STUDIES ON NATURAL PHYTOPLANKTON POPULATIONS IN THE NUTRITION OF COPEPODS FROM THE SOUTHERN ADRIATIC (CRNA GORA)

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Abstract

Paper reports the first results on copepod nutrition in the coastal and open waters of Crna Gora. The data obtained are compared with the earlier studies of copepod diet in some other parts of the Adriatic Sea and observed with respect to differences in phytoplankton composition.

Izvod

ISTRAŽIVANJE PRIRODNIH FITOPLANKTONSKIH POPULACIJA U ISHRANI KOPEPODA CRNOGORSKOG PRIMORJA

U radu se iznose prvi rezultati istraživanja ishrane kopepoda u obalnim i otvorenim vodama Crne Gore. Dobiveni nalazi uspoređeni su s ranijim podacima o ishrani kopepoda u drugim područjima Jadranskog mora, a razmatrani su s obzirom na razlike u sastavu fitoplanktonskih zajednica.

INTRODUCTION

Studies of copepod feeding relations carried out for the last ten years all over the world contribute a lot to the knowledge and understanding of energy exchange in the natural environment. It has been tried to account for this problem from different standpoints. One of the most common approaches has been that of the analysis of gut contents of studied copepods. However, more recently a method of observation of copepods under controlled conditions have been more and more applied (R a y m o n t, 1963). Mixed phytoplankton cultures are added to the experimental tanks with copepods and the qualitative and quantitative composition of consumed food studied. Another similar method is also applied. Phytoplankton species grown in culture are added and preference of

copepods to individual species is studied as well as the rate by which copepods digest different phytoplankton organisms. Feeding of herbivore zooplankton has recently also been studied by determination of chlorophyll and phaeophytin in their intestines (Mackas and Bohrer, 1976) Boyd, Smith and Cowles, 1980). This method however, defines only the quantitative aspect of copepod nutrition. It should therefore be combined with a qualitative analysis of gut contents.

After some authors the method for analysing of the gut contents of copepods from the natural environment gives more reliable data on the composition and quantity of food than that carried out under controlled conditions where both copepods as predators and phytoplankton as prey are exposed to conditions determined by the experiment. We agree with this attitude.

Our studies on the nutrition of copepods started in 1976. They were first rectricted to the Kaštela Bay near Split (Homen and Regner, 1977; Regner, 1979) to be extended later to the channel and open waters of the middle Adriatic (Marasović and Regner, 1979). Later on preliminary results were given for almost the entire eastern Adriatic coastal waters (Regner and Marasović, 1981). The latest material covering the entire Adriatic is being worked out (Regner and Marasović, 1983; Marasović et al., 1985). Of the studies of this problem carried out up to now, those in the northern and middle Adriatic have been of intensive character. Therefore, the results of present study of the material from the southern Adriatic tend on the one side to add to our knowledge of copepod feeding and on the other to establish to what extent the differences in gut contents between copepods from different Adriatic parts are dependent on the composition of phytoplankton from the natural environment.

MATERIAL AND METHODS

Material was collected from two stations in front of the Bay Boka Kotorska on two occasions in winter (February, March) 1980. The depth at the most shallower station closest to the coast was 112 m and that at the deepest station 1160 m. However only the surface layer down to the depth of 60 m was sampled, since the samples we made use of, were collected for fishery investigations (Bongo net, mesh size 250 μm) Regner, S. et al., 1981).

Copepods used for the analysis of gut contents were first thforoughly washed by distilled water and put then on object glass. First of all, purity of water in which they were kept was controlled under microscope. Thereafter the guts were opened and their contents squeezed out. Gut content was carefully observed by microscope and phytoplankton species determined.

