distribution is typically Mediterranean, with the maximum in winter (December) and the minimum in summer (August). The surrounding mainland area is built of highly permeable limestone mass with typically karst hydrogeologic characteristics. The ground water drainage towards the sea as well as underground connections between the ponors, (swallow holes) and the vruljas (submarine springs) are evident and intensive especially during the rainy period.

The salinity values in the Kotor Bay varied between 8.48 and 38.80×10^{-3}. The salinity was high and more constant in the deeper layers and variable near the surface layers (Fig. 2). Low salinity was registered at the surface during the period of a

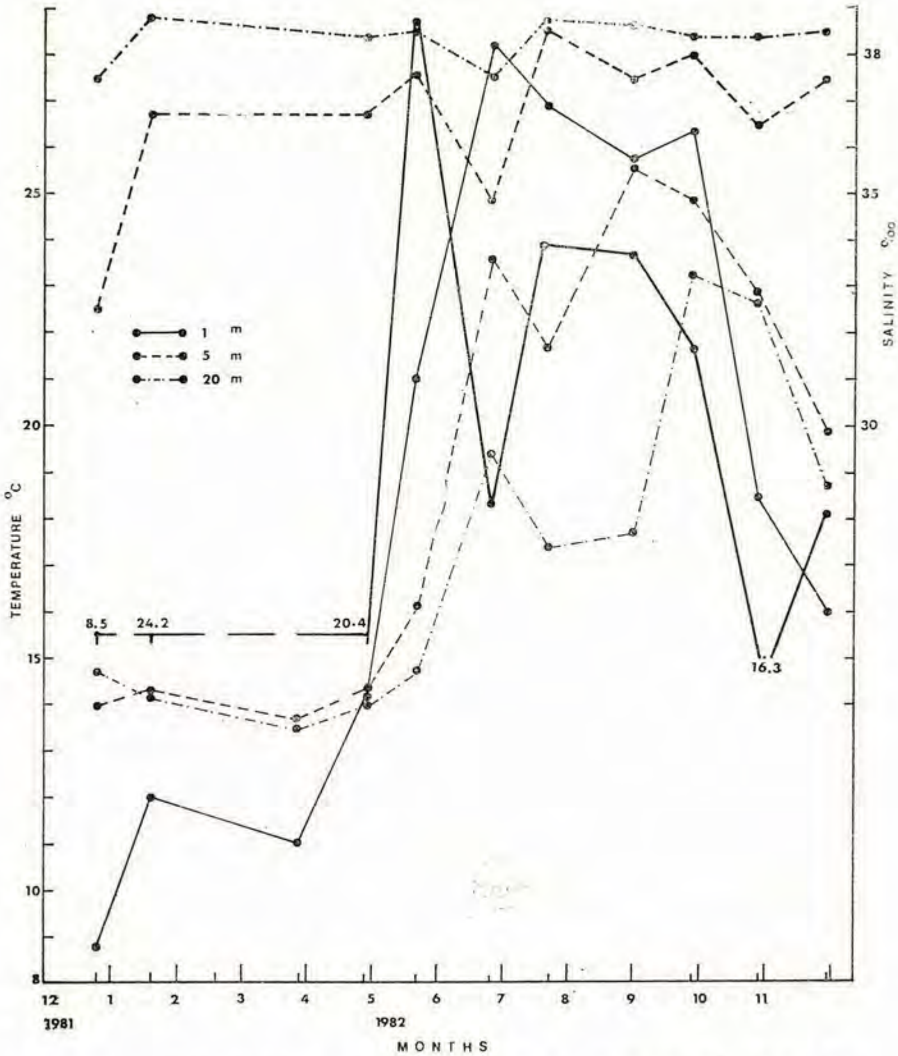

Fig. 2. Seasonal variations of temperature and salinity in the Kotor Bay
Sl. 2. Sezonske varijacije temperature i slanosti u Kotorskom zaljevu

strong precipitation (October-January). A freshwater discharge was also higher in March and April due to a heavy snow melting from the surrounding, montains, with a simultaneous influx of a high quantity of allochtonous materials (natural eutrophication). Meteorological and hydrographical situation registered between May and September was predominantly stable. The annual variations in seawater temperature ranged from 8.7 to 28.3°C, with the maximum temperature being higher if compared to other sampled sites along the southern Adriatic neretic region.

