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SEASONAL AND MULTIANNUAL FLUCTUATIONS OF COPEPODS IN THE KAŠTELA BAY (1960—1969)

SEZONSKE I VIŠEGODIŠNJE FLUKTUACIJE KOPEPODA U KAŠTELANSKOM ZALJEVU (1960—1969)

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Ten years studies of seasonal and multiannual fluctuations of the Kaštela Bay copepods, carried out on the basis of monthly samplings in 1960—1969 period, are analysed.

1. INTRODUCTION

Continuous investigations of the zooplankton have been carried out at monthly intervals since 1954 to study the seasonal and multiannual fluctuations of the plankton in the Kaštela Bay. Result published up to now cover the zooplankton biomass and group composition (Vučetić, 1961 a and b, 1963, 1965, 1966, 1967, 1969, 1970, 1971, 1973a and b, 1975, 1977; Vučetić and Pucher—Petković, 1969; Vučetić and Kačić, 1973), biochemical composition (Vučetić, Damjanić and Čubretović, 1969), pollution by mercury and pesticides (Vučetić, Vernberg and Anderson, 1974; Dujmov, Picer and Vučetić, 1979) and particularly the ecology of the copepod group (Regner, D. 1971, 1973, 1974, 1975, 1976b, 1977a, b; 1978, 1979a, b; Homen and Regner, 1977; Marasović and Regner, 1979; Vučetić and Regner, 1970).

As a part of above investigations the results of the studies of copepods in the 1960—1969 period are brought out. Seasonal and long-term fluctuations of the dominant copepod species were studied from the material collected by »Hensen« net (73/100, silk Nr 3, Vučetić, 1967). Seasonal fluctuations are expressed as the ten year mean values by months, and multiannual fluctuations are given as annual density means of the dominant copepod species for the period of investigations.

2. RESULTS OF INVESTIGATIONS

A total of 54 copepod species were determined in the Kaštela Bay during the 1960—1969 period. They may be listed as follows:

1. *Calanus helgolandicus* (Claus)
2. *Calanus tenuicornis* Dana

3. *Nannocalanus minor* (Claus)
4. *Neocalanus gracilis* (Dana)
5. *Eucalanus elongatus* (Dana)
6. *Paracalanus nanus* G. O. Sars
7. *Paracalanus parvus* (Claus)
8. *Calocalanus pavo* (Dana)
9. *Ischnocalanus plumulosus* (Claus)
10. *Mecynocera clausi* Thompson
11. *Clausocalanus arcuicornis* (Dana)
12. *Clausocalanus jobei* Frost & Fleminger
13. *Clausocalanus pergens* Farran
14. *Clausocalanus parapergens* Frost & Fleminger
15. *Clausocalanus furcatus* (Brady)
16. *Ctenocalanus vanus* Giesbrecht
17. *Euchaeta hebes* Giesbrecht
18. *Diaixis pygmaea* (T. Scott)
19. *Centropages typicus* (Kröyer)
20. *Centropages kröyeri* Giesbrecht
21. *Centropages violaceus* (Claus)
22. *Isias clavipes* Böeck
23. *Temora stylifera* (Dana)
24. *Temora longicornis* Müller
25. *Lucicutia flavicornis* (Claus)
26. *Candacia armata* (Böeck)
27. *Pontella lobiancoi* (Canu)
28. *Pontella mediterranea* (Claus)
29. *Labidocera wollastoni* (Lübbock)
30. *Acartia clausi* Giesbrecht
31. *Oithona nana* Giesbrecht
32. *Oithona helgolandica* (Claus)
33. *Oithona plumifera* Baird
34. *Microsetella norvegica* (Böeck)
35. *Macrosetella gracilis* (Dana)
36. *Euterpina acutifrons* (Dana)
37. *Clytemnestra rostrata* (Brady)
38. *Oncaea venusta* Philippi
39. *Oncaea mediterranea* (Claus)
40. *Oncaea media* Giesbrecht
41. *Oncaea dentipes* Giesbrecht
42. *Oncaea subtilis* Giesbrecht
43. *Lubbockia squilimana* Claus
44. *Sapphirina nigromaculata* Claus
45. *Sapphirina* sp.
46. *Corycaeus (Agetus) typicus* (Kröyer)
47. *Corycaeus (Agetus) flaccus* Giesbrecht
48. *Corycaeus (Onychocorycaeus) giesbrechti* Dahl
49. *Corycaeus (Onychocorycaeus) latus* (Dana)
50. *Corycaeus (Onychocorycaeus) ovalis* Claus
51. *Corycaeus (Ditrichocorycaeus) brehmi* Steuer