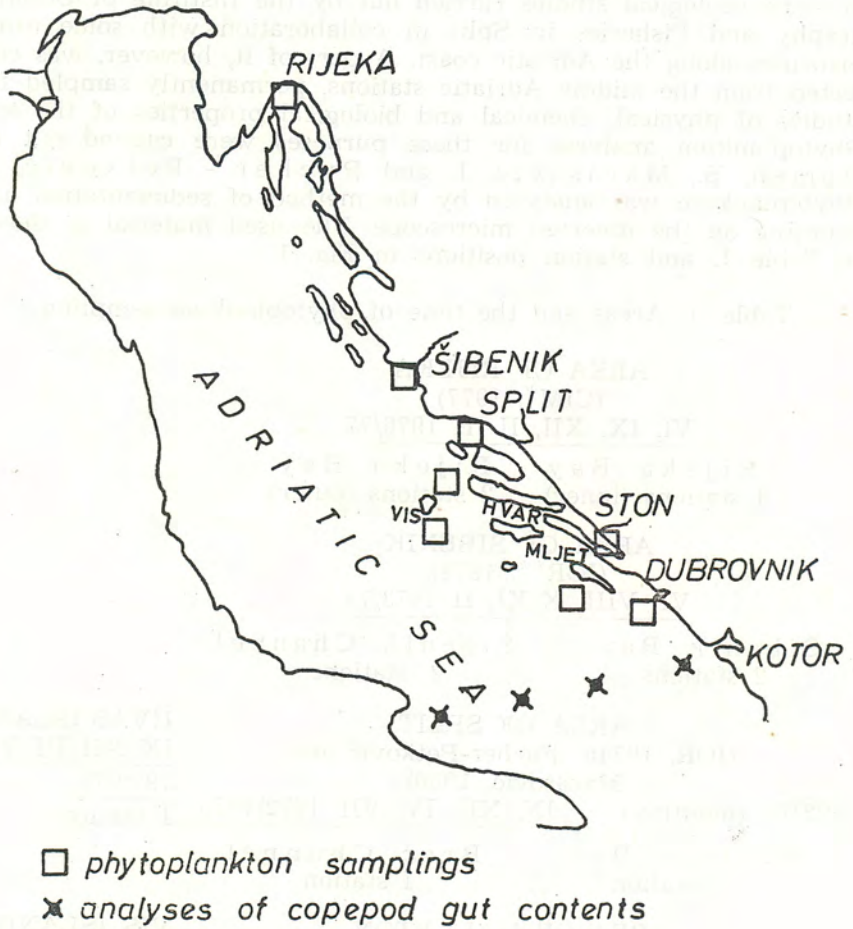

Fig. 1. Station position
Sl. 1. Istraživačke postaje

The material used in this study for the comparison of quantitative and qualitative composition of phytoplankton in natural environment was partly collected and worked out within the frame of some ecological studies carried out by the Institute of Oceanography and Fisheries in Split in collaboration with some other institutes along the Adriatic coast. A part of it, however, was collected from the middle Adriatic stations, permanently sampled for studies of physical, chemical and biological properties of the sea. Phytoplankton analyses for these purposes were carried out by Homen, B., Marasović, I. and Pucher - Petković, T. Phytoplankton was analysed by the method of sedimentation and counting on the inverted microscope. The used material is shown in Table 1. and station positions in Fig. 1.

Table. 1. Areas and the time of phytoplankton sampling

AREA OF RIJEKA
(CIM*, 1977)
VI, IX, XII, II-III 1976/77

Rijeka Bay — 4 stations (inner)
Rijeka Bay — 2 stations (outer)

AREA OF ŠIBENIK
(IOR**, 1974)
VI, VIII, X-XI, II 1973/74

Šibenik Bay — 2 stations
Šibenik Channel — 2 stations

AREA OF SPLIT
(IOR, 1974a; Pucher-Petković and Marasović, 1980)
1972/73 (monthly)
IX, XII, IV, VII 1972/1973

Kaštela Bay — 1 station
Brač Channel — I station

HVAR ISLAND
IX, XII, III, VI
1972/73
1 station

AREA OF MALI STON
(Marasović and Pucher-Petković. 1981)
VII, XII, V 1980/81
4 stations