Phytoplankton

The microphytoplankton population density ranged from 9.3×10^3 to 2.9×10^6 cells $\times\ l^{-1}$. In February-April, June and August an increased population density of 10^6 cells was recorded (Fig. 3A).

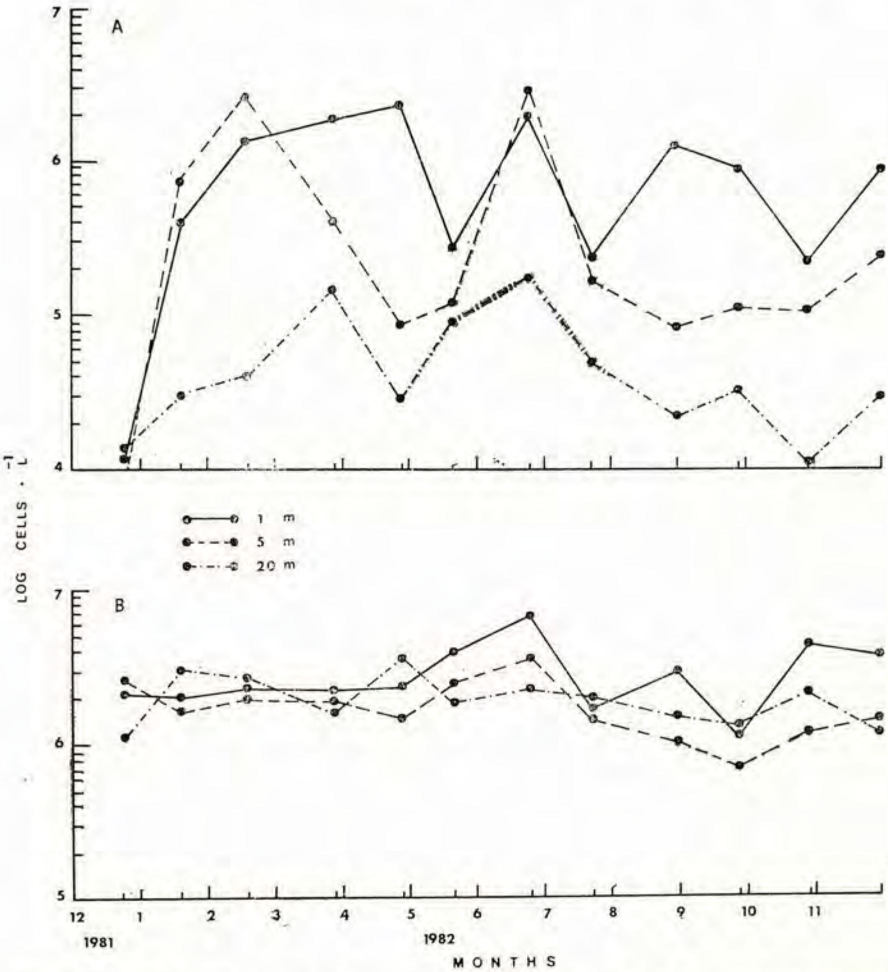

Fig. 3. Seasonal variations of microphytoplankton (A) and nanophytoplankton (B) cell density in the Kotor Bay

Sl. 3. Sezonske varijacije gustoće populacija mikrofitoplanktona (A) i nanofitoplanktona (B) u Kotorsko zaljevu

Seasonal distribution of twenty dominant microphytoplankton species is represented in Table 1.

