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QUANTITATIVE ECOLOGY INVESTIGATIONS OF THE ZOOPLANKTON DURING THE FERTILIZATION EXPERIMENTS IN THE BAY VELIKO JEZERO (I. MLJET)

KVANTITATIVNA EKOLOŠKA ISPITIVANJA ZOOPLANKTONA ZA VRIJEME POKUSA FERTILIZACIJE U VELIKOM JEZERU (o. Mljet)

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1. INTRODUCTION

Stimulated by scientific and practical reasons the Institute of Oceanography and Fisheries, Split, carried out a complex oceanographic investigations from 1951 to 1955 in the bay of Mljet. A large programme of studies, which took several years, has included the determination of the existing conditions in the bay, of the biological production in particular. Experiments in fertilization to increase the production have also been carried out. The present work gives the results of zooplankton investigations during the above mentioned experiments of fertilization.

During the investigations in the bay of Mljet some topographic and geologic examinations have been undertaken (Vuletić, 1953), and samples for determining the temperature, salinity, transparency, acidity (ph) of the sea-water, and the O_2, PO_4, and NO_3 contents (Buljan and Špan, in preparation) have also been regularly taken. For biological examinations the samples of bacteria (Cviić, 1953), phytoplankton (Pucher-Petković, 1957, 1960), and zooplankton (Vučetić, 1957, 1958, 1961 a, b) have been collected. Further, bottom samples for examining the phytobenthos and zoobenthos (tanatocenosis) were taken. The increase of indigenous and transplanted settlements of mollusca has been under observation, while some lesser observations were carried out on pelagic fish and on some bottom fish (Morović, 1958).

In the sea like on land the production depends also on the availability of nutrients, therefore, by artificially increasing the quantity of these salts in the sea (Buljan, 1957), it was tried to increase the production of organic matters in the bay of Mljet. The results of the fertilization have been reflected on some populations (phytoplankton — Pucher-Petković, 1950; ichtioplankton — Buljan, 1957, Vučetić, 1957a, and zoobenthos Morović, 1958) in this biocenosis, as well as on some individual factors conditioning the increase of these populations (Buljan, 1957).

2. MATERIAL and METHODS

During the complex investigations in the bay of Mljet from 1951 to 1955, the zooplankton samples were taken once a month at three permanent stations. The first station was in the part of the bay called the Malo jezero, the second in the Veliko jezero (Vrbovačka), and the third one at the very entrance of the bay (Gonoturska). From time to time the work was done at some other stations in the Veliko jezero. The samples for the vertical migration study were taken at the stations Jejevići and Pošta (V u č e t i ć, 1957b, 1961). Fig. 1.

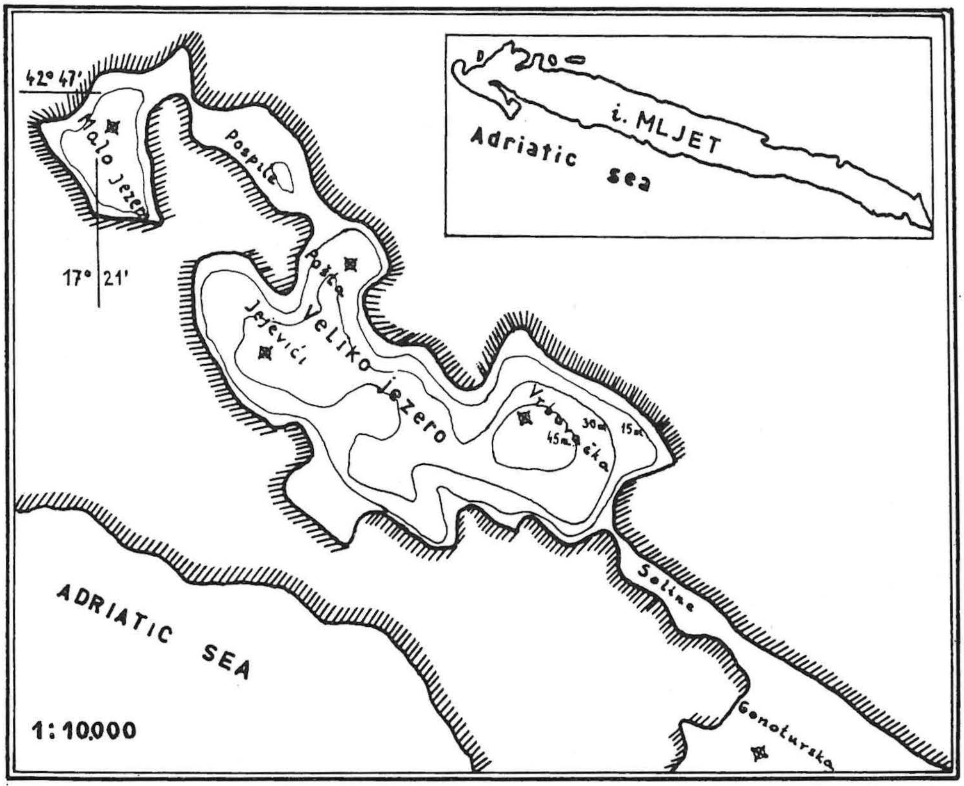

Fig. 1. Ocanographic Stations in Mljet area.

The total field observations in the bay of Mljet were carried on for 39 months with an average of 2 to 8 plankton samples per month.

At each station two parallel vertical hauls from bottom to surface were taken, at an equal hauling rate with the Hensen net (4/73-100). The Nansen clossing-net (4/74) was used for investigating the vertical migrations of zooplankton. From time to time, for other investigations, some plankton samples were taken with other gear (stramin, the small Nansen net).

A part of the samples was used for obtaining the quantitative data, i. e. the dry weight values of zooplankton. Therefore the samples of the vertical haul with a plankton net were first cleaned of the eventual larger anorganic wastes, then filtrated and at last dried up at 110° C. The other part of the samples was used for qualitative analysis and quantitative counts. The less frequently represented species were counted as a whole, while to those more frequently represented partial count was applied.

3. HYDROGRAPHIC CONDITION

The »Mljetska jezera« is a deep bay in the north-west side of the island of Mljet. The bay is running deep into the mainland. It is the outcome of a sunken valley of the upper Cretaceous limestone. A narrow (4.5 m) and shallow (0.60 m) passage connects the Veliko jezero with the bay Soline (Fig. 1). This bay with an average depth of 10—12 m is exposed to the direct influence of the open Adriatic.

Maximal depth of the Malo jezero is 29 m, the Veliko jezero 46 m. They are connected together with a narrow (2.5 m) and shallow (0.20 m) channel. The surface of the bay is 1,691,320 m^2, the Malo jezero being 241,320 m^2, and the Veliko jezero 1,405.000 m^2 (Vuletić, 1953).*)

The bay has a lower salinity and oscillations which are more marked than those in the open Adriatic as a result of the freshwater inflow from smaller sources and from rainfall drainage. This is reflected especially so on the salinity of the surface waters (Buljan, and Špan, in preparation). So in the Malo jezero the surface salinity ranges from 27.9 to 36.4‰, at the depth of 20 m from 35.4 to 38.1‰. In the Veliko jezero the surface salinity ranges from 30.0 to 37.2‰, at the depth of 40 m from 35.0 to 36.9‰ (Fig. 2).

There is also temperature difference between the bay and the open sea. Fluctuations are more pronounced in the Malo jezero. In winter the surface temperature can be 4.5° C (January), while in summer it is up to 29.0° C (August). At the depth of 20 m the temperature ranges from 7.75 to 20.0° C. In the Veliko jezero the surface temperature may lower down to 8.2° C. (February), while in summer it is up to 27.0° C; at the depth of 40 m it ranges between 9.2 and 13.7° C (Fig. 3). Due to these changes there is variation in the density of the sea-water: on the surface from 22.7 to 28.3 σ_t, at the depth of 40 m from 24.6 to 28.5 σ_t, (Fig. 4).

In the Malo jezero under the isobath of 19 m (to 20 m) the zone H_2S was found in 1951 and 1952 (Buljan, 1956). In the course of 1953, and especially so of 1954, the bay was aired, so that at the depth of 25 m there was saturation of O_2 (Fig. 5).

*) As the entrance channel into the Veliko jezero has been made deeper since 1960 it is to be expected that essential changes in hydrography and composition of fauna and flora in the bay itself have taken place.