VIS ISLAND
IX, XII, III, VI
1972/73
1 station

AREA OF DUBROVNIK
(IOR, 1978)
VII, VIII, XI 1977
3 stations (inner)
1 stations (outer)

MLJET ISLAND
IX, XII, III, VI
1972/73
1 station

*CIM (Center of Marine Research, Rovinj, Yugoslavia)
**IOR (Institute of Oceanography and Fisheries, Split, Yugoslavia)

RESULTS AND DISCUSSION

With respect to the quantitative and trophic significance of copepods, which constitute the highest proportion of net zooplankton, their role of the first consumers of organic matter in the sea is of great importance. At the same time copepods are principal food af a large number of commercially important fish species (particularly pelagic fish such as sardine, anchovy and others).

The copepod community structure in the southern Adriatic differs to a certain extent from those in the northern and middle Adriatic, as far as we know from the results of investigations in this part of the Adriatic (Hure and Scotto di Carlo, 1977; Hure et al., 1979, 1980).

In the study area we determined the following copepod species as shown in Table 2.

Table 2. List of copepod species from the stations of study area (0-60 m depth) in winter period 1980

Species	Station 1	Station 2	Station 3	Station 4
Calanus helgolandicus (Claus)	+	+	+	+
Calanus tenuicornis Dana	+	+	+	+
Nannocalanus minor (Claus)	+	+	+	+
Neocalanus gracilis (Dana)	+	+	+	+
Eucalanus attenuatus (Dana)	+	+	+	+
Eucalanus elongatus (Dana)	—	+	+	+
Paracalanus denudatus Sewell	—	—	+	+
Paracalanus parvus (Claus)	+	+	+	+
Calocalanus pavo (Dana)	+	+	+	+
Calocalanus contractus Farran	+	—	+	—
Calocalanus styliremis Giesbrecht	—	—	+	+
Ischnocalanus plumulosus (Claus)	—	+	+	+
Mecynocera clausi Thompson	+	+	+	+
Clausocalanus jobei Frost & Fleminger	+	+	+	—
Clausocalanus arcuicornis (Dana)	+	+	+	+
Clausocalanus parapergens Frost & Fleminger	—	+	+	+
Clausocalanus pergens Farran	+	+	+	+
Clausocalanus mastigophorus (Claus)	—	—	+	+
Clausocalanus lividus Frost & Fleminger	—	—	+	+
Clausocalanus paululus Farran	—	—	+	+
Clausocalanus furcatus (Brady)	+	+	+	+
Ctenocalanus vanus Giesbrecht	+	+	+	+
Aetideus armatus (Boeck)	—	—	+	+

Euaetideus giesbrechti (Cleve)	—	—	+	+
Euchaeta acuta Giesbrecht	—	—	+	+
Euchaeta hebes Giesbrecht	+	+	+	+
Phaenna spinifera Claus	—	—	+	+
Scolecithrix bradyi Giesbrecht	—	—	+	+
Diaixis pygmaea (T. Scott)	+	+	+	+
Temora stylifera (Dana)	+	+	+	+
Pleuromamma abdominalis (Lubbock)	—	+	+	+
Pleuromamma gracilis (Claus)	—	+	+	+
Centropages typicus Kröyer	+	+	+	+
Centropages kröyeri Giesbrecht	+	+	—	—
Centropages violaceus (Claus)	—	—	+	—
Isias clavipes Boeck	+	—	—	—
Lucicutia flavicornis (Claus)	+	+	+	+
Lucicutia ovalis Wolfenden	—	—	+	+
Heterorhabdus papilliger (Claus)	+	+	+	+
Haloptilus longicornis (Claus)	—	+	+	+
Candacia armata Boeck	+	+	+	+
Paracandacia simplex (Giesbrecht)	—	—	+	+
Acartia clausi (Giesbrecht)	+	+	+	+
Oithona helgolandica (Claus)	+	+	+	+
Oithona plumifera Baird	+	+	+	+
Temoropia mayumbaensis T. Scott	—	—	+	+
Clytemnestra rostrata (Brady)	—	—	+	+
Oncaea mediterranea Claus	+	+	+	+
Oncaea media Giesbrecht	—	+	+	+
Lubbockia squllimana Claus	+	+	+	+
Sapphirina metallina Dana	—	—	+	+
Sapphirina nigromaculata Claus	+	+	+	+
Copilia quadrata Dana	—	—	—	+
Corycaeus clausi Dahl	—	—	+	+
Corycaeus typicus Kröyer	+	+	+	+
Corycaeus latus Dana	—	—	+	+
Corycaeus ovalis Claus	—	—	+	+
Corycaeus brehmi Steuer	+	—	—	—
Corycaeus furcifer Claus	—	—	+	+
Corycaeus flaccus Giesbrecht	—	—	+	+
Corycaeus rostrata Claus	+	+	+	+
Copepodits and other Copepods	+	+	+	+

