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ANNUAL VERTICAL DISTRIBUTION OF MICROZOOPLANKTON IN THE BAY OF MALI STON, SOUTHERN ADRIATIC (1983—1984)

GODIŠNJA VERTIKALNA RASPODJELA MIKROZOOPLANKTONA U MALOSTONSKOM ZALJEVU, JUŽNI JADRAN (1983—1984)

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The microzooplankton was sampled at fortnight intervals at the station Usko in the Bay of Mali Ston. Numerical abundance of microzooplankton major groups and organisms was studied. The day-night vertical distribution of non-loricate ciliates, tintinnines, nauplii and »other microzooplankton« is discussed.

INTRODUCTION

The interest for microzooplankton, its population structure, density and its role in the pelagic food web has become increasingly pronounced over the last twenty years (Margalef, 1963; Beers and Stewart, 1967, 1969, 1970; Zaika *et al.*, 1976; Sorokin, 1977; Takahashi and Hoskins, 1978; Smetacek, 1981). The microzooplankton is the link from primary to secondary production within which one or more trophic levels may exist. In consuming the primary producers, the microzooplankton contributes from 10 per cent (Taguchi, 1976) to 70 per cent (Beers and Stewart, 1971). The protozoans have a short generation time, eg. tintinnines from 12 to 24 hours (Heinbokel, 1978). Due to a simple life cycle, these animals can rapidly react to changes in marine environment and in such a way they prevent energy losses in the sea (Capriulo and Carpenter, 1980).

Data on day night microzooplankton are scarce. Nevertheless, the data on the Mediterranean microzooplankton (Zaika and Ostrovskaya, 1972) and tintinnines (Gillbricht, 1954; Vitiello, 1964; Stoecker *et al.*, 1984 ; Dale, 1987) are available. By contrast, for the Adriatic, except for the data on diurnal vertical migration of the three tintinnines species reported by Kršinić (1987), no other information exists.

This study was performed in order to get more knowledge on these small zooplankton, a possible difference existing between the day and night densities and their vertical distribution patterns. As the area to be investigated, the Bay of Mali Ston has been the most suitable site due to its being shallow, not densely populated, well-known for centures long shellfish cultivation (oysters and mussels). According to phytoplankton population density and biomass, the Bay of Mali Ston is determined as a moderately (naturally) eutrophicated ecosystem (Viličić, 1989). The Bay od Mali Ston is determined as a quantitatively rich region in mezozooplankton biomass (Benović *et al.*, 1984). Earlier investigations on microzooplankton in the Bay of Mali Ston were performed in 1975/76 (Kršinić, 1979a) and 1979/80 (Kršinić and Mušin, 1981; Mušin, 1984, 1986; Kršinić, 1987) at monthly intervals in three depth layers. The scope of this paper is to present data on microzooplankton obtained at short temporal intervals throughout the year at the station Usko were the main exchange of water masses occurs. The results were obtained on the basis of the samples taken in the 2 m depth layers during the daytime and at night, and thus may contribute to the knowledge on this zooplankton group in the Bay of eastern Adriatic.

MATERIAL AND METHODS

Investigations on microzooplankton were performed at the station Usko in the Bay of Mali Ston (southern Adriatic) during 29 cruises from April 1983 to March 1984 (Fig. 1).

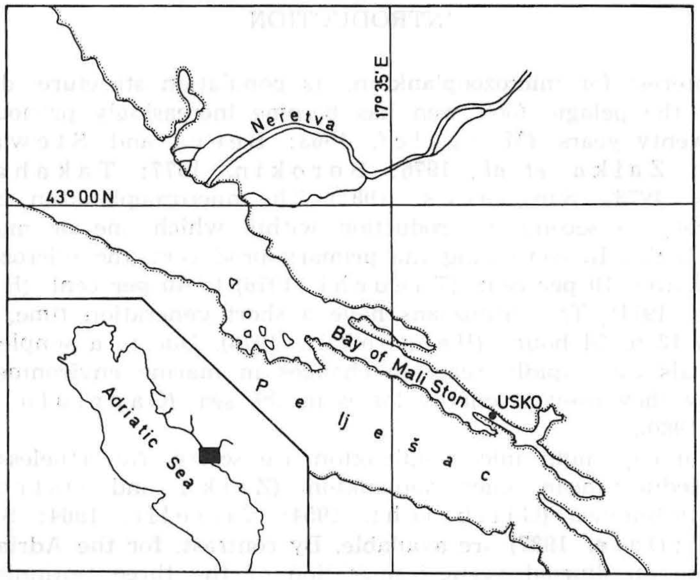

Fig. 1. Area investigated — Station Usko

As many as 406 microzooplankton samples were taken by a 5 l Van Dorn sampler at 2 m depth intervals (maximum depth 12 m). For the qualitative analyses, a 53 μm mesh netting Nansen net was used, towed from the bottom to the surface. All the samples were preserved in 2.5 per cent neutral buffered formaldehyde. Temperature and salinity measurements were performed with a TS probe (Hydrobios LF 191) only during the daytime.

In the laboratory, the Van Dorn samples were concentrated by a 3-step settling method to about few ml within 72 hours. The microzooplankton counts were obtained using a microscope under the magnification of X 100. The species and groups found in higher concentrations were counted in 1/4 or 1/8 of the counting chamber bottom plate.

For the statistical analyses, the whole water column was divided into 3-layers: the surface layer (0 and 2 m), the intermediate (4, 6 and 8 m) and the bottom layer (10 and 12 m).

RESULTS AND DISCUSSION

Hydrography

Minimum and maximum temperature values of 7. 9—25.0°C at Usko were recorded in the surface layer in mid-February and the end of July. During the spring, a vertical stratification occurred (Fig. 5). In the early summer, the thermocline was established in the surface layer (Fig. 6). At the end of August it reached the 6—8 m layer. A decrease in temperature gradient resulted in the isothermy being recorded in the autumn (Fig. 7). By contrast, during the winter, an inverse stratification pattern was noted (Fig. 8). The annual salinity values ranged from 28.9 to 38.2 $S \times 10^{-3}$. Salinity increased with depth, with the annual variations becoming less pronounced. Low salinity values in the surface layer, especially during the summer months, may be associated with the inflow of the fresh waters of the Neretva river into the Bay.