52. *Corycaeus (Urocorycaeus) furcifer* Claus
53. *Corycaeus (Corycella) rostrata* Claus
54. *Caligus rapax* Milne Edwards

Out of the total of species determined at the station »Kaštela Bay«, only the species occuring in greatest abundances are described in more detail. However, the most essential data on the seasonal and multiannual dynamics are given for the rest of the species.

1. *Calanus helgolandicus* (Claus), 1863. — It was present in the material from January to August. The ten year means show that the maximum number of individuals occurs most frequently in March and June what is in agreement with the results of Vučetić (1957, 1964, 1965, 1977).
2. *Calanus tenuicornis* (Dana), 1849. — Even though in small numbers, it occurs throughout the year. It is most numerous in February, rarely occurring in summer months.

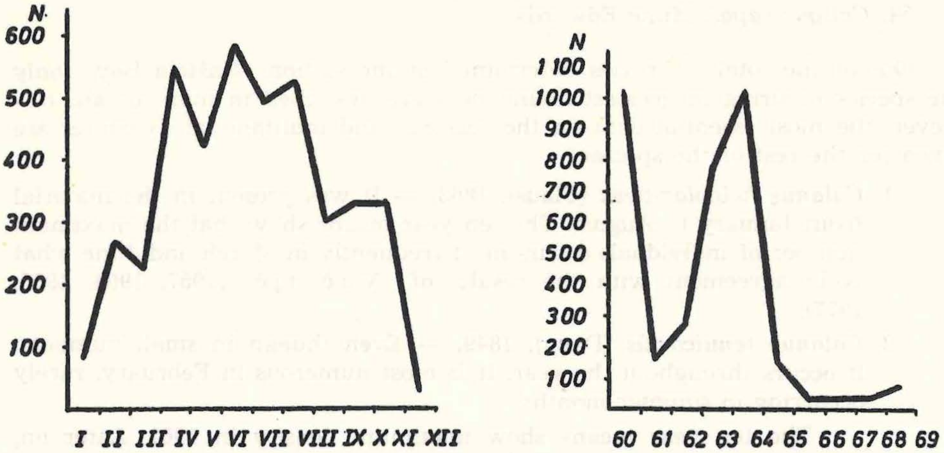
   The ten year means show maximum density in 1961. Later on, a certain increase in the number of individuals occurs every four years.
3. *Nannocalanus minor* (Claus), 1863. — was recorded throughout the year, except in July and September; most numerous was in March. During the ten year period the largest number was found in 1963.
4. *Neocalanus gracilis* (Dana), 1849. — It was recorded only on one occasion; it has no quantitative significance among other copepods.
5. *Eucalanus elongatus* — Very rare and occurring in small numbers.
6. *Paracalanus nanus*, G. O. Sars, 1907. — Occurs in small number of individuals and only from time to time.
7. *Paracalanus parvus* (Claus), 1863. — Larger numbers of individuals occur in the warmer part of the year. Out of the 110 samplings, it was recorded from 44.

   Its percentual presence (in the total number of copepods) varies from 1.2 in December to 12.5% in June; or on an average 7.3%. Among the species dominant with respect to density in comes fifth. Maximum numbers of individuals were mainly recorded in June (1961, 1962, 1965, 1969) as well as in the lake Veliko jezero on Mljet Island (Vučetić, 1957). Minimum number of individuals was most frequently recorded in December. The results obtained from averaged values show that it is represented with larger numbers from April to August (Fig 1a).