The nanoplankton quantity curves (Fig. 3B) showed a more or less monotonous seasonal course, with the population density ranging from 1.3×10^6 to 6.4×10^6 cells $\times l^{-1}$. The cell density and volume maxima were reached in June, and were followed by the October nanoplankton cell density peak attaining values similar to those registered in the neritic region of the southern Adriatic (Viličić, 1985). If compared to *Bacillariophyceae* which are the major representative group of microplankton, prefering surface from the deeper layers, the nanoplankton vertical distribution is irregular, showing no marked depth preference and sometimes reaching quantity maximum near the surface and at other times in deeper layers.

Table 1. Seasonal distribution of population density in 20 dominant microphytoplankton species (with cell density $> 10^4$ cells l^{-1}), in the Kotor Bay, during 1981/82. $4 = 10^4$-10^5, $5 = 10^5$-10^6, $6 = > 10^6$ cells l^{-1}

Tabl. 1. Sezonska raspodjela 20 dominantnih vrsta mikrofitoplanktona (sa gustoćom populacija $> 10^4$ stanica l^{-1}) u Kotorskom zaljevu, u razdoblju 1981/1982. $4 = 10^4$-10^5, $5 = 10^5$-10^6, $6 = > 10^6$ cells l^{-1}

	Months											
Vrsta	12	01	02	03	04	05	06	07	08	09	10	11
Cerataulina pelagica			5	5		4						4
Chaetoceros brevis			4									
Chaetoceros costatus												4
Chaetoceros curvicetus			4									5
Chaetoceros decipiens			4									4
Chaetoceros delicatulus				6	6							
Eucampia cornuta								4	4			
Leptocylindrus adriaticus				4		4						
Leptocylindrus danicus			6	4		4	5	4				
Leptocylindrus minimus				5	4	4	6		6	5		5
Microflagellates (thecate)					4				4	4		
Navicula sp.							4					
Nitzschia »delicatissima«		4	4	4	4					5	4	
Nitzschia longissima			4									4
Prorocentrum micans									4			
Prorocentrum scutellum									4			
Rhizosolenia alata f. gr.								5	4	4		
Rhizosolenia fragilissima		4	4									
Skeletonema costatum		5	5			4	5		4	4	4	
Thalassionema nitzschioides												4

Microzooplankton

Heliozoa

The species *Sticholonche zanclea* was only sparsely present in December 1981 and January 1982. Its occurence in the Kotor Bay plankton concurred with its being present in the bays and coastal waters of the eastern Adriatic as well as in the northern Adriatic (Kršinić et al. 1988).

Ciliata other than tintinnina

Since the methods used have proved unsuitable in sampling ciliates smaller than 20 μm, which are of delicate structure, preserve poorly and are easily destroyed, the identification of these organisms was difficult, resulting in our results being necessarily approximate. According to Sorokin (1977), the ciliates can be correctly determined only if fanalysed alive or at the latest, an hour after collecting. Non-loricate ciliates larger than 20 μm were present in all the layers in the Kotor Bay plankton and were markedly dominant during the April-May period and in September (Fig. 4) with the maximum of 673 ind $\cdot$ 1^{-1} being registered at the surface an April. Their population centre was found to be at the surface or at 5 m, with the lowest values being recorded in the near bottom layers of the Bay.

Tintinnina

Out of a total of seventeen tintinnine species recorded in the Kotor Bay, eleven were estuarine and neretic, and six oceanic (Table 2). Estuarine and neritic tintinnines occured mainly in winter-spring with a relatively low population density not exceeding 20 ind $\cdot$ 1^{-1} whereas in June-July, these organisms completely disappeared from the plankton. Only single specimens of the open sea species occured in spring and autumn, with only *Dictyocysta elegans* being quantitatively important. A neretic form *Codonellopsis schabi* occured in August, and in September reached a maximum value of 432 ind $\cdot$ 1^{-1} at 20 m depth, which has been the highest value registered so far in the Kotor Bay (Fig. 4).