Microzooplankton abundance and composition

At the station Usko the mean microzooplankton density values ranged from 110 to 936 ind l^{-1} during the day and from 132 to 1053 ind l^{-1} during the night (Fig. 2). The annual day and night means and standard deviations (sx) were 249 +/— 189.1 ind l^{-1} and 273 +/— 201.5 ind l^{-1}, respectively. The counts didn't correspond to actual values, since the organisms smaller than 20 μm, heterotrophic flagellates and ciliates were not counted due to their being very difficult to distinguish from the autotrophic organisms.

Towards the end of April, the microzooplankton was completely absent from the surface at night. No explanation has been found as to the occurrence of this phenomenon. The maximum microzooplankton numbers of 1643 ind l^{-1} was recorded in the early April at the 12 m depth. It was mainly due to high numbers of the tintinnines species *Helicostomella subulata,* 944 ind l^{-1} (Table 1). Kršinić (1987) reports huge numbers of this tintinnine exceeding 1000 ind l^{-1} in the late March 1983 that suggests the microzooplankton density over the same years as being higher than recorded during our investigation due to a simultaneous decline in protozoan numbers. Huge protozoan numbers with the predominance of ciliates were recorded during the earlier investigations in the Bay of Mali Ston. The maxima total microzooplankton values in 1975/76 and 1979/80 (Kršinić, 1979a; Mušin, 1984) were 1.3 and 2.6 times lower than 1983/84 maxima.

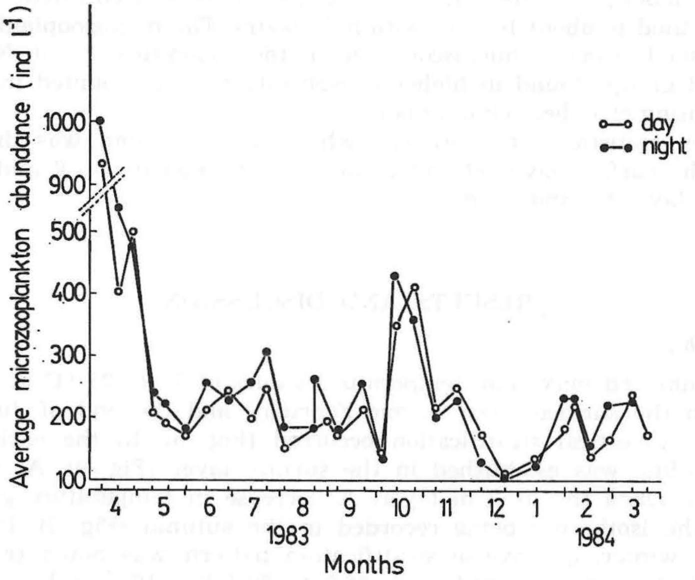

Fig. 2. Seasonal distribution of average microzooplankton abundance throughout the 12 m water column at the Station Usko

In other parts of the Adratic, microzooplankton maxima recorded are lower than those reported for the Bay of Mali Ston (Kršinić, 1979b; 1981; 1982). Revalante and Gilmartin (1983) nevertheless, report maximum microzooplankton density of 5.6×10^4 ind l^{-1} in the northern part of the Adriatic, near the river Po estuary. According to their results, ciliates were dominant contributing from 90 to 98 per cent to the total microzooplankton. Since the ciliates are, along with bacteria, important decomposers of

Table 1. Range of numerical abundance (ind l^{-1}) of the microzooplankton groups at the Station Usko in 1983—1984.

	range	
	day	night
Non-loricate ciliates	5— 415	0— 363
Tintinnines	0— 944	0— 798
Nauplii	4— 392	0— 426
»Other microzooplankton«	0— 557	0— 473
Microzooplankton	58—1643	0—1553

the supended organic matter, outstandingly high numbers were due to their aggregating on the organic detritus carried into the northern Adriatic by the river Po. Due to different method used for the conservation and the analyses of the samples, the authors were able to count the organisms smaller than 30 μm. Additionally, a highly eutrophicated area near to the Po river estuary (Revelante and Gilmartin, 1976) can by no means be compared to the Bay of Mali Ston which is different regarding its hydrographical and other ecological characteristics.

The percentage contribution of the ciliates (non-loricate ciliates and tintinnines) and nauplii to the total microzooplankton numbers varied throughout the year (Fig. 3). Nauplii were most abundant group and their contribution to the total microzooplanktion population averaged 40 (10—67) per cent. The tintinnines formed from 5 to 61 (averaged 32) per cent of the total in the autumn whereas in the winter months non-loricate ciliates were plentiful, contributed 70 per cent to the total numbers in mid-March. No differences were observed in the contribution of certain groups within the total microzooplankton numbers between day and night.

Throughout the year, the total microzooplankton numbers were most frequent within the 100—200 ind l^{-1} abundance class (Fig. 4). In the northern Adriatic, the frequency maximum was in the 100—500 ind l^{-1} abundance class during the autumn, and in the 1000—5000 ind l^{-1} class in the period of pronounced stratification (Revelante and Gilmartin, 1983).