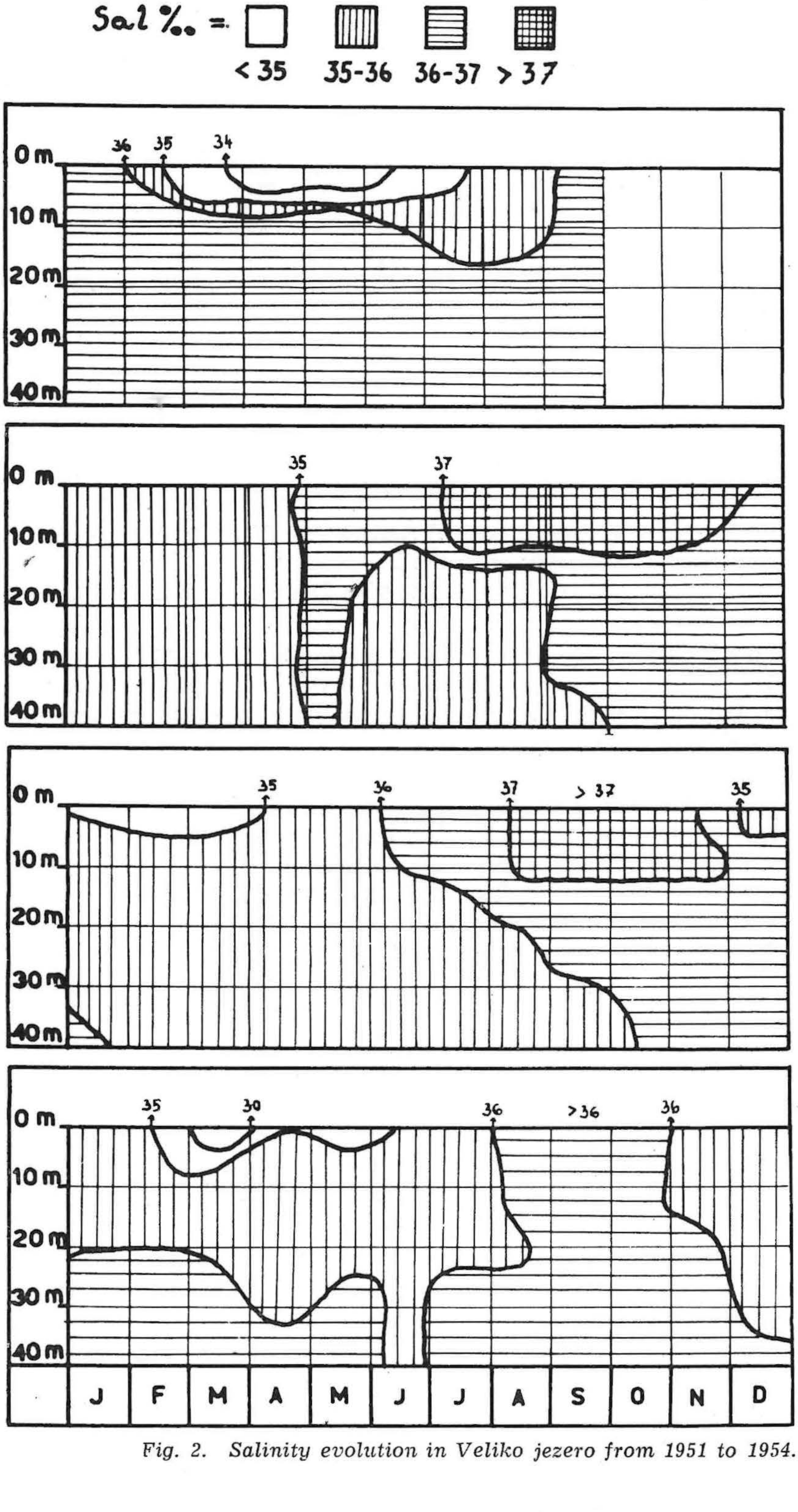

Fig. 2. Salinity evolution in Veliko jezero from 1951 to 1954.

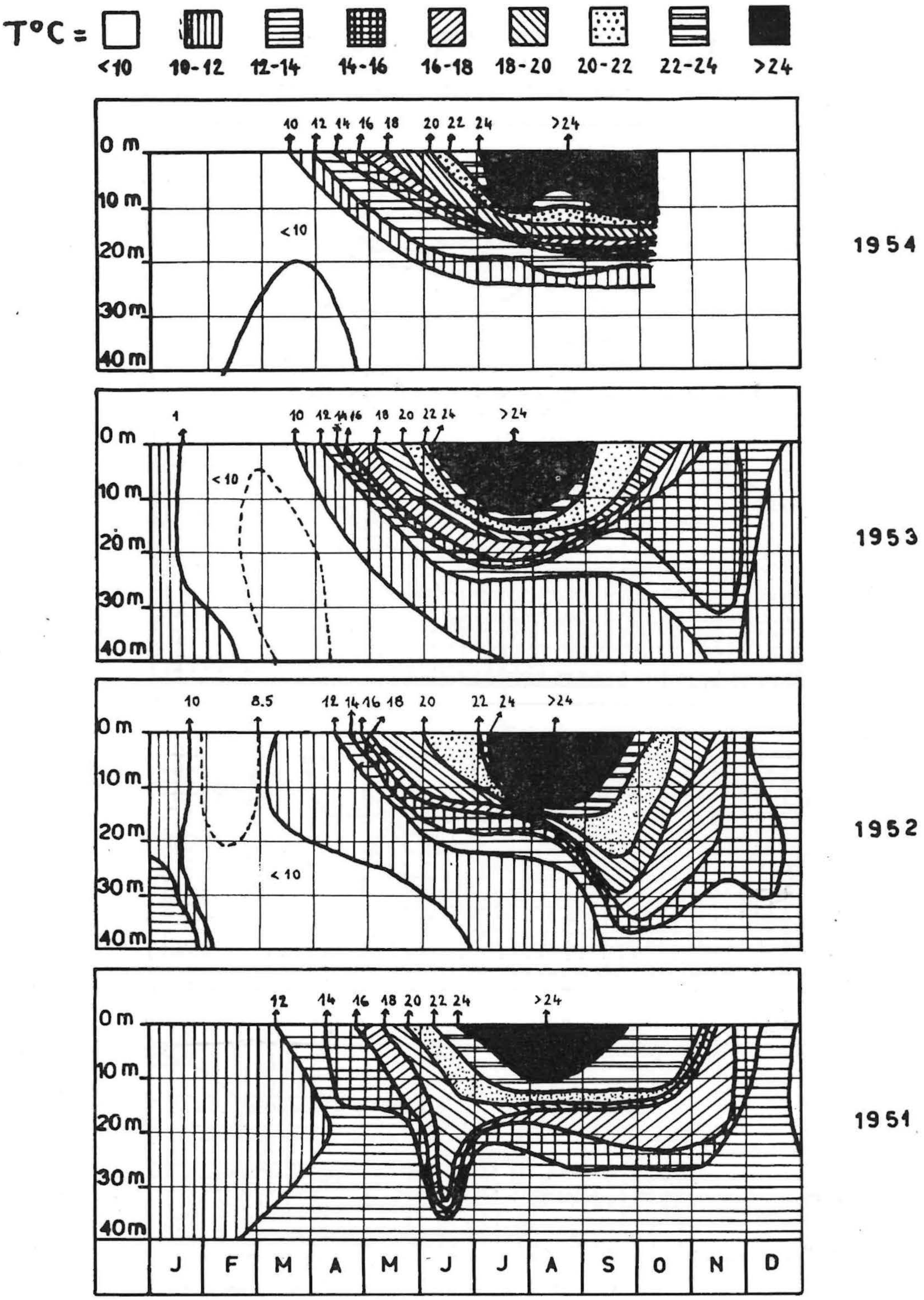

Fig. 3. Temperature evolution in Veliko jezero from 1951 to 1954.

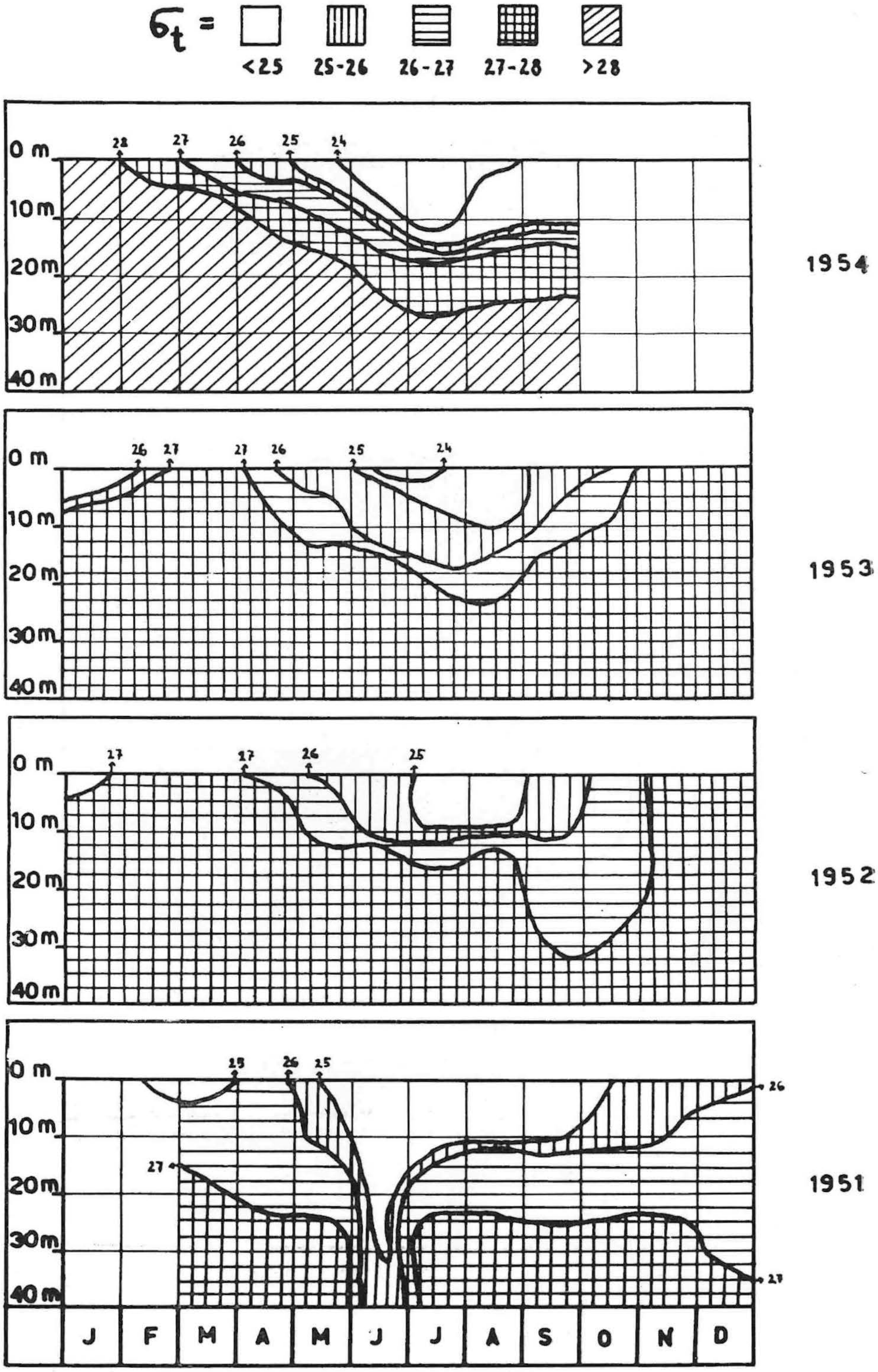

Fig. 4. Sea density σt, evolution in Veliko jezero from 1951 to 1954.