   It occurs within the temperature range 9.6—23.7°C with the maximum density between 15.3 and 21.7°C what best evident from Fig. 1c. At the same time it was recorded at sea salinity ranging from 34.25—38.10‰, maximum numbers at 36—37.8‰ what is given in Fig. 1d. For the period of ten years rather high densities were recorded in 1960, 1963 and 1964. Fig. 1b.
8. *Calocalanus pavo* (Dana), 1840. — Maximum values were found in November; rather numerous was in January.

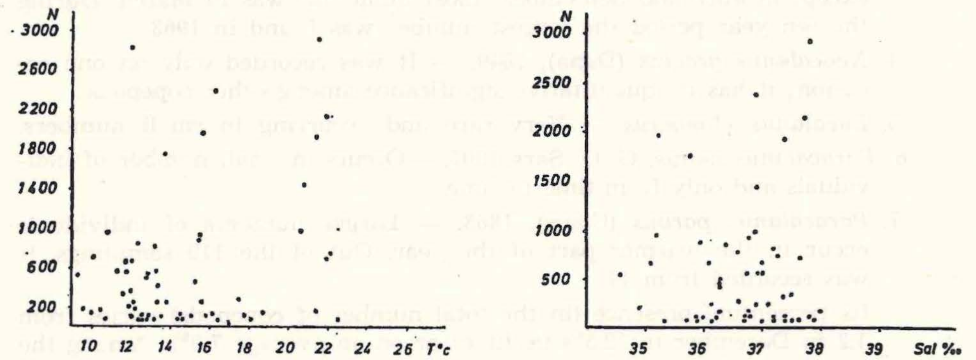
   For the period of ten years it was most abundant in 1968.

Fig. 1. *Paracalanus parvus*



a) Seasonal density oscillations (10 years months means)

b) Long term (1960—1969) density oscillations (annual means)



c) Relation between density and temperature at 10 m

d) Relation between density and salinity at 10 m

9. *Ischnocalanus plumulosus* (Claus), 1863. — It is quantitatively insignificant, very rarely occuring.

10. *Mecynocera clausi* (Thompson), 1888. — From Kaštela Bay material as a whole, it was recorded only several times, in November (1964 and 1965) and in January, March, September and October (1968).

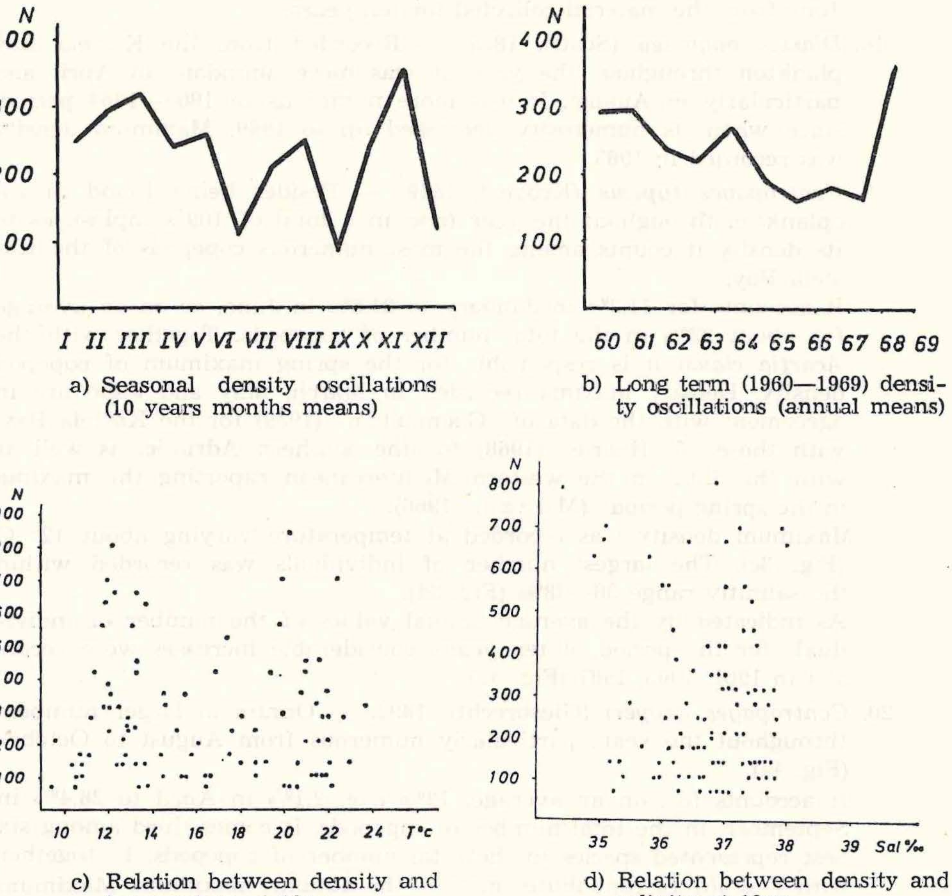
11. *Clausocalanus arcuicornis* (Dana), 1849. — It was present throughout the year during the ten year period of investigations. As indicated by the multiannual monthly means it is most numerous in autumn (Fig. 2a).