Of 27 tintinnines species, the most numerous was *H. subulata* that was the only tintinnine found in the early April. Due to large numbers of the species *Stenosemella ventricosa* during the autumn, and *S. nivalis* during autumn/winter with the mid-March maximum registered, simultaneously high tintinnines density was recorded. Non-loricate ciliates were represented by the following genera: *Strombidium, Strombilidium* and *Lohmaniella.* Napulii were not determined and were mostly the developmental stages of the small copepods of the genera *Oithona* and *Oncaea.* According to Lučić (1985), these were also the nauplii of most abundant copepods *Acartia clausi, Centropages kroyeri, Paracalanus parvus* and *Temora longicornis.* Among »other microzooplankton« included were the following organisms: of protozoans, the species *Sticholoncke zanclea*, among micrometazoans, the small copepods and copepodites of the genera *Oithona* and *Oncaea,* pteropods, juvenile chaetognaths ,appendicularians and the larvae of the benthic organisms. The four species of the small *Oncaea* copepods, *O. zernovi, O. ivlevi, O. exigua* and *O. vodjanitskii,* were recorded for the first time in this area. The first data on their numerical abundance will be presented in paper by Rudenjak-Lukenda (in preparation). Their presence in the area investigated may be attributed to the influx of the open sea waters.

Vertical distribution

The annual vertical distribution pattern of total microzooplankton, tintinnines, non-loricate ciliates, nauplii and »other microzooplankton« is illustrated in the Figures 5, 6, 7 and 3.

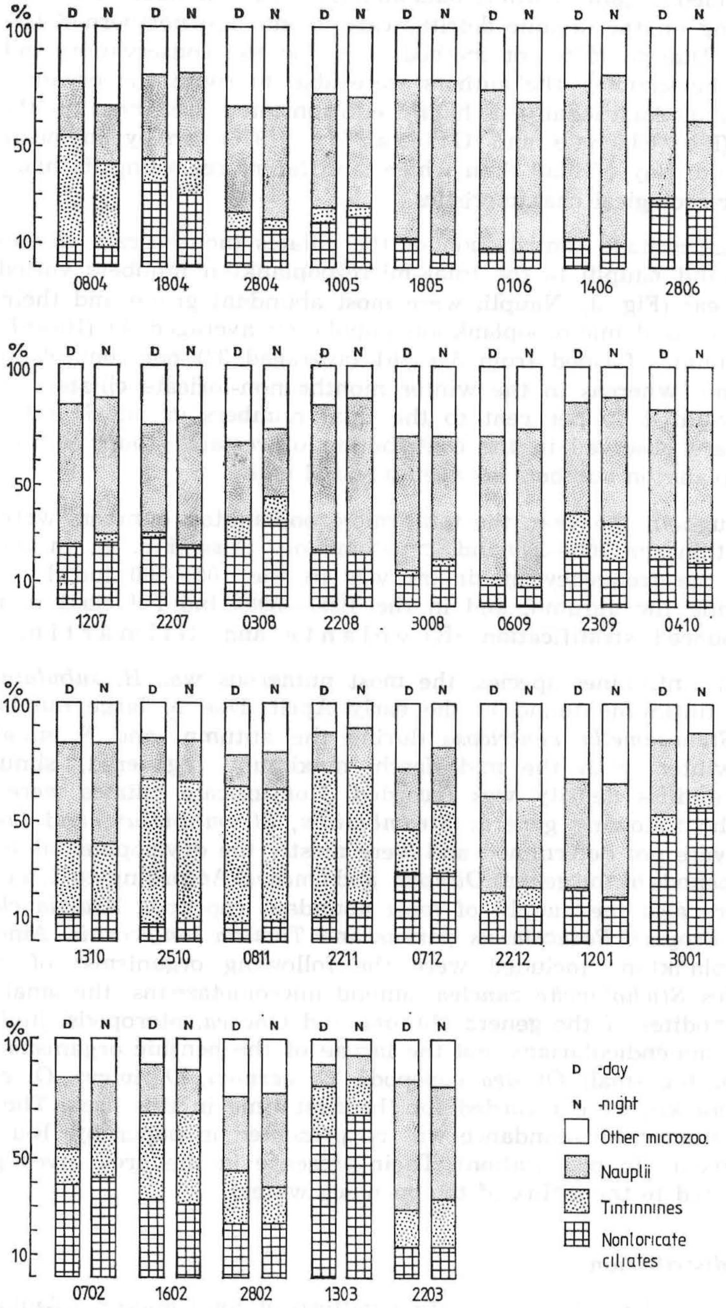

Fig. 3. Relative contribution of different groups to the average microzooplankton numbers during the day and at night at the station Usko

The microzooplankton density increased with depth during the period from April until the mid-June (Fig. 5). During the stratified summer period, the majority of the population was found in the layer above the thermocline except at the beginning of September when an increase in numbers with depth was observed (Fig. 6). During the autumn, the microzoplankton density varied irregularly due to the numerically most important groups, tintinnines and non-loricate ciliates (Fig. 7). During the winter period (January—March) the total microzooplankton numbers increased with depth except towards the end of January during the daytime when the maximum values were registered at surface owing to large numbers of non-loricate ciliates (Fig. 8). There were no significant differences in day and night densities of the total microzooplankton according to analyses of variance ($p > 0.05$). Our data registered during the stratified condition (summer) are in agreement with data on vertical distribution of the microzooplankton in the northern Adriatic by Revelante and Gilmartin (1983). In general, data on the vertical distribution of microzooplankton are pretty hard to interpret. According to Rassoulzadegan and Gostan (1976) the vertical distribution of microzooplankton changed at the intervals of 17 minutes in the Bay of Villefranche with the maximum depth of 19 m.