As seen the studied stations showed different copepod compositions, that is, different relations between species groups, irrespective of the fact that surface layer was sampled. Stations 1 (112 m depth) and 2 (250 m depth) showed somewhat different properties from stations 3 (900 m depth) and 4 (1160 m depth). The most abundant copepod species at stations 1 and 2 were *Paracalanus parvus, Acartia clausi, Centropages typicus, Ctenocalanus*

vanus, Clausocalanus pergens, Clausocalanus paululus and *Temora stylifera*. This was to expect due to the fact that samplings were carried out to depths not exceeding 60 m. The community recorded from these stations was, accordingly, a mixed community made up of both widely distributed surface copepods of coastal Adriatic waters and pelagic species of the southern Adriatic. Irrespective of the surface sampling, beside mentioned species, a still larger number of pelagic and south Adriatic copepods were recorded from the stations 3 and 4: *Lucicutia flavicornis, Euchaeta acuta, Pleuromamma gracilis, Haloptilus longicornis, Temoropia mayumbaensis* etc.

For food analyses dominant copepod species were separated, both the widely distributed coastal species and markedly pelagic south Adriatic species.

Table 3. Dominant copepod species analysed with respect to gut contents

Stations 1 and 2	Stations 3 and 4
Paracalanus parvus	Paracalanus parvus
Acartia clausi	Acartia clausi
Centropages typicus	Centropages typicus
Ctenocalanus vanus	Ctenocalanus vanus
Temora stylifera	Clausocalanus pergens
Clausocalanus pergens	Clausocalanus paululus
Clausocalanus paululus	Lucicutia flavicornis
	Euchaeta acuta
	Pleuromamma gracilis

Quantity and particularly the composition of the material obtained from the guts proved our earlier observations that the stations closer to the coast differed from those in the open sea to a certain extent. Namely, the obtained and determined material from the guts of copepods from stations 1 and 2 showed that they took somewhat larger quantities of considerably different food that taken by copepods from stations 3 and 4.

Thus whereas the gut contents of copepods from stations 1 and 2 showed a larger number of phytoplankton species of different systematic groups, guts of copepods from stations 3 and 4 mainly contained coccolithophorids. Size of recorded phytoplankton cells ranged from 10 to 20 μ m with the exception of one specimen, the dinoflagellate *Dinophysis dens*, which was of about 50 μ m in length.

The following table 4. presents phytoplankton species found in the guts of copepods from the stations in the southern Adriatic.

Table 4. Qualitative composition of phytoplankton from copepod gut contents (southern Adriatic, winter, 1980)

Station 1	Station 2
Navicula sp.	Melosira sulcata
Gymnodinium sp.	Melosira sp.
Coccolithophoridae spp.	Synedra sp.
Carteria sp.	Navicula sp.
Chlamydomonas fusiformis	Diploneis crabro
	Nitzschia bilobata
	Dinophysis dens
	Coccolithophoridae spp.