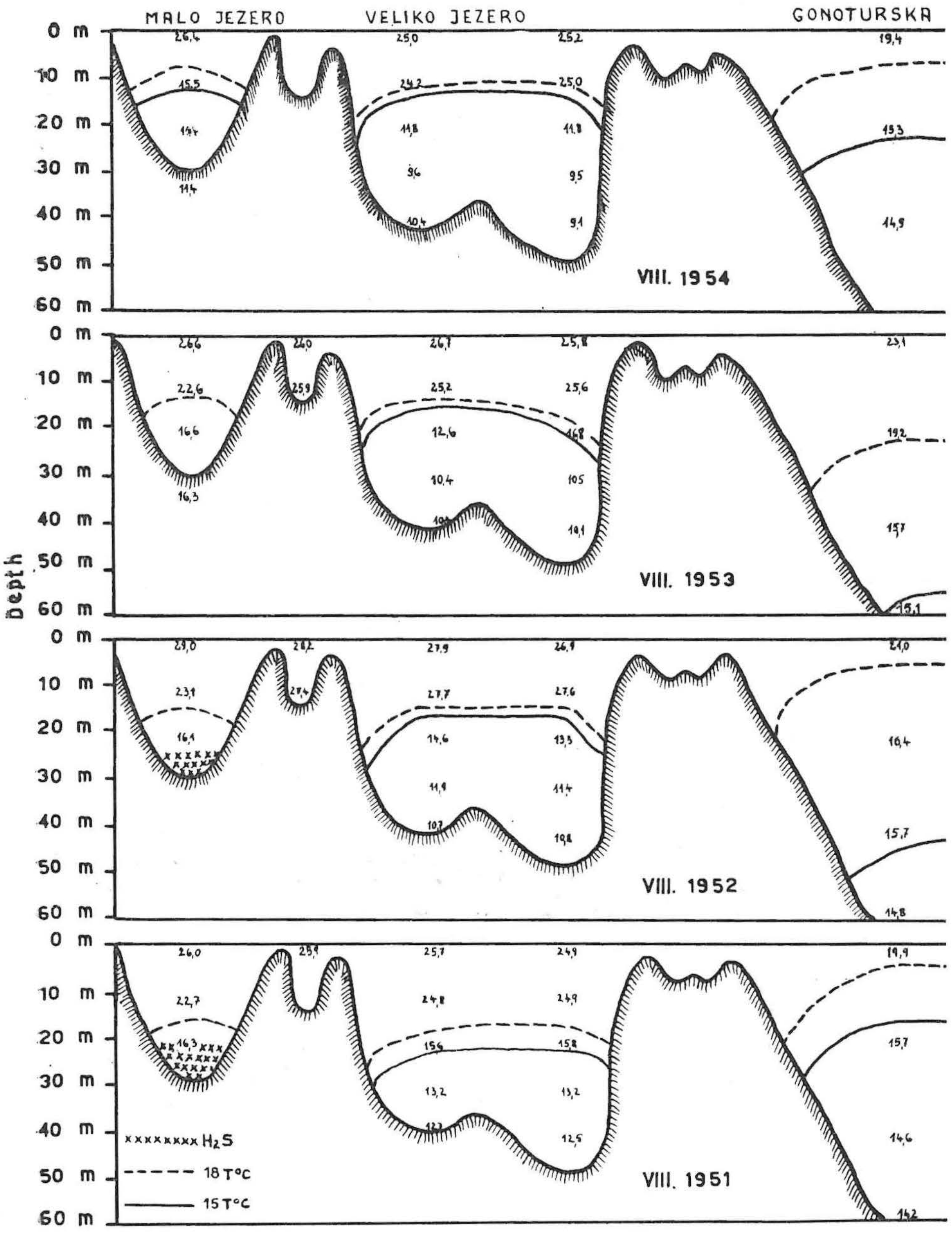

Fig. 5. Temperature profile in Mljet area for August 1951, 1952, 1953, 1954.

The sea water transparency (obtained by Secchi disc) changes considerably each season, the annual differences might be in the Malo jezero from 5.7 to 9.5 m, in the Veliko jezero from 10.5 to 21 m.

In the area of the narrow passages a) Malo jezero — Veliko jezero, and b) Veliko jezero — Soline rapid flows occur.

During these investigations, at the outer station Gonoturska, the surface temperatures ranged from 12.5 to 24.2° C, salinity being from 35.8 to 38.5‰ and transparency from 16.5 to 32 m.

All the hydrographic data used in the present work have been placed at my disposal by the kindness of Dr. Miljenko Bulјan to whom I am especially indebted.

4. RESULTS

4.1. COMPOSITION OF ZOOPLANKTON COMMUNITIES AND THEIR FLUCTUATION

The qualitative analysis of the zooplankton community in the bay of Mljet shows that it is the question of typical neritic plankton with the species which only in the population density differ from the similar biocenoses of other localities. Special topographic and hydrographic conditions, and vegetation density of the surrounding area seem to condition the high standing crop of zooplankton, if this be not the result of an unbalanced relation between the primary producers and the consumers. According to the composition of the zooplankton (Table 1, Vučetić, 1957) the Malo jezero is considerably poorer in species than the Veliko jezero. But the number of species is from time to time on an increase, so that in August and September 1954 the copepod *Calanus helgolandicus* could be found even in the Malo jezero where it had never been found before. At that time the temperature was 11.0° C (Fig. 5) at the depth

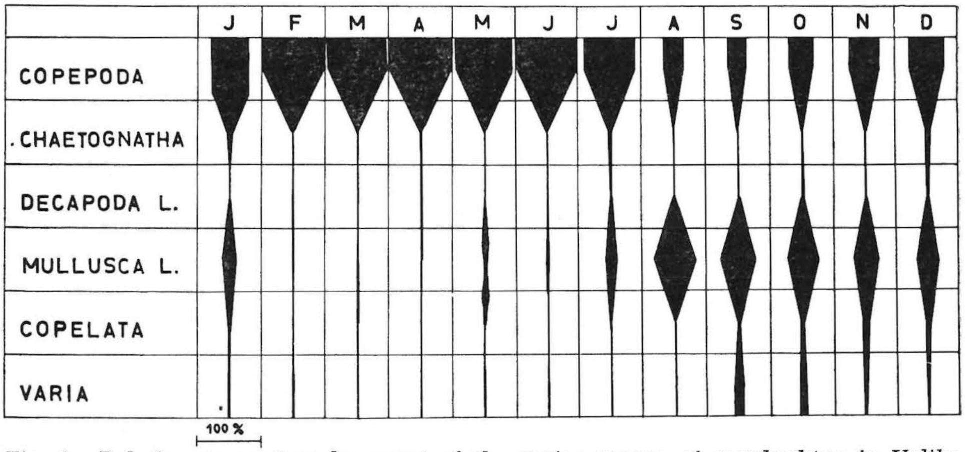

Fig. 6. Relative percentage by count of the major groups of zooplankton in Veliko jezero.

TAB. I. ZOOPLANKTON — NUMBER OF DIFFERENT SPECIES IN A VERTICAL HAUL FROM 0—40 M.

	1952.									1953.						
	II	IV	V	VI	VII	VIII	IX	XI	XII	I	III	V	VI	VIII	IX	XI
Calanus helgolandicus . ♀	208	398	144	385	660	1125	1179	341	120	566	76	127	806	87	125	16
,, ,, . ♂	58	41	41	107	96	136	5	42	81	45	9	80	183	22	81	7
,, ,, . V	140	973	1231	2737	1551	136	34	107	1294	582	86	826	198	70	290	74
,, ,, . IV	106	720	36	60	30	—	90	60	3138	90	180	—	—	90	270	64
,, ,, . III	876	1440	300	—	—	—	270	180	3540	—	630	90	—	90	90	—
,, ,, . II	1436	600	198	—	—	—	60	60	1950	60	980	30	—	60	30	86
,, ,, . I	1356	18	—	—	—	—	120	330	60	300	360	—	—	180	30	21
,, ,, . N	1802	78	78	—	—	—	90	120	336	30	2910	—	—	210	30	43
Paracalanus parvus . . ♀	2323	2880	3120	26100	1580	1590	270	480	258	1260	2490	780	120	300	180	860
,, ,, . . ♂	9961	1236	720	1320	810	360	120	180	156	330	1200	1260	180	60	60	559
Pseudocalanus elongatus ♀	6524	12156	22296	16140	33750	25080	16980	4380	1200	1260	2490	780	120	300	180	860
,, ,, ♂	3211	2160	1158	1320	780	360	210	—	90	330	1200	1260	180	60	60	559
Paracalanus Pseudocalanus kopepodits	12274	12390	23100	29390	26800	17250	2580	720	720	5010	39540	20580	6000	2560	1560	2236
Acartia clausi . . . . ♀	586	618	378	270	30	30	—	—	—	—	60	—	—	—	—	—
,, ,, ... ♂	686	1038	258	330	120	30	—	—	—	—	60	—	—	—	—	—
,, ,, kopepodits .	—	1440	780	390	210	—	—	90	—	—	240	—	—	—	—	43
Centropages kröyeri . ♀	—	—	—	—	30	180	120	—	—	—	—	120	180	180	480	—
,, ,, . ♂	—	—	—	90	420	150	120	—	—	—	60	60	120	240	600	—
,, kopepodits . .	—	—	—	90	180	240	90	—	—	—	—	150	180	480	360	—
Isias clavipes	121	—	120	60	—	—	—	—	—	60	—	—	—	—	—	—
Oitona nana	773	132	1938	1300	720	420	510	380	2580	180	2400	1080	480	180	360	645
Sagitta setosa adul.	19	490	114	407	482	186	147	38	148	42	114	235	76	48	47	240
,, ,, med.	—	—	—	799	635	490	216	—	—	—	—	—	265	50	166	—
,, ,, juv.	495	—	292	238	641	1466	130	19	691	1447	720	1464	223	129	1848	477
,, ,, eggs	—	60	—	210	90	—	—	—	—	90	—	—	—	—	—	—
Dekapoda larvae	73	117	250	163	62	41	89	37	6	—	519	326	120	—	338	47
Evadne sp.	53	—	60	—	30	90	—	630	378	—	150	540	120	120	950	129
Obellia dichotoma	—	—	—	60	—	—	330	30	35	3	—	180	120	120	60	43
Bougainvillia automnalis . .	—	—	—	—	—	—	7	—	35	7	—	—	—	60	2	2
Aurelia aurita	26	—	—	—	90	1380	8700	450	360	150	90	660	950	360	1560	344
Muggiaea kochii	773	240	—	—	7350	86130	45360	5400	8700	2970	1020	60	120	1120	12540	3866
Lamellibranch larvae . . .	121	198	5736	2286	7176	8250	2580	—	—	540	60	9720	10980	1260	3180	688
Gastropod ,, . . .	—	—	120	1150	330	180	360	—	—	—	—	90	60	120	60	—
Oicopleura dioica	826	60	2376	—	784	870	600	1260	1200	1320	1260	720	300	240	—	1720
Fish eggs	—	—	14	8	—	—	—	+	—	—	—	—	—	—	—	—
,, *larvae*	—	—	16	4	—	—	—	+	—	—	—	—	—	—	—	—

of 20 m. This is a considerably lower temperature than the one that limits the distribution of this copepod. Examining the vertical migrations it was, namely, found that the temperature of about 15° C was limitary temperature which the adult *Calanus* in normal conditions never crossed (V u č e t i ć, 1961). Besides that, the analyses of the sea-water showed that at that time (September 1954) there was no H_2S zone which in 1951 and 1952 had been betected at the bottom layers. It has been established that, during the thermocline, the *Calanus* is present below the thermocline stratification, but if this layer is by chance polluted by H_2S the *Calanus* cannot be detected because its normal development has been probably hindered.