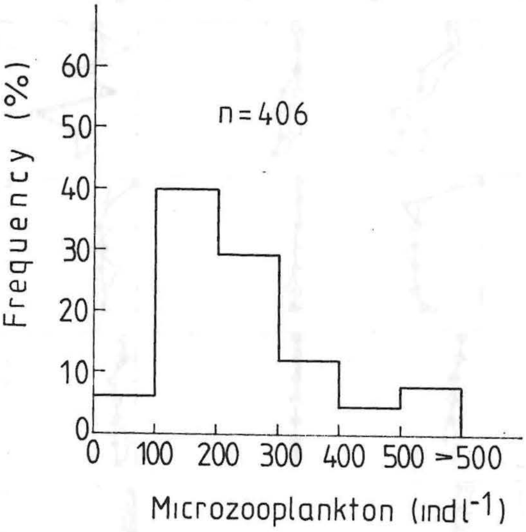

Fig. 4. Frequency distribution of total microzooplankton abundance at the Station Usko

Tintinnines increased to relatively high numbers in the early April and in the October—November period. The majority of April population was found in the 10—12 m layer when the species *H. subulata* dominated in numbers exceeding 900 ind l^{-1} (Fig. 5). This tinitinnine was the most nu-

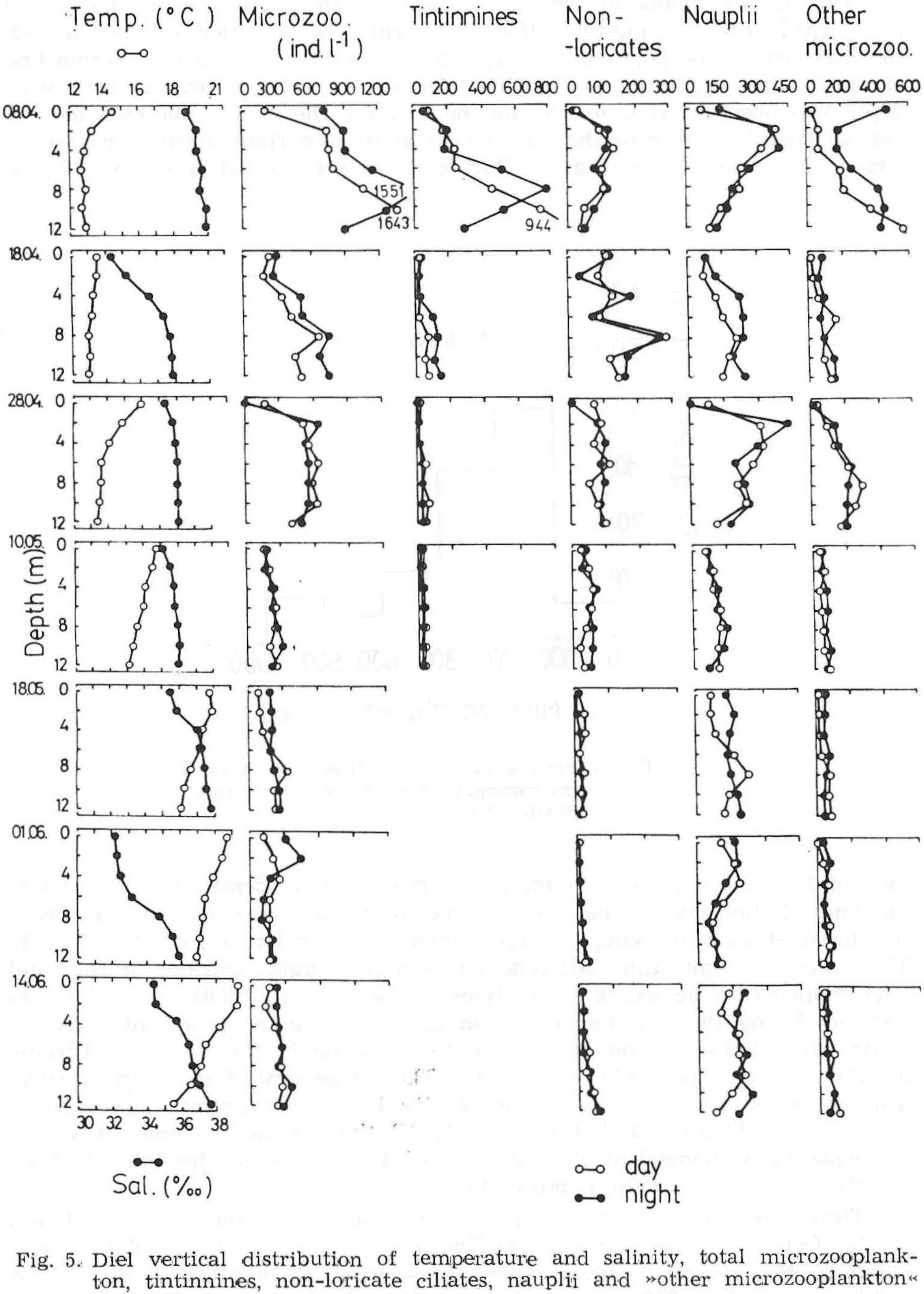

Fig. 5. Diel vertical distribution of temperature and salinity, total microzooplankton, tintinnines, non-loricate ciliates, nauplii and »other microzooplankton« at the Station Usko in the spring