The comparison of data on the food of copepods from the southern Adriatic to the earlier data for the northern and middle Adriatic shows some differences particularly with respect to the quality of food taken. Whereas diatoms made up the bulk of the food of copepods in the northern and middle Adriatic (Regner and Marasović, 1981) coccolithophorids were best represented in the food of south Adriatic copepods. The abundance of diatoms and dinoflagellates in the guts of copepods from the southern Adriatic was far lower. (Tables 4 and 5).

Table 5. List of phytoplankton species recorded from the copepod gut contents in the northern and central Adriatic (winter, 1979)

Species	
Coscinodiscus excentricus	Licmophora sp.
Coscinodiscus sp.	Synedra sp.
Chaetoceros lorenzianus	Thalassionema nitzschioides
Hemiaulus hauckii	Navicula maior
Navicula sp.	Exuviaella sp.
Diploneis crabro	Gymnodinium sp.
Cocconeis sp.	Pronoctiluca spinifera
Pleurosigma angulatum	Glenodinium sp.
Nitzschia seriata	Peridinium steinii
Nitzschia sp.	Gonyaulax polyedra
Pinnularia sp.	Gonyaulax sp.
Surirella sp.	Dictyocha fibula
	Coccolithophoridae spp.

These results support to a considerable extent our assumption that food composition of copepods quite well reflects the composition of the phytoplankton of the area they inhabit.

Our first research of copepod feeding in the Kaštela Bay (Homen and Regner, 1977) showed that copepods mainly took

diatoms, the proportion of which is very high in that area. Therefore, Homen (1979) suggested selective zooplankton grazing. However, we hold that in that case food composition only reflected the composition of phytoplankton from that area since microplankton fraction is relatively significant constituent of the Kaštela Bay phytoplankton (Pucher - Petković and Homen, 1979).

Moreover, our assumption was best supported by the investigations carried out at Stončica near the island of Vis (Marasović and Regner, 1979) when a quite unusual situation in the sea was reflected in the food composition of copepods from that area. Namely, a mass bloom of *Nitzschia seriata,* otherwise never present in high quantities in the opet waters of the middle Adriatic, was recorded. The gut contents of copepods analysed showed highest percentages of *Nitzschia seriata* in as long chains as 278 μm.

Summing up all these results obtained for the area alongshore the Adriatic we noticed another very interesting fact which supported our assumption that copepods did not actively select food, at least as far as food quality was concerned. Namely, it was shown that in the northern and middle Adriatic as well as in the southern Adriatic the proportion of coccolithophorids in the food of copepods increased if one proceeded from the coast offshore. Nevertheless, it may be of interest to mention that a very little number of phytoplankton species was found in the guts of copepods collected from the open southern Adriatic if compared to their fullness. Future investigations will have to throw some more light on this problem. We assume that naked flagellates make up a significant proportion of the total phytoplankton of this area. They, as we supposed were digested to the extent that it was impossible to determine them.

This assumption is supported by the results of investigations of the proportion of different groups of phytoplankton in the composition of phytoplankton communities along the eastern Adriatic coast (Table 7) which show that the relative abundances of »microflagellates« in the area of Dubrovnik exceed those at more northern stations. The personal communication of Dobrosavljević about her studies in the southern Adriatic proved these findings.

With respects to the results obtained by the studies of copepod feeding carried out up to now we have held it useful to systematize the data on phytoplankton so as to establish the differences in qualitative-quantitative relations between phytoplankton communities of different parts of the Adriatic, proceeding from the northern towards the southern Adriatic and from the coast offshore (Fig. 1). The areas compared for this purpose are presented in Table 1. The material was organized so as to observe to-

gether the stations directly influenced by the land (left column, Table 1) and together the more maritime stations (right column). Table 6 presents mean phytoplankton densities at the coastal, channel area and open sea stations.