Examining the composition of the zooplankton in the Veliko jezero, the period of occurence of individual species was established as well as their numerical occurence for the period February 1952 to November 1953 (Table I).

TAB. II. FREQUENCY (%) OF THE DIFFERENT GROUPS IN THE TOTAL ZOOPLANKTON OF VELIKO JEZERO

	J	F	M	A	M	J	J	A	S	O	N	D
Copepoda	59,4	94,6	93,3	97,0	86,1	94,6	79,4	32,2	27,9	37,3	46,6	55,3
Chaetognatha	9,2	1,1	1,4	1,2	0,6	1,5	2,0	1,5	0,6	0,4	0,3	2,9
Decapoda l.	0,3	0,2	—	0,3	0,4	0,2	0,1	0,2	0,1	0,1	0,2	0,1
Mollusca l.	21,7	2,0	2,0	1,1	8,8	1,4	17,0	64,5	58,8	48,3	37,9	34,7
Copelata	8,1	1,8	2,1	0,2	3,7	—	0,9	0,6	0,7	4,3	7,9	4,3
Varia	1,6	0,3	0,4	0,2	0,4	1,1	0,5	1,2	11,9	9,4	6,9	2,8

For a better survey the zooplankton has been put into six major groups. The relative occurence of the group in the total sample has been expressed in percentage in Table II. The annual fluctuation of these values thus listed shows that the copepods are the most represented (27.9—94.6%), followed by mollusc larvae (1.1—64.5%), chaetognaths (0.4—9.2%) and copelats (0—8.1%), and at last by other groups in smaller quantities (Fig. 6).

TAB. III. DRY WEIGHT (mg/m³) OF ZOOPLANKTON IN MLJET AREA FOR THE PERIOD 1951—1955.

MALO JEZERO

Date	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Mean
1951	—	—	0,95	3,6	9,3	3,85	6,5	3,9	1,4	1,6	1,05	--	3,56
1952	—	1,0	2,6	—	3,0	1,9	4,4	2,1	1,0	—	0,9	1,8	2,07
1953	0,9	—	0,2	—	1,6	2,2	—	1,6	1,2	—	1,1	—	1,25
1954	1,8	—	0,8	—	3,5	—	3,9	19,0	11,7	—	2,6	—	5,7
1955	—	2,3	—	—	—	6,5	—	—	—	—	—	—	—

VELIKO JEZERO

Date	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Mean
1951	—	—	11,9	23,0	16,0	26,7	17,0	32,0	38,7	17,5	2,24	—	21,3
1952	—	10.0	—	19,6	18,8	55,2	61,7	70,9	58,8	—	6,2	38,4	37,4
1953	12,8	—	8,4	—	22,0	23,8	—	6,8	13,9	—	4,8	—	13,2
1954	2,2	—	22,2	—	28,9	—	50,4	44,2	16,2	—	13,7	—	25,9
1955	—	15,6	—	—	—	62,1	—	—	—	—	—	—	—

GONOTURSKA

Date	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Mean
1951	—	—	4,2	8,9	8,5	4,2	2,1	2,9	—	6,4	2,0	—	4,9
1952	—	6,3	—	15,9	7,7	4,1	5,3	4,2	3,9	—	2,2	2,8	5,8
1953	7,0	—	2,0	—	3,0	0,5	—	2,0	3,0	—	0,7	—	2,6
1954	1,4	—	5,9	—	7,2	—	2,9	2,0	2,2	—	1,6	—	3,3
1955	—	2,9	—	—	—	2,5	—	—	—	—	—	—	—

4.2. SEASONAL AND ANNUAL QUANTITATIVE VARIATIONS OF ZOOPLANKTON

Fluctuation of zooplankton production in the bay of Mljet was followed by measuring the standing crop with different methods (V u č e t i ć, 1957). The volume of zooplankton sediments and the wet and dry weights were measured. The most accurate data for estimating the quantitative changes of the standing crop were obtained by drying up and weighing the zooplankton. Table III shows all the data obtained by measuring the dry weight of zooplankton at the stations in the Malo and the Veliko jezero and at the entrance into the bay at the station Gonoturska, in the period 1951—1955. Following the fluctuation of these values it is possible to conclude that the maximal quantities of the total zooplankton can be found in the bay usually in summer months (June to September), while at the entrance into the bay, at the station Gonoturska, much earlier, i. e. at the end of winter and at the beginning of spring (March — April) (Fig. 7). All the values obtained during these investigations were used for

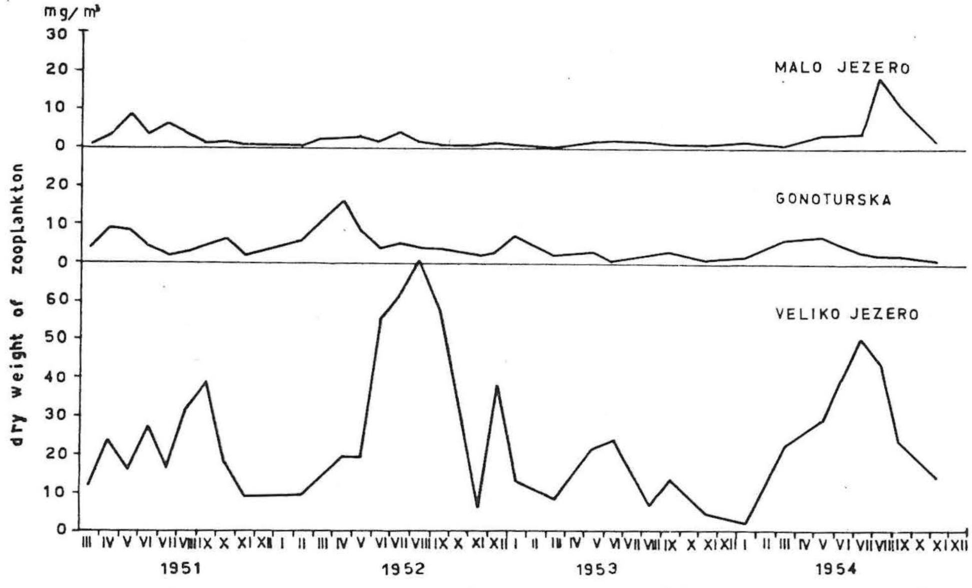

Fig. 7. Annual fluctuations of the zooplankton in the Mljet area during the four year period.

estimating the relative abundance of zooplankton in the investigated area. The unit was the quantity of zooplankton per 1 m^3 and the following annual mean values were obtained:

	1951	1952	1953	1954
Malo jezero	3.6	2.1	1.3	5.7
Veliko jezero	21.3	37.4	13.2	25,9
Gonoturska	4.9	5.8	2.6	3.3

(the values are in mg/m^3)

According to the above data it follows that the values of dry weight of the zooplankton from the Malo jezero and Gonoturska, and the Veliko jezero, are in ratio 1 : 3 : 12, which shows that the Veliko jezero is by far the richest. The Veliko jezero is also richer in zooplankton than the open Adriatic, where the annual values obtained are about 13 mg/m^3. The North Adriatic shows somewhat higher values (14.3 mg/m^3) than the Middle Adriatic (8.1 mg/m^3) (Vučetić 1961).

4.21. INFLUENCE OF ECOLOGIC FACTORS ON THE SEASONAL FLUCTUATION OF ZOOPLANKTON

Biotic factors

Bacteria — While examining the diurnal fluctuation of the bacterial populations in the euphotic zone in the bay of Mljet it was found that the diurnal fluctuations of the phytoplankton and zooplankton exist simultaneously (Cviić, 1953). Larger concentrations of zooplankton, phytoplankton and bacteria appear by day in deeper layers of the euphotic zone, while at night they are nearer the surface. Maximal quantities of bacteria appear in deeper layers than the

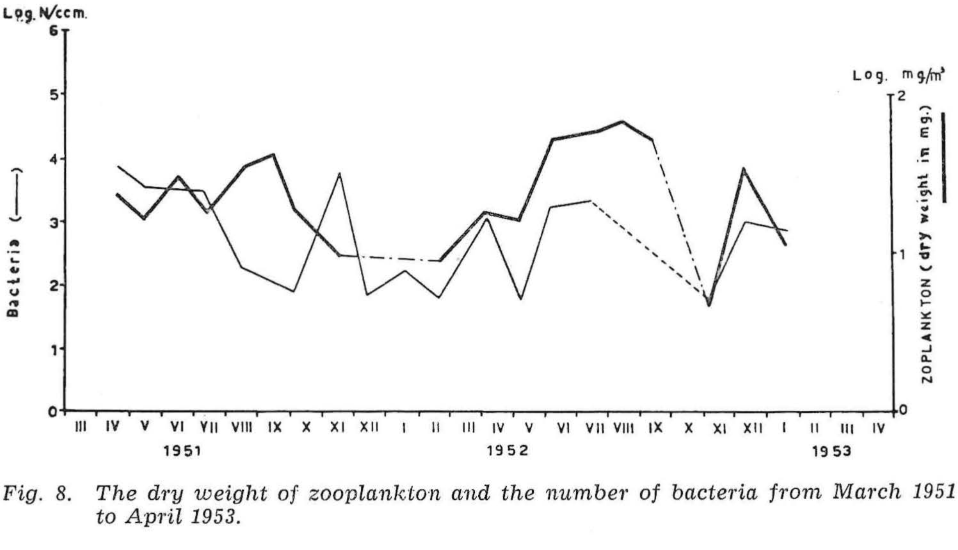

Fig. 8. The dry weight of zooplankton and the number of bacteria from March 1951 to April 1953.