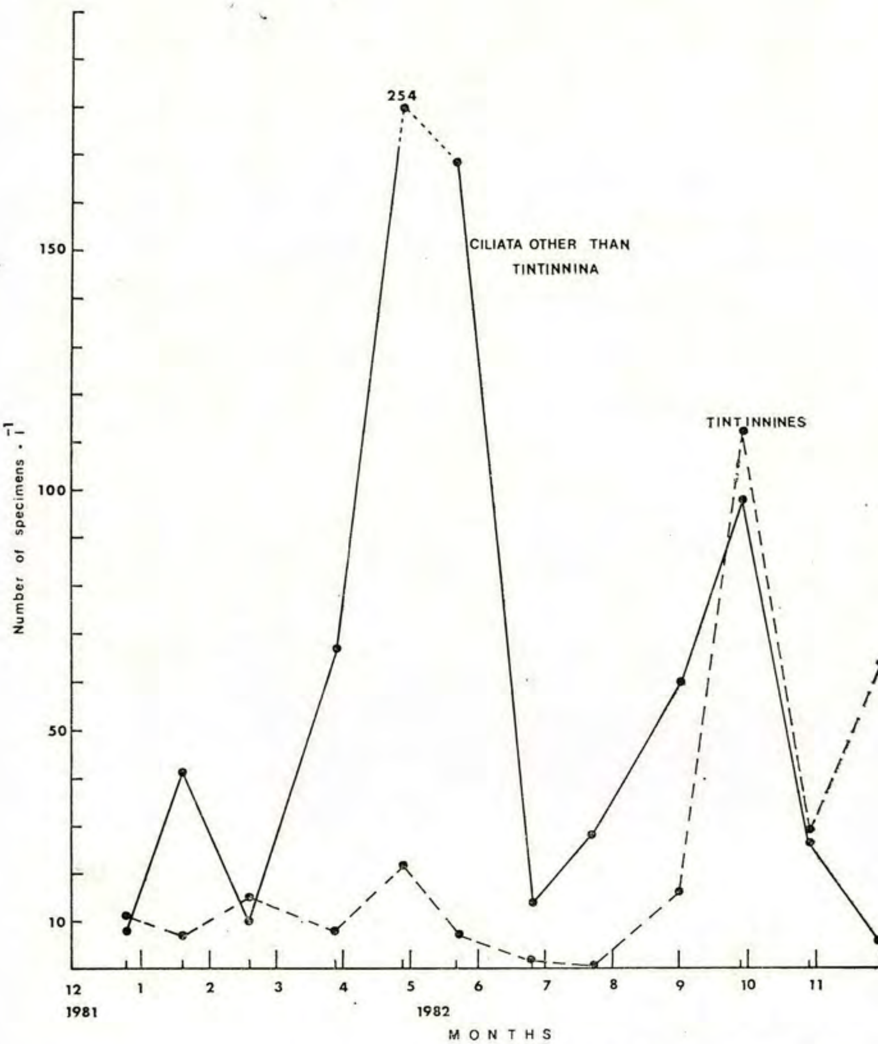

Fig. 4. Seasonal variations of ciliates cell density in the Kotor Bay
Sl. 4. Sezonske varijacije gustoće populacije cilijata u Kotorskom zaljevu

Table 2. List of tintinnines in the Kotor Bay, December 1981 to December 1982

Tabl. 2. Popis tintinina Kotorskog zaljeva, prosinac 1981 — prosinac 1982.