Table 6. Mean phytoplankton densities in the study areas

Area	No×10³cells l^{-1}	Area	No×10³cells l^{-1}
Rijeka Bay (inner)	153	Rijeka Bay (outer)	115
Šibenik Bay	735	Šibenik Channel	78
Kaštela Bay	400	Brač Channel	70
The Bay of Mali Ston	270		
Dubrovnik (inner)	570		
		Dubrovnik (outer)	181
		Hvar Island	40
		Vis Island	32
		Mljet Island	70

Proceeding alongshore from the northern towards the southern stations the phytoplankton density varied from one area to another within the same order of magnitude if only the series of stations closest to the coast were considered (left column of the table). However, at a very small distance from the coast the phytoplankton density was considerably lower and more offshore the lowest (right column of the table). Thus the inner stations in the Rijeka Bay showed greater phytoplankton abundance than the more offshore ones in the bay as well as did the Šibenik Bay waters with respect to the Šibenik channel waters. This regularity was recorded also in the Split and Dubrovnik areas.

Prior to bringing out relative abundances of individual phytoplankton groups in the communities of these areas it would be of interest to mention some well known facts. Earlier investigations have already shown that the proportions of diatoms in the phytoplankton of the coastal middle Adriatic are higher than those in the phytoplankton of the open sea and channel area. This means that already the proportions of individual phytoplankton groups may show whether a station is affected by the open sea or by the land (P u c h e r - P e t k o v i ć, 1963, 1964, 1966).

Relative proportions of phytoplankton groups, presented in Tables 7 and 8, prove this statement. Thus the proportions of diatoms in the total phytoplankton recorded from the stations closest to the coast were higher in all cases than those at stations slightly apart from the coast. Extremely low values were recorded from the open sea. It may be concluded that the drop of phytoplankton density in a transverse direction accross the Adriatic is

directly dependent on the decrease in the proportion of diatoms since all other phytoplankton groups behave quite differently, that is their relative abundance in a community is increased going offshore. This is particularly evident in coccolithophorid group the proportion of which is gradually increased in the offshore direction.

Table 7. Relative abundance of different phytoplankton groups in the coastal eastern Adriatic

Area	Group % Rijeka Bay (inner)	Group % Rijeka bay (outer)
Diatomeae	54,8	29,9
Coccolithophoridae	12,2	17,2
Dinoflagellata	9,5	16,3
»Microflagellata«	23,4	36,5
Silicoflagellata	0,1	0,1
	Šibenik Bay	Šibenik Channel
Diatomeae	93,7	54,7
Coccolithophoridae	3,4	35,0
Dinoflagellata	2,6	7,7
»Microflagellata«	0,2	2,6
Silicoflagellata	0,1	0,0
	Kaštela Bay	Brač Channel
Diatomeae	84,6	51,4
Coccolithophoridae	10,9	36,6
Dinoflagellata	2,6	6,7
»Microflagellata«	1,9	5,3
Silicoflagellata	0,0	0,0
	The Bay of Mali Ston	
Diatomeae	76,0	
Coccolithophoridae	11,4	
Dinoflagellata	7,2	
»Microflagellata«	5,4	
Silicoflagellata	0,0	
	Dubrovnik (inner)	Dubrovnik (outer)
Diatomeae	50,3	45,0
Coccolithophoridae	6,5	6,1
Dinoflagellata	15,1	18,8
»Microflagellata«	28,0	29,9
Silicoflagellata	0,1	0,2

Moreover, as far as dinoflagellates and »microflagellates« are concerned an increase of proportion was recorded only in the coastal area that is, they were higher at more maritime coastal stations than at those more affected by the land. Accordingly, the difference in qualitative composition between coastal stations and open sea ones is in fact the difference in proportions of coccolithophorids and diatoms. This conclusion was to be expected with respect to the fact that coccolithophorids were observed as indicators of Mediterranean water in the Adriatic (Pucher - Petković et al., 1971; Zore - Armanda and Pucher - Petković, 1976).

In north-south direction the coastal stations (from Šibenik southwardly) show the same tendency that is the decrease of diatom proportion in communities with an increase of proportions of other groups even though the differences are less marked than those in east-west direction. Significantly higher proportions of dinoflagellates and »microflagellates« in Dubrovnik area in relation to all more northern stations should be pointed out. This is not applicable only to the Bay of Rijeka which evidently requires further studies.