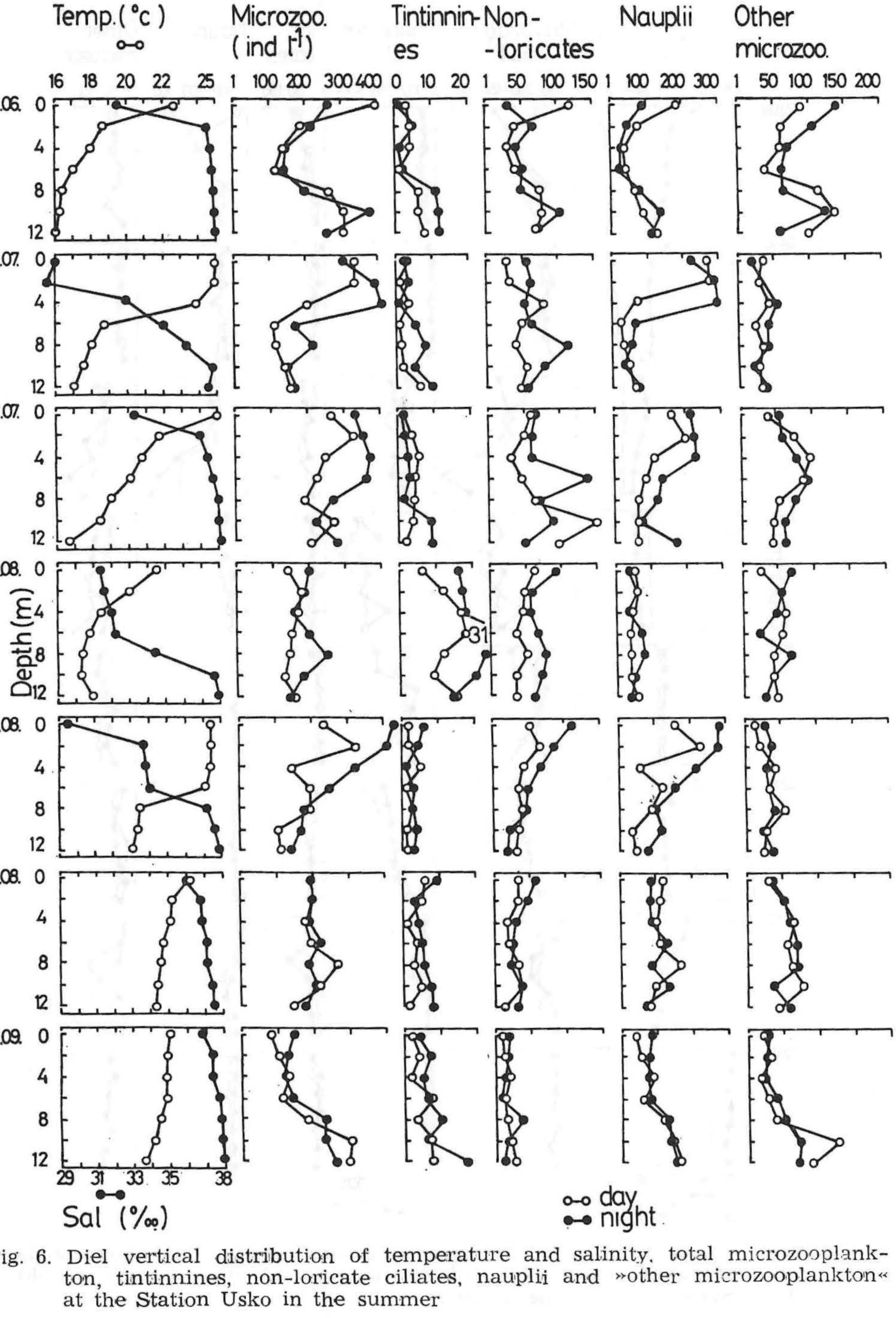

Fig. 6. Diel vertical distribution of temperature and salinity, total microzooplankton, tintinnines, non-loricate ciliates, nauplii and »other microzooplankton« at the Station Usko in the summer

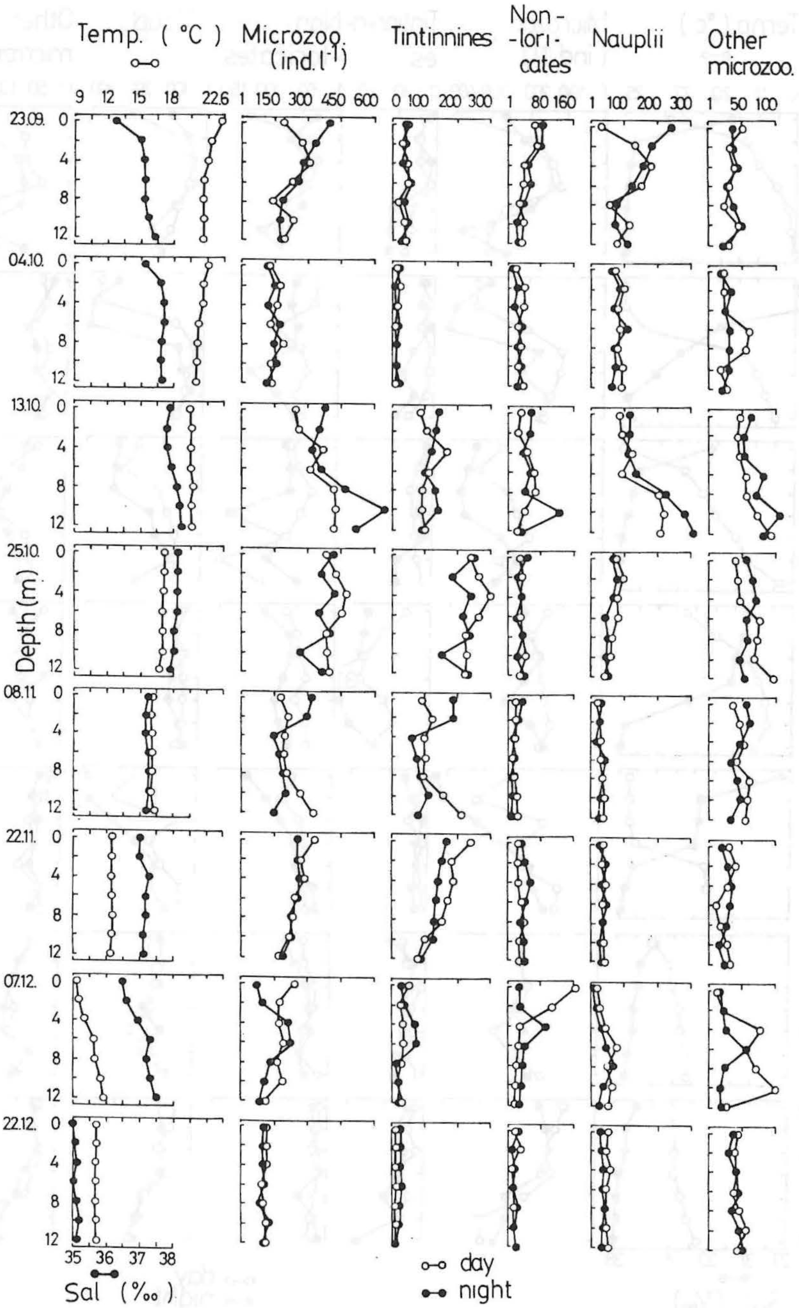

Fig. 7. Diel vertical distribution of temperature and salinity, total microzooplankton, tintinnines, non-loricate ciliates, nauplii and »ther microzooplankton« at the Station Usko in the autumn