	Months											
	12	01	02	03	04	05	06	07	08	09	10	11
Tintinnopsis radix	+				+		+		+			+
T. campanula	+			+	+				+		+	
T. fracta	+										+	+
T. compressa					+							
T. levigata		+									+	+
T. nana		+	+									
T. beroidea							+					
Stenosemella ventricosa	+	+	+	+	+	+			+			
S. nivalis	+	+	+	+								+
Codonellopsis schabi	+								+	+	+	+
Favella ehrenbergii											+	+
Steenstrupiella steenstrupii					+							
Eutintinnus fraknoi						+						
E. lusus-undae					+	+						+
Dictyocysta elegans				+	+	+			+	+	+	+
Rhabdonella spiralis											+	
Petalotricha ampula											+	
Total	6	4	3	4	7	4	2	0	5	2	9	7

Nauplii

Nauplii dominated the micrometazoan population in the Kotor Bay (Table 1, Fig. 5). During a one-year study, as many as five naupliar population density peaks were noticed, with the maximum of 300 ind · l^{-1} being recorded at the surface in May. During the peaks, the nauplii in the younger stages were observed to dominate the surface samples, whereas the advance nauplii mainly inhabited the 5 and 10 m layers. Although rarely found at 2 m depth in other seasons, in April to July period high nauplii numbers inhabited this layer.

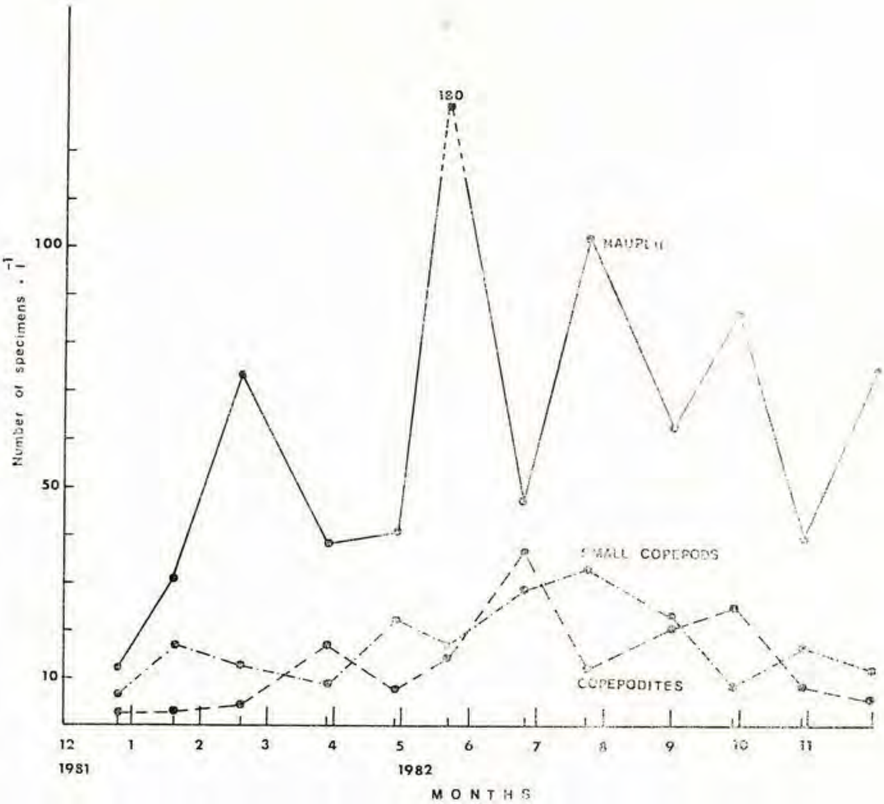

Fig. 5. Seasonal variation of micrometazoans in the Kotor Bay
Sl. 5. Sezonske varijacije mikrometazoa u Kotorskom zaljevu

Copepodites and adult small copepods

The copepod genera *Oncaea* and *Oithona* were quantitatively important in the Kotor Bay. As regards numerical abundance, *Oncaea* dominated in June and September, whereas *Oithona* copepodites in March and August with a maximum of 86 ind $\cdot$ 1^{-1} being registered at 5 m depth in June. *Oncaea* copepodites inhabited all the depths from May to July. In other seasons they hardly even appeared at the surface. As contrasted with the nauplii, copepodites preferred middle and deeper layers.