As to the quantity it was more numerous in 1960—1962, whereas maximum density occurred in 1969 (Fig. 2b).

Percentage presence in the total number of copepods varies from 1.5% in September to 9.7% in January, or on an average 5.7%, what means that it comes sixth among the dominant species of the Kaštela Bay. Maximum density was found about 12°C, as shown in Fig. 2c.

It was more numerous in 1960—1962, whereas maximum density occurred in 1969 (Fig. 2b).

Fig. 2. *Clausocalanus arcuicornis*



a) Seasonal density oscillations (10 years months means)

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c) Relation between density and temperature at 10 m

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12. *Clausocalanus jobei* (Frost & Fleminger), 1968. — It is also very numerous, particularly during the warmer part of the year.

13. *Clausocalanus pergens* (Farran), 1926. — Occurs from time to time in small numbers of individuals.

14. *Clausocalanus parapergens* — Occurs very rarely with only few individuals.

15. *Clausocalanus furcatus* (Brady), 1883. — As indicated by seasonal fluctuations two maximum may be distinguished, one in April and other in November. For the period of investigations (ten years) it was most numerous in 1960 and 1967.

16. *Ctenocalanus vanus* (Giesbrecht), 1888. — Recorded throughout the year, particularly abundant from February to May. From 1964 on, an increase in the number of individuals was recorded, with maximum in 1967.
17. *Euchaeta hebes* (Giesbrecht), 1888. — Very rare in the Kaštela Bay. Only few individuals were recorded in January, February, March and June from the material collected for ten years.
18. *Diaixis pygmaea* (Scott), 1899. — Recorded from the Kaštela Bay plankton throughout the year, it was more abundant in April and particularly in August. It was more numerous in 1960—1964 period, since when its numerosity decreased up to 1969. Maximum density was recorded in 1963.
19. *Centropages typicus* (Kröyer), 1849. — Besides being found in zooplankton throughout the year (and in a total of 109 samples), as to its density it counts among the most numerous copepods of the Kaštela Bay.

    It accounts for 11.2% in January to 21.6% in June, or on an average for about 22% in the total number of copepods. Together with the *Acartia clausi* it is responsible for the spring maximum of copepod density. Density maxima recorded in March, May and June are in agreement with the data of Gamulin (1939) for the Kaštela Bay, with those of Hure (1968) for the southern Adriatic, as well as with the data on the western Mediterranean raporting the maxima in the spring period (Mazza, 1966).

    Maximum density was recorded at temperature varying about 12° C (Fig. 3c). The largest number of individuals was recorded within the salinitiy range 36—38‰ (Fig. 3d).