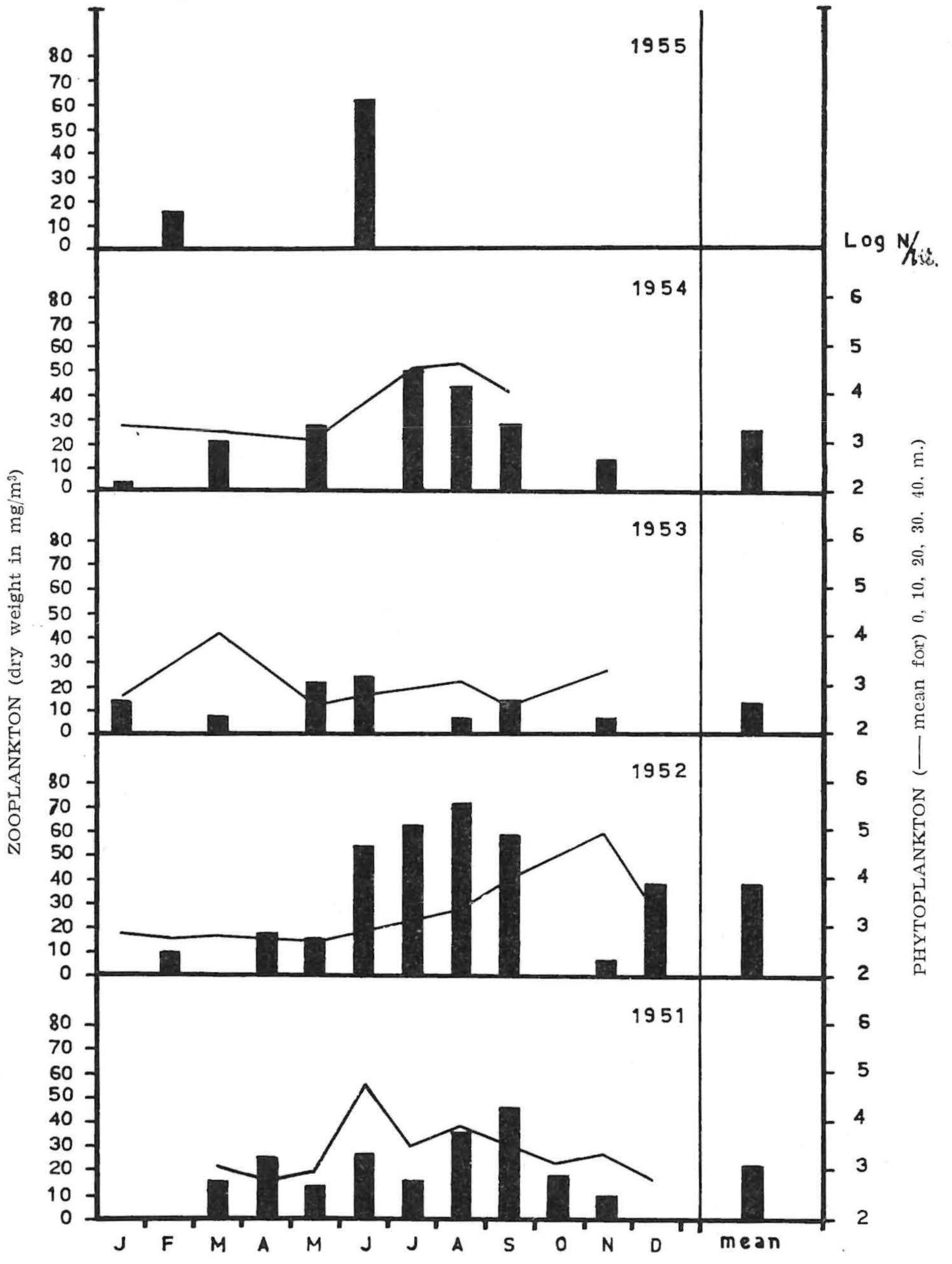

Fig. 9. Fluctuation of zooplankton dry weight and phytoplankton number from 1951 to 1955.

phytoplankton maximum could be found, somewhere nearer the place of a larger zooplankton concentration.

Following the seasonal fluctuation of the total zooplankton in 1951 in the Veliko jezero it is evident that the considerable increase of the bacterial population was preceded by the zooplankton increase (Fig. 8). In summer 1952 this was not the case. Then the maximal quantities of the zooplankton approached the time of the maximal quantity of the bacterial populations.

Phytoplankton — It is a well known fact that in the relation of the total zooplankton and the phytoplankton, the increase of the zooplankton is most frequently preceded by the increase or flowering of the phytoplankton populations. This could be concluded from the data of the Veliko jezero in the period 1951—1955 (Fig. 9). Sometimes earlier — at the end of winter (March), and sometimes later — at the beginning of summer (June), the first maximum of phytoplankton appears, while the second one usually appears in autumn (November). This could not issue from the data of 1954, but it is highly probable that the vernal phytoplankton maximum was of short duration so that it was not registered because of the rarely taken samples; besides, the fertilization could also have effected the summer iecrease of phytcplankton (Pucher-Petković, 1960).

It must be noticed that sometimes it might happen that considerably lower values for the zooplankton biomass are obtained because of the decrease of the filtration capacity of the net caused by the phytoplankton flowering. The rapid flowering of some phytoplankton species could also have a negative effect on some zooplankton species.

Seasonal variation of zooplankton in relation to abiotic factors

Temperature — It was tried to establish the relation between the zooplankton biomass fluctuation and the changes in the sea-water temperature. To this purpose the data for temperature (Fig. 10), obtained by computing the mean values for the layers extending from the surface to the depth of 20 m, were used. Analysing the total material the relation in the positive direction was established, i. e. larger quantities of the zooplankon biomass appear in the periods of increased temperatures. The first cause of this is that at the begining of stronger insolation the sea starts to warm up and parallel to this the phytoplankton in the surface productive or euphotic layers is blooming. At the same time, due to better feeding conditions, the zooplankton organisms begin their reproduction in the upper surface layers. So in the Veliko jezero in the period of a stronger insolation there was a bluming up of the plytoplankton, the growth and reproduction of some zooplankton groups, which conditioned the higher density of the zooplankton populations. This is the reason of an increased density of the zooplankton in spring, but later, when the surface layers become warmer and the thermocline is established, while at the same time the nutritive salts have been exhausted, the result is the stagnation in the phytoplankton production. The density of the phytoplankton populations decreases, and it would be quite logical to expect the same manifestation in the zooplankton. In littoral

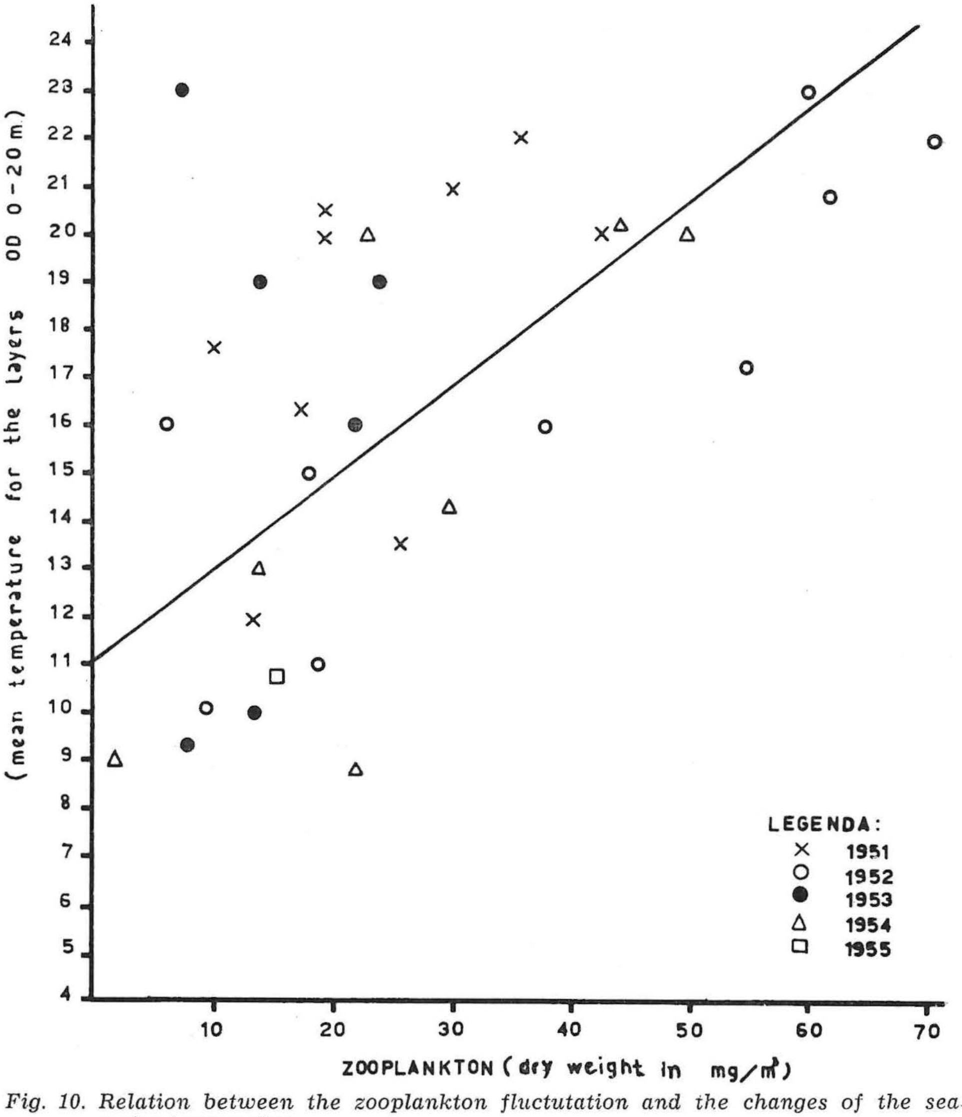

Fig. 10. Relation between the zooplankton fluctutation and the changes of the sea water temperature.

plankton the summer stagnation is not so obvious in the zooplankton because the larvae of benthonic organisms (mollusca, ciripedia, polychaeta) have their maximum in the summer period.