Among adult small copepods in the Kotor Bay, the following species were present: *Oncaea media, Oncaea subtilis, Oncaea zernovi, Oncaea ivlevi, Oithona nana, Euterpina acutifrons, Microsetella norvegica* and *Paracalanus parvus*. Adult small copepods scarcely ever occurred in the surface layer. The most of the population was observed to inhabit deeper layers. As opposed to the eastern Adriatic coast as well as the northern Adriatic, where *O. nana* was a major contributor to the small copepods numbers, in the Kotor Bay this species was of lesser importance, with the *Microsetella norvegica* being dominant. *M. norvegica* was present in the plankton throughout the year with the maximum density being reached during the warmer season. It was rarely found in the surface layer. Nevertheless, the maximum of 50 ind $\cdot$ l^{-1} was registered at 1 m depth in July, which has been so far the highest value recorded for this species in the Adriatic Sea.

Other Metazoa

Among other metazoans in the Kotor Bay, *Penilia avirostris, Polychaeta larvae, Bivalvia larvae* and juvenile *Appendicularia* were present. *Penilia avirostris* occured in the plankton from June to October with a relatively high density of 50 ind $\cdot$ l^{-1} being registered at 5 m depth in June. Juvenile *Appendicularia* were continually present in the Bay from January to September, with higher values being registered in March and May.

DISCUSSION

The qualitative composition of tintinnines in the Kotor Bay is similar to that of the Bay of Gruž (Kršinić, 1987). The tintinnine fauna of the Kotor Bay was characterized by the occurrence in the plankton of a small number of estuarine and neretic species. Due to the Kotor Bay being situated in the vicinity of the open sea, the salinity values in the near bottom layer were relatively high throughout the year ($S > 38.00 \cdot 10^{-3}$). However, the population density of oceanic species was low, and only single specimens were observed to immigrate into the Bay in April and in autumn. On the other hand, due to a fresh water influx from the land, a decline in salinity was registered at the surface, resulting in the estuarine species numbers being low with the density values mostly below 20 ind $\cdot$ l^{-1}. Only a neritic form *Codonellopsis schabi* reached the maximum density of 432 ind $\cdot$ l^{-1} in September, in the near bottom layer, when the salinity and temperature values were 38.34×10^{-3} and 23.23°C, respectively.

Ciliata other than tintinnina attained the maximum population density at the surface in April at a low salinity of 20.4×10^{-3} and a rearing temperature of 14.0°C. Another density maximum occurred in September during a decline in the surface temperature and salinity. In the other part of the year, ciliates were not numerically important in the Bay, whereas their April population

Table 3. The abundance of microzooplankton (No./1) in the Kotor Bay, December 1981 to December 1982
Tabl. 3. Količina mikrozooplanktona (No./1) u Kotorskom zaljevu, prosinac 1981 — prosinac 1982.