Table 8. Relative abundance of different phytoplankton groups at the open sea stations (Hvar island, Vis island, Mljet island)

Group %	Hvar island	Vis island	Mljet island
Diatomeae	21,4	20,8	15,3
Coccolithophoridae	67,0	61,9	68,4
Dinoflagellata	6,5	9,9	12,3
»Microflagellata«	5,2	7,4	4,0
Silicoflagellata	0,0	0,0	0,0

These results may be brought into connection with the results of phytoplankton studies with respect to its size fractions: the nanoplankton one (<50 μm) and the microplankton one (>50 μ m). In general, the smaller size component is quantitatively more important in the Adriatic. However, it is well known that the abundance of microplankton is higher in the more productive areas, that is in the areas closer to the coast than in the open sea (Pucher - Petković, 1973; Pucher - Petković and Homen, 1979; Pucher - Petković and Marasović, 1982). Since diatoms are the main representatives of the larger phytoplankton fraction and coccolithophorids, »microflagellates« and a part of dinoflagellates, particularly unarmoured dinoflagellates, belong to the smaller size group, the differences in quanti-

tative relations between phytoplankton groups of different Adriatic areas were confirmed in this way too.

CONCLUSION

The analysis of gut contents of dominant copepods in the coastal area of Crna Gora showed differences between the stations closer to the coast and those in the open sea.

Phytoplankton species of all systematic groups were recorded from the gut contents of copepods from the coastal area. However, gut contents of copepods from the open sea showed only coccolithophorids. These records as well as the results of some earlier studies in the northern and middle Adriatic show an increase of coccolithophorid proportions in copepod food in the offshore direction. An increase of coccolithophorid abundance in the southern Adriatic with respect to the middle and northern Adriatic, where diatoms make up the main proportion of copepod food, was also recorded.

The comparison of relative proportions of phytoplankton groups in communities of the coastal and open Adriatic shows that the food composition of copepod gut contents reflects to a considerable extent the phytoplankton composition of the environment.

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ISTRAŽIVANJE PRIRODNIH FITOPLANKTONSKIH POPULACIJA U ISHRANI KOPEPODA CRNOGORSKOG PRIMORJA

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Rezime

U radu se donose rezultati istraživanja ishrane kopepoda u vodama Crne Gore. Materijal je sakupljen zimi 1980. godine na četiri postaje otvorenog mora ispred Boke Kotorske.

Zajednice kopepoda na postajama 1 i 2, koje su bliže obali, sačinjavaju pretežno neritske površinske vrste širokog rasprostranjenja i neke pelagijske južnojadranske vrste. Međutim, na postajama 3 i 4, koje su udaljenije od obale, prevladavaju pelagijske i južnojadranske vrste.

Probavni trakt dominantnih vrsta kopepoda na postajama 1 i 2 bio je nešto puniji i sadržaj raznolikiji nego na postajama 3 i 4, na kojima su probavila kopepoda sadržavala samo kokolitoforine. Inače je u probavnom traktu kopepoda nađen relativno mali broj fitoplanktonskih vrsta u odnosu na njegovu punoću. Pretpostavlja se da je razlog tome veća proporcija golih flagelatnih vrsta u vodama južnog Jadrana nego u njegovim sjevernijim djelovima.

Ranija istraživanja ishrane kopepoda u sjevernom i srednjem Jadranu ukazala su na razlike u sadržaju probavila kopepoda između obalnog pojasa i otvorenog mora kao i od sjevera prema jugu.

Razlike u proporcijama između različitih fitoplanktonskih skupina, koje su zabilježene kako u transverzalnom tako i u longitudinalnom smjeru Jadrana, potvrđuju raniju pretpostavku da sastav hrane kopepoda u velikoj mjeri ovisi o sastavu fitoplanktona u okolnom moru. Prema tome, naši nalazi ne podržavaju mišljenje o selektivnoj ishrani kopepoda.