Except the above mentioned, it is supposed that in the Veliko jezero the positive relation between the zooplankton increase and the (surface) temperature increase could to some degree be much more intense in some years because

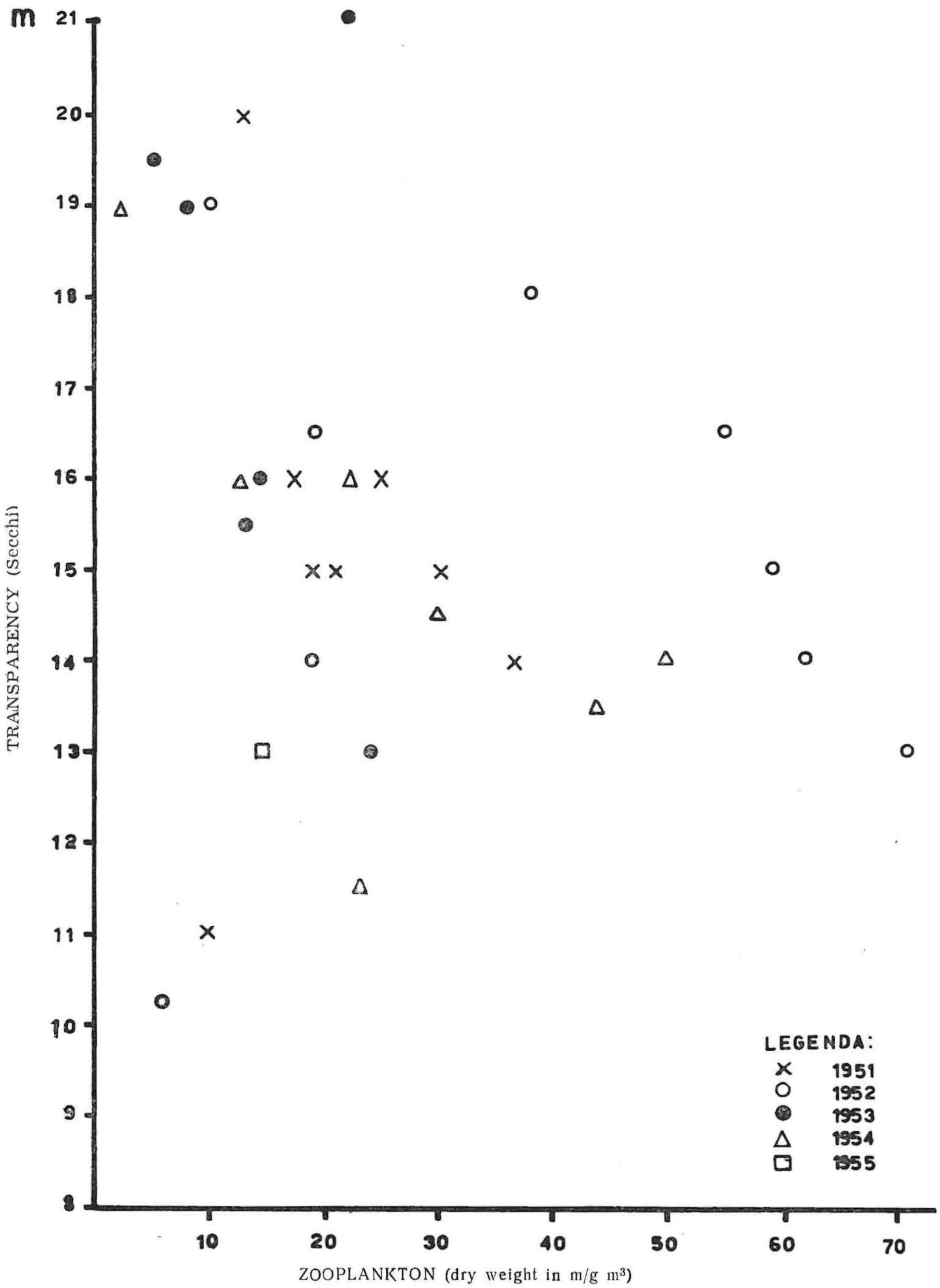

Fig. 11. Relation of zooplankton dry weight and the transparency of sea water.

of the vertical and horizontal migration of the individual zooplankton species. Namely, while investigating the vertical migrations of zooplankton (Vučetić, 1961) the temperature limit for some copepod species has been established. The lowest temperature limits have been stated for *Pseudocalanus elongatus* and *Calanus helgolandicus*, and it is supposed that the same species do a certain shifting in the horizontal direction during intense warming up. During the most intense warming up of the surface, the upper copepods, which are usually equally distributed in the whole bay, are concentrated at the bottom layers above the deepest depression in which area is the station Vrbovačka. In this depression, even during the most pronounced thermocline, the deep layers remain cool (Fig. 5).

Transparency — In the bay of Mljet it was generally found that a larger quantity of zooplankton (dry weight) causes a decrease in the sea-water transparency (Fig. 11). But the sea-water transparency decrease was also recorded with the low values of zooplankton, which proves that some other factors are responsible. The sea-water transparency in the Veliko jezero depended upon the density of the phytoplankton and zooplankton populations as well as upon the unorganic pollution of the water, and sometimes upon the qualitative composition of zooplankton (Pucher-Petković, 1960; Vučetić, 1597). It has been, namely, stated, that when there was a high production of copelata populations, in this case of *Oicopleura dioica*, the quantity of zooplankton dry weight was low, but the number of cells was so large that it made the sea-water turbid.

4.22. STANDING-CROP VARIATIONS IN RELATION TO FERTILIZATION

It was tried to establish the effect of fertilization on zooplankton by comparing the annual mean values of zooplankton dry weight. These values showed a noticeable increase after the fertilization in 1954 at the station the Malo jezero, while in the Veliko jezero that was not the case. But, in order to get the most realistic picture possible of the true state, pairs of measurings in the same months of 1951, i. e. before the fertilization, and, of 1954, during the fertilization, were taken; this yielded the following differences:

Years		Mars	May	July	Aug.	Sept.	Nov.	Mean	
	1951.	11.9	16.0	17.0	32.0	38.7	9.2	20.8	(mg/m^3)
	1954	22.2	28.9	50.4	44.2	18.5	13.7	29.6	„

In all the months of investigations the variations have been very pronounced except for the zooplankton dry weight values in September. If mean values are taken from these measurings it follows that the zooplankton biomass dry weight in 1954 was 8.8 mg/m^3 higher than in 1951, i. e. cca 42%.

If individual annual conditions of zooplankton in relation to the other factors which influence the stability of one ecosystem is analyzed, then some other explanations or corrections for the high mean values in 1952 can be obtained. Namely, with these evaluations one must always have in view the whole ecosystem and the changes in it bacause of the effect of ecologic factors on various structural elements connected with the feeding cycles.

As already mentioned higher values for zooplankton were registered in 1952 before the fertilization took place, especially at the time of a more intense warming of the surface layers of the bay (Fig. 9). If the annual mean values of the sea for the whole period of investigations are analyzed, it strikes us that these values for zooplankton are considerably higher in 1951 and 1952 than in later years.

Sea temperatures at the station Vrbovačka from 1951 to 1954

T° C at the depth of:		Years 1951	1952	1953	1954
30 m	min.	12.1	9.2	9.2	8.0
	max.	13.4	19.9	10.6	9.7
	mean.	*12.7*	*14.5*	*9.9*	*8.8*
40 m	min.	12.3	9.2	9.3	8.0
	max.	13.2	13.6	12.5	9.7
	mean.	*12.7*	*11.4*	*10.9*	*8.8*

Due to these increases in the sea temperature, the increase of the zooplankton could have been obtained in the following way. The temperature limits which the copepoda *Calanus helgolandicus* and *Pseudocalanus elongatus* never cross during the diurnal vertical migration have already been stated and described (Vučetić, 1961). In connection with this it has been concluded that with the very intense warming up of the surface layers in the Veliko jezero these copepods make the horizontal shifting into the direction of deeper levels which have preserved relatively low temperatures even with the most intense warming up in summer. Because of this it was possible that in 1951, and especially so in 1952, there was a great concentration of the copepods at the station Vrbovačka at which there is the maximal depth of the bay. This might be one of the main reasons the high values of the total zooplankton could be obtained in those years. Had the dispersion of the zooplankton been greater, the standing crop values would have been much lower. It has also to be mentioned that in the summer samples of 1952 the mollusc larvae had appeared in a strikingly large number, so that, because of their shells, they had a considerable effect on the increase of the zooplankton dry weight values.

It follows that maybe the above mentioned temperature increase of the sea and the occurence of the mollusc larvae were the reason of a higher quantities (dry weight) of the zooplankton in 1951 and 1952. On the other hand, the certain decrease of the zooplankton crop in 1953 and 1954 might be due to a more intense occurrence of the sardine and anchovy in the bay. It was in those years that a larger quantity of pelagic fish occurred along the coast and it might be possible that, attracted by a more intensive production, they had entered the bay. Large sardines (size 18—20 cm, 16—17 per kilo) were caught in larger quantities in June, July and August, in somewhat smaller ones in September of 1954. The possibility that the occurrence of these plankton feeding fish is the reason for not having found a larger zooplankton standing crop is not to be excluded. This was largely due to the increase of fish eggs and larvae with a very low mortality due to very favourable feeding conditions (V u č e t i ć, 1937).