	24. 12. 1981.				19. 01. 1982.				19. 02. 1982.				26. 03. 1982.				27. 04. 1982.			
Depth (m)	1	5	10	20	1	5	10	20	1	5	10	20	1	5	10	20	1	5	10	20
HELIZOA																				
Sticholonche zanclea		3					1													
TINTINNINA																				
Tintinnopsis nana					2			4				35					10			
Tintinnopsis compressa																				
Tintinnopsis levigata					19								2	21			12	16	1	
Tintinnopsis campanula																				
Tintinnopsis radix																				
Stenosemella ventricosa		21	1	1														6	3	3
Stenosemella nivalis			8	6		1			29	2	24	6				8	1	2	2	14
Codonellopsis schabi		1	1	2		1										3				
Favella ehrenbergii																				
Dictyocysta elegans																			3	15
CILIATA OTHER THAN TINTINNINA	12	8	8	6	20	96	40	10	12	10	10	8	43	140	68	20	673	192	88	64
COPEPODA																				
Copepoda, naupliar	2	20	24	7		40	65	20	160	40	58	40	0	50	72	28	45	10	16	96
Oncaea, copepodites		6	5	4		1	5	2			10	8	1							26
Oncaea media																				5
Oncaea subtilis		1	1	1		1	7	2			1	3				7			1	22
Oncaea zernovi											1	2			1	4		1	1	
Oithona, copepodites				1		2			3					28	37	8		7	2	
Oithona nana						7	3	4		2	2	4		8	7	1		15	3	6
Euterpina acutifrons			4			1	4	2		6	6	4							2	4
Microsetella norvegica	1	8	11	3		3	25	8		8	10	6		1	2	8		2	6	20
Paracalanus parvus																		2	2	1
OTHER METAZOA																				
Penilia avirostris																				
Polychaeta larvae			3				10	6		8										
Bivalvia larvae						1								3	2	1				
Appendicularia juv.						4	3	2	3	6				18	5	3	4	3	3	2

Table 3. continued a

	20. 5. 1982.				24. 06. 1982.				21. 07. 1982.				31. 08. 1982.			
	1	5	10	20	1	5	10	20	1	5	10	20	1	5	10	20
TINTINNINA																
Tintinnopsis campanula															4	
Tintinnopsis radix								6							32	
Stenosemalla ventricosa			1												15	
Codonollopsis schabi															11	
Dictyocysta elegans			20	8											4	
CILIATA OTHER THAN TINTINNINA	300	160	156	60	16	4	14	22	8	56	8	40	24	15	44	160
COPEPODA																
Copepoda, naupliar	300	65	120	240	66	16	30	80	95	86	18	210	42	86	74	52
Oncaea, copepodites	6	15	18	20	31	86	21	10	16	4	12	12			2	7
Oncaea media									1							3
Oncaea subtilis				4					4							8
Oncaea zernovi				1										24	48	4
Oithona, copepodites																
Oithona nana	4	8	6		6	8	8	8	7	10	7	16			8	4
Euterpina acutifrons					4	3	4			1					5	2
Microsetella norvegica		1	10	24		36	20	18	50	26	16				43	16
Paracalanus parvus		1	2	4				1	1			3				
OTHER METAZOA																
Penilia avirostris					4	50	8		8	8	24	2			16	
Appendicularia juv.	1	10	4	1	8	4	6	6	3	1	2	3			3	1

Table 3. continued b

	27. 09. 1982.				28. 10. 1982.				08. 12. 1982.			
	1	5	10	20	1	5	10	20	1	5	10	20
TINTINNINA												
Tintinnopsis levigata					20				189	24		
Tintinnopsis campanula							1					
Tintinnopsis radix											4	
Stenosemella nivalis							46					
Codonellopsis schabi		8	12	432		6	38	2	2	1		
Favella ehrenbergii		4							20			
Dictyocysta elegans											10	6
CILIATA OTHER THAN TINTINNINA	336	48	4	4	48	40	16	4	4	8	8	6
COPEPODA												
Copepoda, naupliar	160	93	52	40	10	98	50	3	140	60	96	14
Oncaea, copepodites	10	70	18	4	1		10	8		7	8	
Oncaea media				4			4	6				
Oncaea subtilis							1	3				
Oithona, copepodites						12	4		5	4	2	1
Oithona nana	1	2				10	1			2	1	
Euterpina acutifrons		3	3	2	1	4	2		1	2	3	4
Microsetella norvegica		1	14	12		10	8	2		10	24	10
Paracalanus parvus					1							
OTHER METAZOA												
Penilia avirostris	1	24	6	5								

density values were relatively high if compared with the values registered along the eastern Adriatic coast. Similar values were recorded only in the strongly eutrophicated northern Adriatic region in summer (Kršinić et al. 1988).