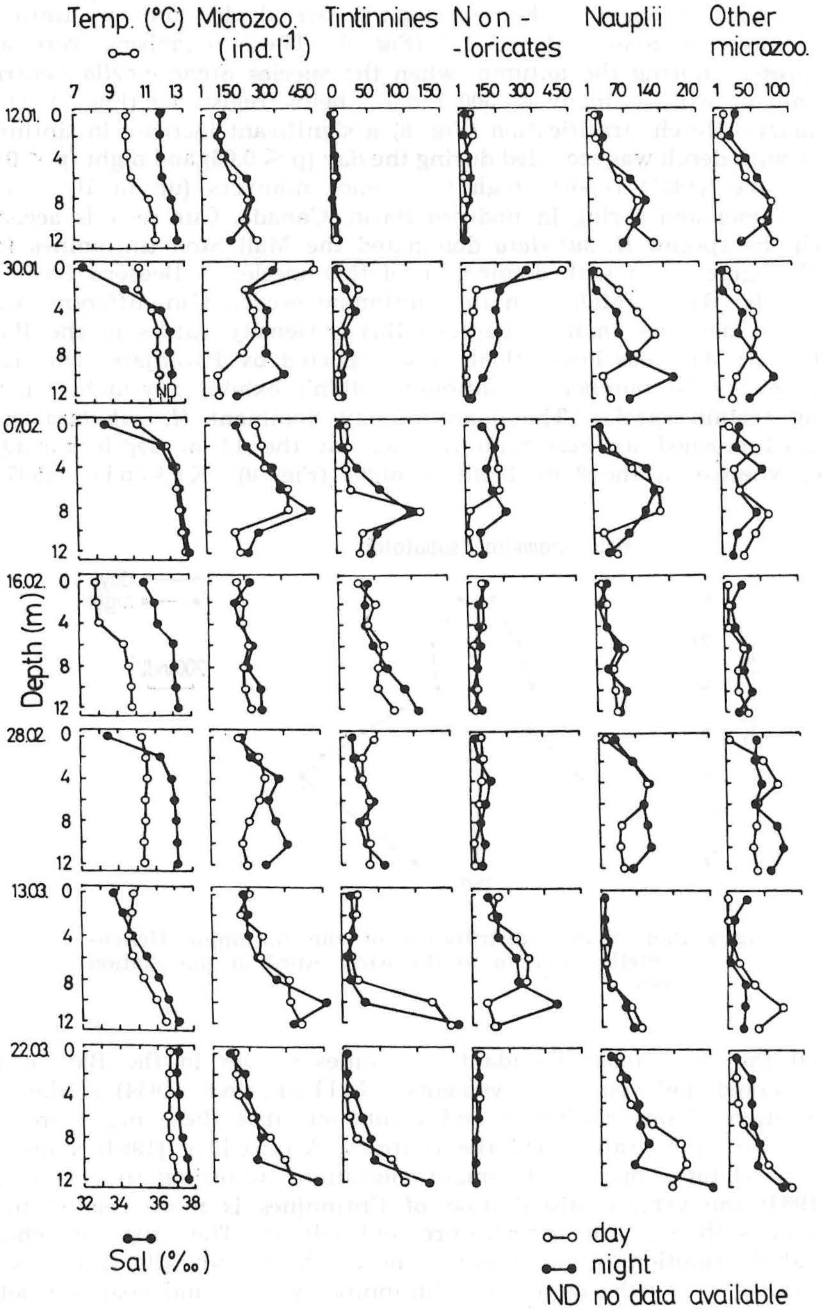

Fig. 8. Diel vertical distribution of temperature and salinity, total microzooplankton, tintinnines, non-loricate ciliates, nauplii and »other microzooplankton« at the Station Usko in the winter

merous species throughout the investigated period. In summer, tintinnines numbers never surpassed 31 ind l^{-1} (Fig. 6). These organisms were abundantly present during the autumn, when the species *Stenosemella ventricosa* was dominant with as many as 300 ind l^{-1} being registered (Fig. 7). During the January—March stratification (Fig. 8) a significant increase in tintinnines numbers with depth was recorded during the day ($p < 0.05$) and night ($p < 0.005$). Paranjape (1987) reports high tintinnines numbers (up to 10^4 ind l^{-1}) in late summer and spring in Badford Basin, Canada. Our records according to which the species *H. subulata* dominated the Mali Ston tintinnines fauna are in the agreemenen with domination of this species in Bedford Basin. However, in the Bay of Mali Ston this tintinnine occurred in different seasons and reduced densities than in Badford Basin. Density values in the Bay of Mali Ston are 30 times lower than those reported by Paranjape. During our investigations, total number of tintinnines didn't exhibit day-night variation excepting certain species. The quantitatively dominant *H. subulata* in the early April reached its maximum numbers at the 12 m depth during the daytime, whereas at the 8 m depth at night (Fig. 9). Kršinić (1987) investigated the three most abundant tintinnines species in the Bay of Mali Ston and noted diel vertical movements. Gillbricht (1954) studied vertical migration of one tintinnine and points out that these organisms have a limited diurnal migration. On the contrary Vitiello (1964) states that tintinnines exhibit a marked day-night migration. According to Stoecker *et al.* (1984) the vertical distribution of tintinnines is more related to the dinoflagellates than to the temperature and salinity. They reported changes in vertical distribution of these organisms at the four-hourly intervals and the depth of 4 m. Furthermore, most tintinnines were found near the bottom at night and at the surface in the morning.