It has been suggested that maybe due to the variations in the sea-water acidity there was no greater zooplankton increase after the fertilization. Namely, the periodical increase of pH after fertilization has a negative effect on zooplankton organisms. M a r s h a l l, S. M. and A. P. O r r (1948) got a rich zooplankton the first year during fertilization, but the second year it decreased and remained poor. They think that it was probably the intensive fertilization, due to a dense phytoplankton and other vegetations, that made pH raise periodically to the level dangerous to animal organisms. In the bay of Mljet pH oscillations were also found, so that at the station Vrbovačka there was an increase up to 8.2, while near the bottom pH fell to 7.7. But this is still much lower than the values obtained by the experiments of M a r s h a l l and O r r when the values were pH 10, so that we suppose the pH changes in our experiments had not a negative effect.

5. DISCUSSION AND CONCLUSIONS

In order to improve our diet it has been tried to increase the production of organic matter on land and sea, to which purpose various ecosystems have been examined, i. e. natural conditions of production are first examined, and then experiments on artificial increase of production are carried out. Somewhat similar has been intended to be achieved with these investigations in the bay of Mljet. The particularities of this biotope — natural aquarium — have enabled us to carry out a large experiment with which, in completely natural conditions, it has been quite possible to control and follow the changes in the plankton community as well as the changes in ecologic factors of the surroundings. As a part of the total investigations of plankton, the zooplankton biomass fluctuations in relation to the ecologic factors in natural conditions, as well as after the fertilization, were examined.

The seasonal changes of zooplankton communities are the result of the activity of a number of factors, and all the efforts were directed to establishing the most important ones. As there have been no preliminary data of the effect of these factors upon the zooplankton biomass in the Adriatic, a number of measurings on the material from the bay of Mljet, as well as from some other localities in the Adriatic, had to be carried out. The bay of Mljet itself has offered a unique opportunity for such investigations. Its topographic and hydrographic peculiarities have enabled this deep bay to preserve rather low sea temperatures in summer, because the currents of the inflow and outflow, have only a surface effect due to the narrow and shallow entrance opening. The result of this is that there is no great exchange of water with the open sea. Such a special biotope is reflected on the zooplankton composition which shows the typical neritic character, with the only difference that its standing crop differs considerably from the similar localities along the coast. The Veliko jezero is much more rich in zooplankton than the other investigated stations in the bay, and the other investigated areas in the Adriatic. The maximal quantities were always obtained in summer months as distinguished from the stations of the open Adriatic, where the greatest values occur in winter-spring period (Gamulin, 1954; Hure, 1955; Hoenigman, 1958; Vučetić, 1957).

The high standing crop which was found need not mean a high degree of production. Although it is quite sure that the rich vegetation of the surrounding land and the drainage into the bay contribute to the increase of production in this basin, the high standing-crop need not be the result of this only, but it may also be the sign that the system is not well balanced, i. e. the ratio producer — consumer is defective in this case, for there are not enough direct zooplankton consumers — the pelagic plankton feeders.

Studying the relation of the ecologic factors of the surroundings to the zooplankon fluctuation in the Veliko jezero, the ratio phytoplankton — zooplankton did not show any particular regularities, but still, it corresponded to the established pattern for the temperate seas (Cushing, 1959; Heinrich, 1962), according to which the phytoplankton maximum is always followed by the zooplankton increase. The zooplankton fluctuation has been followed by bacterial fluctuation so that the maximal quantities appeared either at the same time with or somewhat earlier than the bacteria.

The zooplankton increase occurs at the time of temperature increase of the surrounding layers (Fig. 7). This is quite understandable as it is known that one of the phytoplankton increases begins in spring, which, together with the parallel sea temperature increase, hastens the growth of holozooplankton which spawns at the time. Besides, there is a more intensive appearance of mezozooplankton. The biomass increase can be the result of the direct influence of temperature upon the processes in the sea. Maybe the temperature is also indirectly responsible for the biomass increase (in this case at the station Vrbovačka in the Veliko jezero) due to the influence of the temperature on the horizontal shifting of the zooplankton. Namely, in summer, while the surface and littoral parts of the bay are intensely warmed up, *Calanus helgolandicus* and *Pseudocalanus elongatus* shift towards the depression in the Veliko jezero where even at this period low sea temperatures are still preserved.

No regularities can be concluded from the relation between the changes in the transparency of the sea in the Veliko jezero and the zooplankton increase. Decrease in transparency was noticed at the time of the phytoplankton flowering and later during the zooplankton increase. Transparency decrease occurred also at the time when low dry weight values of zooplankton were found because of a large number of copelata *Oicopleura dioica*.

As already mentioned one of the aims of the investigations carried out in the bay of Mljet was to try to artificially increase the production. To this purpose, after establishing the original state, nutritive salts in the form of fertilizers were added. In the first series, following the method of extermination (Buljan, 1957), 2,270 kg Ca-cyanamide was thrown into the Veliko jezero in May and June 1953 in order to increase the production. In 1954 a total of 21,500 kg superphosphate was added mixed with concentrated H_2SO_4 and soil extract. In 1954 a total of 36.7 mg P-PO_4 per each ton of water was added.

B u l j a n (1957) thinks that the fertilization of the bay has effected the production because there was a decrease in oxigen contents in the lower levels of the bay owing to the mineralization of the increased quantities of organic matters which were shifting towards the bottom. He also thinks, basing on the data obtained by measuring O_2 and comparing the values O_2-O_2' before and after fertilization, that the fertilization has caused at least 6.4 times higher production of organic matters, if not even more. Namely, this method of computing the production always yields lower values because the turbulence of water layers, oxigen consumption and other organisms present, have not been taken into consideration.

Though the measuring of phytoplankton standing crop represents only the surplus of the production which has not been used up, according to the data of P u c h e r - P e t k o v i ć (1960) the fertilization with considerable oscillations has reflected itself positively upon the density increase of phytoplankton populations, especially in summer. Based on the phytoplankton measurings relatively higher values have been obtained for the production increase than those by O_2-O_2' method. So during the summer months (July, August, September) of 1954, after the fertilization the phytoplankton population density increased more than 20 times than the values obtained earlier (in 1951, 1952 and 1953). Here the number of cells found in one litre of sea-water is meant. But the total quantity of organic matters during these maxima did not increase very much because the main phytoplankton species as *Leptocylindrus adriaticus* and *Nitzchia sp.*, which then occurred, belong to the phytoplankton forms of small dimensions.

The effect of fertilization could also be followed on the benthonic vegetation, and it was especially evident at the end of May 1954, when in one part of the saturation of oxigen at the very bottom occurred in the quantities that have never yet been found in the Adriatic (from 198.3% to 216.2%).

The transparency decrease in the bay was the result of a higher development of the phytoplankton after the fertilization so that the values were very low, i. e. much lower than those in the previous years.

Though it is known that the increase of primary production in a basin need not reflect in a considerable increase of the biomass of one trophic level, nevertheless, it was tried to analyze the relation between the fluctuation of the zooplankton biomass before and after the fertilization. The results have shown that there was a considerable increase of zooplankton in 1954 in relation to 1951. But even before the fertilization very high values could have been obtained in 1952, even higher than those in 1954. This phenomenon was related to the high temperatures of the sea which had effected the horizontal shifting of the plankton and its concentration in the depression of the bay (where the plankton samples were taken) which even in the season of the highest warming up of the sea preserves relatively very low temperatures.

Considering the generally low temperatures of the sea in 1954 it could be concluded that this horizontal dispersion in summer 1954, was much higher than in previous relatively warmer years (1951 and 1952). It is, perhaps, due to this dispersion that in 1954 higher values of zooplankton at the station Vrbovačka could not have been obtained. Besides, as the number of plankton consumers in 1954 was generally increased, maybe there was no abnormally high or sudden increase of zooplankton standing crop, although it is quite possible that the zooplankton production was much higher due to fertilization. Not only the number or density of predators was increased (*Engraulis encrasicholus, Sardina pilchardus*), but it seems that, due to exceptionally good feeding conditions, the spawning intensity increased and the eggs mortality decreased. The number of dead eggs of anchovy was considerably lower than usual (V u č e t i ć, 1958). The relatively uniform increase of the standing crop in a greater number of trophic levels in the Veliko jezero shows that the transmission of energy or the reproducted organic matter was efficient, which is the »steady state« system of C u s h i n g (1959). Considering some data for zooplankton in 1955 (high values of zooplankton dry weight and the phenomenon of superfluous feeding of copepods) we suppose the positive effect of the fertilization has reflected in the year following the experiments.

* * *

One of the central problems of present time investigations is the evaluation of ecological efficiencies of trophic levels. All the efforts of today's investigators are directed to the study of the feeding cycles and their effectiveness. It has been tried to make detailed examinations of the effect of the phytoplankton cycles on the zooplankton herbivora and carnivora, then to learn more about the population dynamics of individual herbivora and the laws which govern the transmission of energy from the first producers onto the next level.

The standing crop estimation which marks the momentary state or the largeness of the population can only to some degree help estimate the organic production because the length of the life cycle (natality, growth, reproduction, mortality and destruction), and the rate of the succession of generations, are very different with individual members of trophic chains and with the members of the same chain but of different seasons of the year. When determining the rate of growth of individual populations in the plankton community, with the primary producers it is very difficult to determine the rate of division of planktonic algae in a determined time interval, while with their nearest consumers, the zooplankton organisms, it is very difficult to measure the rate of growth and the succession or number of generations.

The copepod populations are one of the main components of the bay of Mljet zooplankton community (Fig. 9, V u č e t i ć, 1957) and the main herbivora which feed upon the phytoplankton. Among the copepods, judging by the biomass, the most important is the copepod *Calanus helgolandicus*. With detailed studies of the population dynamics of this species, according to H e i n r i c h's (1962) type of life history, many moments in the zooplankton ecology of this special biotope might be explained. This might contribute to improve the knowledge of the relation between the different members in the feeding cycle. These examinations are the subject of another work (V u č e t i ć, in preparation).

6. SUMMARY

Based on the rich material collected during the complex oceanographic investigations from 1951 to 1955 in the region of the bay of Mljet ecologic examinations of zooplankton were carried out. The present work brings the results of these examinations during the experiment of fertilization in the bay Veliko jezero.