Among small copepods, typically coastal forms occured in the Kotor Bay. Their presence in the Bay was registered by earlier investigations such as Car (1896), Gamulin (1938), Vukanić (1971). During our investigation, the presence of the species *Oncaea zernovi* and *O. ivlevi* was for the first time recorded in the deeper layers of the Bay in February and March, which was probably due to a weak immigration of the open sea species into the Bay. Most of the year, nauplii were the dominant component of the total Kotor Bay microzooplankton. A decline in their average population density down to 40 ind $\cdot$ l^{-1} was registered only in December 1981 whereas the maximum value of 180 ind $\cdot$ l^{-1} was registered in May 1982. Therefore, it may be concluded that the first and probably most important nauplii maximum in the Kotor Bay took place considerably earlier than in other areas of the eastern Adriatic coast. It was in August that nauplii were dominant in the total microzooplankton in the Bay of Mali Ston (Mušin, 1986), the Kvarner region (Kršinić, 1979) and the northern Adriatic (Kršinić et al. 1988). Although *O. nana* almost regularly dominate the copepods fauna of the above mentioned regions in warmer months, this species was of lesser importance in the Kotor Bay where *Microsetella norvegica* was observed to have attained the highest value registered so far in the Adriatic.

Recently, more attention has been paid to the role of microzooplankton in the coastal ecosystem food web, and especially to the relationship existing between phytoplankton and microzooplankton. In world plankton literature, many methods used to estimate zooplankton grazing have been analysed, since a considerable discrepancy has been observed to exist among the data provided by these methods, which have proved to be inefficient to identify all the factors that act upon processes in the pelagic waters. The methods used in grazing estimation are: Indirect methods (Beers and Stewart, 1970; Rassoulzadegan and Etienne, 1981; Burkil, 1982) or direct methods, among which most reliable technique is »the dilution method« (Landri and Hassett, 1982; Burkil et al. 1987; Gifford, 1988). According to Beers and Stewart (1970), microzooplankton has consumed 7-52% $\cdot$ d^{-1} of primary production in California Current, whereas, in Celtic Sea, Burkil et al. (1987) have found that microzooplankton could account for 13-65% $\cdot$ d^{-1} of primary production. Gifford (1988) has found the microzooplankton to consume from 0 to 100% of the diatoms in Halifax Harbour. During a November bloom of large diatoms, grazing was not pronounced, whereas in March, grazing and phytoplankton growth were in balance, indicating that 100% of the daily chlorophyll production was grazed. According to Verity (1986) an annual mean microzooplankton grazing accounted for 62% of nanophytoplankton chlorophyll a production in the Narragansett Bay. This paper presents the preliminary results on the relationship between phyto- and microzooplankton populations. These are the first data on the appearance and the succession of dominant microzooplankton groups. On the basis of the presented data, a more through investigation into the grazing processes is possible in the near future.

No significant linear correlation was observed to exist between nano- microphytoplankton and the microzooplankton groups. The nanophytoplankton population density was high throughout the year, and uniformly distributed through all the layers (10^6-10^7 cells $\cdot$ 1^{-1}). Ciliates appeared to be important phytoplankton consumers only a short period of time, namely in April-May and September, when a marked increase in their numbers was recorded. A decline in nanophytoplankton density in September was presumably due to a simultaneous predominance of protozoans. In spring, the grazing of ciliates other than tintinnines is supposed to have been in balance with the primary production. Since nauplii were present in high concentrations throughout the year, and copepodites and small copepods in the summer month, these organisms may be supposed to be important regulators of microphytoplankton primary production. High nauplii numbers in May and July as well as large numbers of small copepods registered in July, considerably affected a substantial simulataneous decline in microphytoplankton cell densities. As regards the population density, the larger zooplankton of the Kotor Bay may be supposed to be of lesser importance. In May 1982 Benović and Onofri (1983) registered highest copepod density of approximately 1 ind · 1^{-1} using a 250 µm mesh netting net.

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