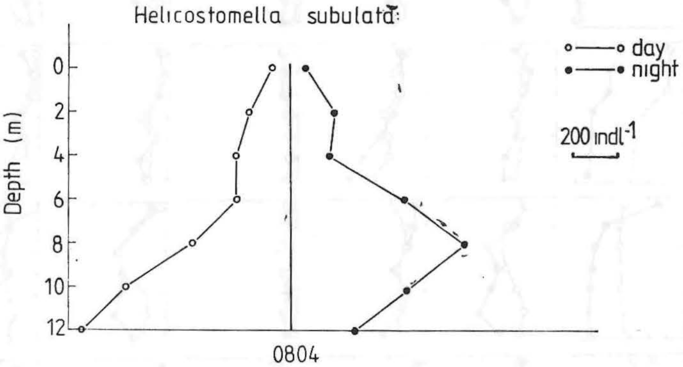

Fig. 9. Diel vertical distribution of the tintinnine *Helicostomella subulata* in the early April at the Station Usko

Non-loricate ciliates are of tender structure, easily destroyed and due to their small size they preserve poorly and are very difficult to sample and analyse. In the period April—June, the vertical stratification of non-loricate ciliates was noted to vary irregularly and their numbers amounted to 300 ind l^{-1} (Fig. 5). During the summer months, their density increased with depth but the density values didn't exceed 150 ind l^{-1} (Fig. 6). Non-loricate ciliates were present in relatively small numbers during the period September—December, not more than 80 ind l^{-1}, except the mid-October and the beginning of December (Fig. 7). In winter, a well-marked vertical stratification was noted during the daytime ($p < 0.05$) with maximum numbers of 415 ind l^{-1} being registered at the surface in the late January (Fig. 8). No differences were noted between the day and night samples due to analysis of variance), presumably because the organisms were considered in total and not each species separately. Dale (1987) states that total planktonic ciliates do not exhibit diel vertical migration in the landlocked fjord of the 40 m depth and divides these organisms into 4 major groups. The first group migrates from 15 to 10 m depth with the velocity of 1 m h^{-1}. The second group shows no or little migration. The third group is comprised of organisms inhabiting surface layers that by the exchange of water masses outflow from the Bay. The fourth group is made of holotrich ciliates that exhibit irregular fluctuations in their vertical distribution. Due to ciliates having a well-developed swimming ability along with the influence exerted by physical parameters, the changes in their vertical distribution in the shallow waters occur. Since our samplings were performed twice daily at the intervals of cca 12 hours, ciliates were likely to increase in their numbers under favourable ecological conditions.

The maximum naplii number of 426 ind l^{-1} was recorded at the beginning of April at night. This record corresponds to the values reported by Mušin (1986) for the Mali Ston Bay area which are highest values reported so far for the Adriatic. A low corelation was found to exist between nauplii numbers and temperature ($r = 0.32$; $n = 202$; $p < 0.001$). In the period from April to the early June, the majority of the nauplii population was in the 2—6 m layer (Fig. 5). High density of nauplii in the summer months was recorded in the layer above the thermocline (from the 2—8 m depth) excepting the late August and the early September when their numbers increased with depth (Fig. 6). The number of individuals in the period September—December didn't exceed 96 ind l^{-1}, and were uniformely distributed throughout the water column (Fig. 7). In the winter months, the density increased with depth due to the occurrence of the inverse stratification (Fig 8). Vertical stratification was pronounced during the daytime over summer ($p < 0.005$) whereas during the winter months both at night ($p < 0.01$) and during the day ($p < 0.05$). The difference between day and night numbers was not significant due to analysis of variance. Data on moving patterns exhibited by nauplii are scarce. Banse (1964) reports the migrations of nauplii through the temperature and salinity gradient in the Bay of Kiel. Under the experimental condition, the velocity of the so-called »quiet« movements was 0.4—6.6 m h^{-1} whereas that of the »precipitated and jumpy« amounted to 11—37.6 m h^{-1} (Zaika and Ostrovskaya, 1972).

Of »other microzooplankton«, numerically important were small copepods and copepodites. In the early April, the small copepods attained the maximum of 240 ind l^{-1} at the surface at night whereas copepodites reached 339 ind l^{-1} at the 12 m depth during the day in the same month (Fig. 5). Both were sparsely or not at all found at the surface during the day. Simultaneously with maxima registered the number of small copepods increased by 60 times at the surface at night (Fig. 10). Small copepods and copepodites were the only microzooplankton groups to exhibit diel vertical migration. While investigating the metazoan fraction of the microzooplankton in the Bay of Mali Ston, Mušin (1986) has reported 447 ind l^{-1}, the value higher than the one we recorded in the same area. Total numbers of »other microzooplankton« increased with depth. During our study these organisms exibited diurnal-noctural differences in density in the surface layer, $p < 0.05$, according to Student's t-test (Fig. 5, 6, 7 and 8) throughout the year. The vertical distribution was pronounced during the day in the spring months ($p < 0.005$) and autumn ($p < 0.05$), and both during the day and at night in winter ($p < 0.001$ and $p < 0.005$).