Examinations have shown that the bay of Mljet is a unique biotope for ecologic examinations of plankton communities due to its topographic and hydrographic conditions. This deep bay, in one of its parts (Veliko jezero) preserves very low temperatures even in the summer period. The inflow and outflow currents are of surface character because the entrance is very narrow and shallow and, as the bay does not greatly exchange water with the open sea, it could serve as a large natural aquarim. In the basin of the Veliko jezero the temperature varies from 8.2 to 27.0° C, the salinity being from 30.0 to 37.2‰ c. Due to these changes there is some oscillation in the sea-water density so that the surface layers density varies from 22.7 to 28.3 σ_t. The sea-water transparency changes considerably each season, the annual differences might be from 10.5 to 21 m. In the bay Malo jezero the periodical occurrence of H_2S was established with the result that at that time it was much poorer in species than the Veliko jezero. It was thus found that in 1954 the Malo jezero was aerated i. e. without H_2S, while at the same time considerable quantities of copepod *C. helgolandicus,* which had not been present before in this part of the lake, were detected.

As the main qualitative characteristic of the zooplankton community of this biotope, it has been established that the zooplankton is represented with few species, but with a high density of population. The main biomass consists of the copepods which have been represented throughout the year from 27.9—94.6%, followed by the mollusc larvae from 1.1—64.5%, chaetognaths 0.4—9.2%, copelats 0—8.1%, and at last by other groups in smaller quantities.

Among the copepods per biomass first is *Calanus helgolandicus,* followed by *Paracalanus parvus* and *Pseudocalanus elongatus.* It has been found that the population density of the copepod *C. helgolandicus* in the Veliko jezero has reached the highest values up to now recorded in the Adriatic.

Examining the total zooplankton data (dry weight) it has been established that the Veliko jezero, according to the high standing-crop, comes first in relation to the other areas in the Adriatic.

The seasonal variations in the zooplankton production show that the maximal quantities always appear during the warm period (June, July, August), while in the open Adriatic usually much earlier, in March and April.

The relation between the zooplankton crop fluctuation and the ecologic factors has been examined. The relation between the zooplankton and the

bacteria has shown that the zooplankton increase appears at the same time with (1952) or somewhat earlier (1951) than the bacterial increase. The relation between the zooplankton and the phytoplankton is rather similar, i. e. in 1952 and 1953 the zooplankton increase started after the phytoplankton did, except in 1954. Then the main vernal phytoplankton maximum lasted for a short time so that it could not have been registered, but the later phytoplankton increase was the result of the fertilization (Pucher-Petković, 1960).

Analyzing the fluctuation of the zooplankton changes it has been stated that with the temperature increase, the zooplankton increases as well. This is the result of, besides the phytoplankton production and the holozooplankton reproduction, a higher presence of merozooplankton during the warmer part of the year. According to the findings it seems that, due to the temperature increase of the surface layers, there might be a horizontal shifting of the zooplankton towards the bay's depression (station Vrbovačka) in which there are rather stable low temperatures even during the summer months. This might result in a certain biomass increase or the zooplankton density in this part of the bay.

The transparency changes of the sea-water were not the result of the phytoplankton production increase only (Pucher-Petković, 1960), but also of the more intensive zooplankton increase. The low transparency was recorded with the low values of zooplankton but with the appearance of the copelats *Oicopleura dioica* in greater quantity.

It was found that the standing crop of the zooplankton in 1951, i. e. before the fertilization, and the one in 1954, during the fertilization, differed in 8.8 mg per m^3 or cca 42% which is also one indirect proof of the primary production increase in the Veliko jezero after the fertilization besides those previously established by Buljan (1957), Morović (1958), and Pucher-Petković (1960).

Besides this, the increase in carnivora in 1953 was established, especially in the pelagic fish and larvae which, due to good feeding conditions, had a low mortality (Buljan, 1957; Vučetić, 1957). This is thought to have contributed to the balance of the zooplankton production, i. e. it has prevented a higher accumulating of the zooplankton standing crop, which is, according to Cushing (1959), the sign of a balanced system or production cycle.

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KVANTITATIVNA EKOLOŠKA ISPITIVANJA ZOOPLANKTONA ZA VRIJEME POKUSA FERTILIZACIJE U VELIKOM JEZERU (o. Mljet)

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8. KRATAK SADRŽAJ

Na bogatom materijalu sakupljenom u sklopu kompleksnih oceanografskih istraživanja od 1951—1955. god. u području Mljetskih jezera izvršena su ekološka ispitivanja zooplanktona. Ovaj rad donosi rezulate ispitivanja, za vrijeme pokusa umjetne fertilizacije u uvali Veliko jezero.

Ispitivanja su pokazala da su Mljetska jezera zbog specijalnih topografsko--hidrografskih svojstava jedinsveni biotop za ekološka ispitivanja planktonskih zajednica. Ova duboka uvala u jednom dijelu (Veliko jezero) sačuva vrlo niske temperature i u ljetnjem periodu. Ulazne i izlazne struje su površinskog karaktera, jer je ulaz vrlo uzak i plitak pa pošto jezera nemaju velike izmjene vode sa otvorenim morem, mogla su poslužiti kao veliki prirodni akvarij. U bazenu Velikog jezera temperatura varira od 8,2 do 27,0° C, a salinitet od 30,0 do 37,2‰. Uslijed ovih promjena dolazi do oscilacija gustoće morske vode pa u površinskim slojevima gustoća varira od 22,7 do 28,3 σ_t. Prozirnost morske vode znatno se mijenja iz sezone u sezonu, a godišnje razlike mogu biti od 10.5 do 21 m. U uvali Malo jezero utvrđeno je povremeno prisustvo H_2S, pa je ovaj dio jezera u to doba znatno siromašniji vrstama od Velikog jezera. Tako je nađeno da je u 1954. god. Malo jezero bilo prozračeno, odnosno bez H_2S, a istodobno su nađene i znatne količine kopepoda C. *helgolandicus* koji se ranije nije zadržavao u ovom dijelu jezera.

Kao glavna kvalitativna karakteristika zooplanktonske zajednice ovog biotopa, utvrđeno je, da je zooplankton zastupan s malim brojem vrsta, ali s velikom gustoćom populacije. Glavnu biomasu sačinjavaju kopepodi koji su tokom godine zastupani od 27,9—94,6%, zatim slijede larve moluska sa 1,1—64,5%, hetognati 0,4—9,2%, kopelati 0—8,1%, a iza toga ostale grupe u manjim količinama.

Među kopepodima, po biomasi, na prvom mjestu dolazi *Calanus helgolandicus,* a zatim slijede *Paracalanus parvus* i *Psudocalanus elongatus.* Nađeno je da gustoća populacije kopepoda *C. helgolandicus* u Velikom jezeru dostigne najviše vrijednosti do sada zabilježene u Jadranu.

Ispitivanjem kolebanja sveukupne zooplanktonske biomase (suha težina) utvrdilo se da Veliko jezero, po visini »standing crop-a« zooplanktona dolazi na prvo mjesto u odnosu na druga područja u Jadranu.

Sezonsko variranje u produkciji zooplanktona pokazuje da se maksimalne količine uvijek javljaju u toku toplijih mjeseci (juni, juli i august), dok u otvorenom Jadranu obično znatno ranije, već u martu i aprilu.

Ispitivan je odnos između kolebanja zooplanktonske biomase i ekoloških faktora, pa je odnos između zooplanktona i bakterija pokazao da povećanje zooplanktonske biomase pada u isto doba (1952. god.) ili pak nešto ranije (1951. god.) nego povećanje bakterijske biomase. Odnos između zooplanktona i fitoplanktona nekako je sličan, tj. 1952. i 1953. god. porast zooplanktona nastupa iza fitoplanktona osim 1954. god. Tada je glavni proljetni maksimum fitoplanktona kratko trajao pa ga se nije uspjelo registrirati, a kasnije do povećanja fitoplanktona došlo je uslijed fertilizacije (Pucher-Petković, 1960).

Analizirajući kretanje vrijednosti zooplanktonske biomase u odnosu na promjene temperature, utvrdilo se, da porastom temperature, raste i biomasa zooplanktona. Ovo je posljedica što se, osim povećanja produkcije fitoplanktona, zatim razmnožavanja holozooplanktona, javlja u toplijem dijelu godine i jače prisustvo merozooplanktona. Prema nalazima izgleda da uslijed povišenja temperature površinskih slojeva, može doći do horizontalnog pomicanja zooplanktona prema jezerskoj depresiji (postaje Vrbovačka), gdje vladaju prilično stabilne niske temperature i tokom ljetnjih mjeseci. Ovo može prouzrokovati izvjesno povećanje biomase ili gustoće zooplanktona u ovom dijelu jezera.

Do promjene prozirnosti morske vode došlo je ne samo radi povećanja produkcije fitoplanktona (Pucher-Petković, 1960), već i radi jačeg povećanja zooplanktonske biomase. Međutim bila je zabilježena mala prozirnost i kod niskih vrijednosti zooplanktona, ali kod pojave kopelata *Oicopleura dioica* u velikim količinama.

Nađeno je da se vrijednosti suhe težine zooplankonske biomase iz 1951. god., tj. prije fertilizacije i one iz 1954. god. za vrijeme fertilizacije, razlikuju za 8,8 mg po m^3 ili cca 42%, pa je to još jedan indirektan dokaz povećanja primarne produkcije u Velikom jezeru nakon fertilizacije, pored onih koji su bili ranije utvrđeni od Buljana (1957), Morovića (1958) i Pucher-Petković (1960. godine).

Osim toga utvrđeno je povišenje karnivora u 1953. god., a naročito pelagične ribe i to posebno larvalnih stadija, koji su uslijed dobrih prilika za ishranu imali i smanjen mortalitet (Buljan, 1957; Vučetić, 1957), pa se smatra, da je to pridonijelo, da se produkcija zooplanktona zadržala u ravnoteži, odnosno da nije došlo do jačeg nagomilavanja »standing crop-a« zooplanktona, što je ujedno (Cushing, 1959) znak dobro uravnoteženog sistema ili ciklusa produkcije.

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CONTENTS

Tisak: Novinsko izdavačko poduzeće »Slobodna Dalmacija« — Split