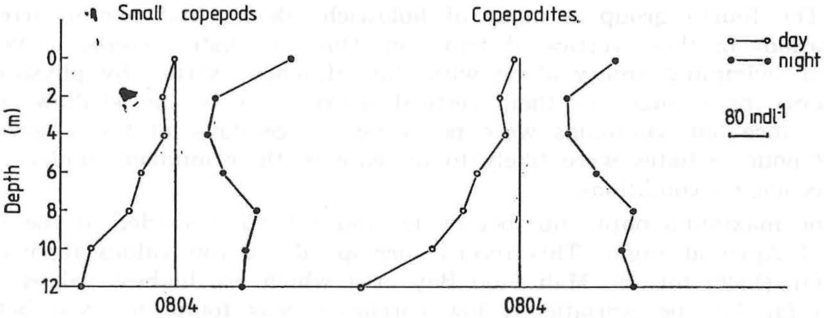

Fig. 10. Diel vertical distribution of small copepods and copepodites in the early April at the Staton Usko

In investigating the trophic relationships between the pelagic communities, it is indespensable to determine vertical distribution patterns of the plankton. Primary factors responsible for the different migration patterns of the plankton are biological and physical movements, biological and physico-chemical interactions and changes occurring with time. Although the microzooplankton organisms are capable of swimming movements, the protozoans and small metazoans have a limited migration due to their small size (Banse, 1964). Furthermore, the shallowness of the area investigated (12 m depth at Station Usko) may be a limiting factor. The paucity of the data on other plankton components, numerous consumers of microzooplankton and physico-chemical factors made it impossible to determine parameters responsible for vertical distribution which wasn't the primary scope of our descriptive study. Therefore, in future investigations of the Bay of Mali Ston, detailed studies on the microzooplankton ecology of the shallow coastal waters could be performed and other parameters continually observed in order to get data to be used in improving the shellfish cultivation methods in the area.

CONCLUSIONS

From the results of this investigation, the following conclusions may be drawn:

— Numerically most important were nauplii that formed as much as 40 per cent of the total microzooplankton population throughout the year.

— Total microzooplankton numbers increased with depth in spring and winter, whereas during the summer, most microzooplankton was recorded above the thermocline. During the autumn, the microzooplankton population was unequally distributed through the water column. No significant differences were noted through the year between the day and night samples.

— The tintinnines were most abundant in the 10—12 m layer in April. During the winter, their numbers increased with depth. During the same time, these organisms exhibited a marked vertical stratification ($p < 0.05$ during the daytime, $p < 0.005$ at night). The day-night difference was noted in some of the species and not in total tintinnines numbers.

— The vertical stratification of non-loricate ciliates was pronounced during the winter ($p < 0.05$) with the maximum being recorded at the surface. Numerical abundance of total ciliates numbers didn't exhibit day and night differences. Therefore, each ciliates species should be analysed separately in order to get more accurate knowledge on the differences between the day and night samples.

— The vertical stratification of nauplii as related to temperature, was pronounced during the daytime in summer, whereas during the winter both during the day ($p < 0.05$) and at night ($p < 0.01$). No significant differences between day and night samples were noted.

— »Other microzooplankton« were the only group that exhibited significant differences between day and night numbers at the surface throughout the year ($p < 0.005$). The maximum of small copepods, 240 ind l^{-1}, recorded in April represents the higest value so far registered for the microzooplankton in the Adriatic Sea.

— The four *Oncaea* species *(O. zernovi, O. ivlevi, O. exigua, O. vodjanitskii)* were recorded for the first time in the area investigated presumably due to the inflow of the open seas.

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GODIŠNJA VERTIKALNA RASPODJELA MIKROZOOPLANKTONA U MALOSTONSKOM ZALJEVU, JUŽNI JADRAN (1983—1984)

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KRATKI SADRŽAJ

Istraživanje mikrozooplanktona na postaji Usko u Malostonskom zaljevu se temelji na analizi 406 dano-noćnih uzoraka u godini 1983/84. Prilikom 29 izlazaka na teren sakupljeni su uzorci Van Dorn crpcem (5 litara), a obrađeni metodom sedimentacije. Kvalitativni podaci su dobiveni obradom uzoraka planktonske mreže finoće tkanja 53 μm, promjera 45 cm.

Prosječna gustoća mikrozooplanktona je dostigla 936 jed l^{-1} danju i 1053 jed l^{-1} noću početkom travnja, a maksimalan broj jedinki (1643 jed l^{-1}) je na 12 m dubine. Najčešća vrijednost ukupnog broja mikrozooplanktona je u području 100—200 jed l^{-1}. Naupliusi su najbrojnija skupina sa prosječnim udjelom 40 posto u ukupnom broju organizama tijekom godine. Ukupan broj se povećavao dubinom u proljeće i zimi, dok je ljeti glavnina organizama u sloju iznad termokline. U jesen je vertikalna raspodjela nepravilna. Gustoća mikrozooplanktona se nije mijenjala noću. Analizom varijance nije utvrđena značajna razlika ($p > 0.05$) u ukupnom broju mikrozooplanktona između dana i noći.

Tintinini dostižu maksimum početkom travnja, 944 jed l^{-1}, sa najvećom gustoćom u sloju 10—12 m kao i zimi. Nelorikatni cilijati su najbrojniji zimi, 415 jed l^{-1}, u površinskom sloju uz izraženu vertikalnu stratifikaciju ($p < 0.05$). Vertikalna raspodjela naupliusa je povezana sa temperaturom ($r = 0.32$; $n = 202$; $p < 0.001$), u proljeće su najbrojniji u sloju od 2 do 6 m dubine, ljeti u sloju iznad termokline. U jesen su ravnomjerno raspoređeni u cijelom vodenom stupcu, dok zimi broj naupliusa raste dubinom uslijed inverzne stratifikacije. Skupina »ostali mikrozooplankton« ima izraženu vertikalnu raspodjelu u proljeće ($p < 0.005$), u jesen ($p < 0.05$), te zimi danju i noću ($p < 0.001$; $p < 0.005$). To je jedina skupina mikrozooplanktona kod koje je utvrđena dano-noćna razlika i to u površinskom sloju tijekom cijele godine ($p < 0.005$). Glavninu te skupine čine kopepoditi i mali kopepodi koji pokazuju pravilnu dano-noćnu izmjenu u vertikalnoj raspodjeli. Maksimalan broj malih kopepoda, 240 jed l^{-1}, ujedno je i najveći do sada zabilježen u Jadranskom moru za ovu frakciju zooplanktona. Po prvi put su utvrđene 4 vrste malih kopepoda roda *Oncaea (O. zernovi, O. ivlevi, O. exigua, O. vodjanitskii)* na malostonskom području u travnju.