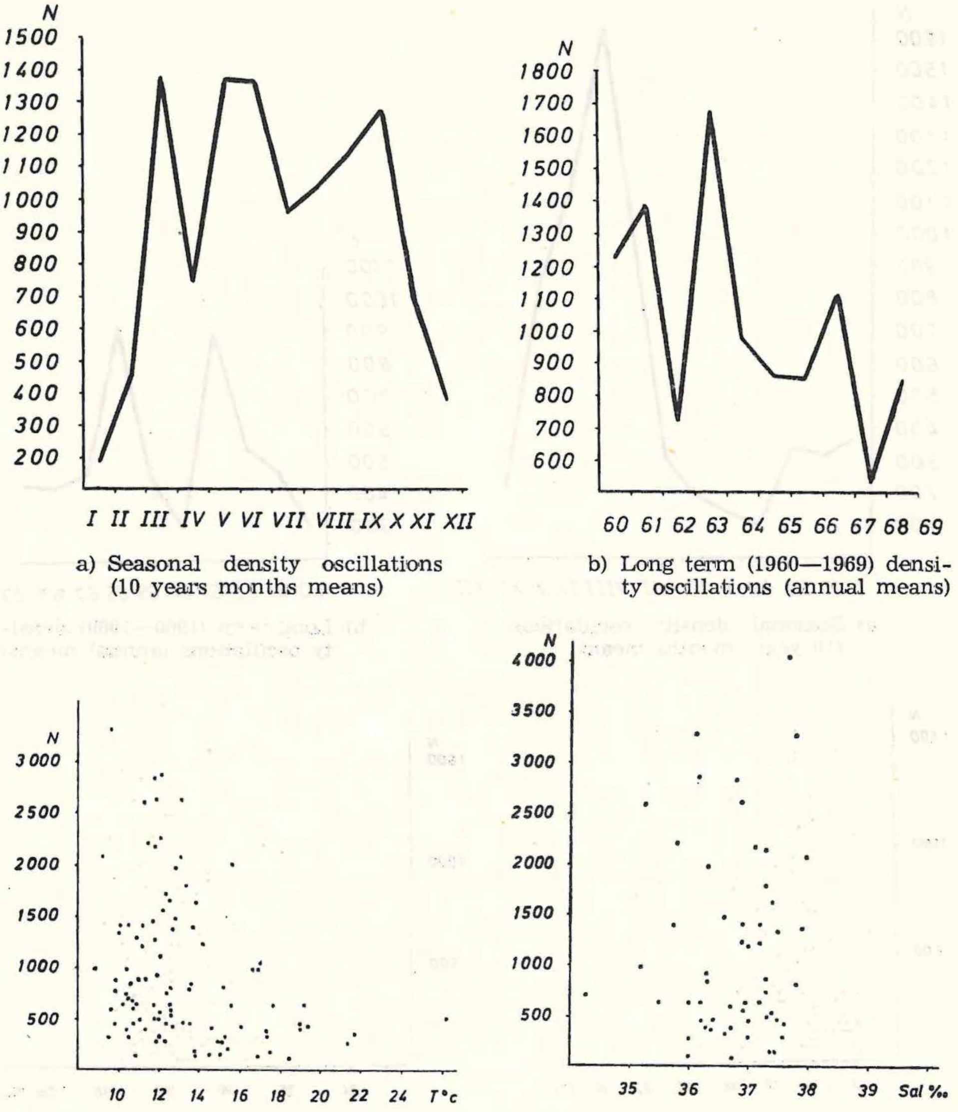
    As indicated by the average annual values of the number of individuals for the period of ten years, considerable increases were recorded in 1961, 1963, 1967 (Fig. 3b).
20. *Centropages kröyeri* (Giesbrecht), 1892. — Occurs in larger numbers throughout the year; particularly numerous from August to October (Fig. 4a).

    It accounts for, on an average, 12% i. e. 2.1% in April to 28.4% in September, in the total number of copepods. It comes third among six best represented species in the total number of copepods. It, together with *T. stylifera* contributes most to the autumn maximum. Maximum number of individuals was recorded at temperature range of 14—22°C (Fig. 4c) and at salinity range of 36.2—37.9‰ (Fig. 4d).

    Annual means for the ten year period show two marked maxima, in 1963 and 1966 (Fig. 4b).
21. *Centropages violaceus* (Claus), 1863. — Very rare species, only few individuals were found.
22. *Isias clavipes* (Böeck), 1864. — Occurs throughout the year, particularly in the winter—spring period. It is more numerous from February to May, and most numerous in March.

    As indicated by annual density means for the 1960—1969 period, the unusually large number of individuals was recorded in 1961, and an increase of lesser extent in 1967.

Fig. 3. *Cetropages typicus*



a) Seasonal density oscillations (10 years months means)

b) Long term (1960—1969) density oscillations (annual means)

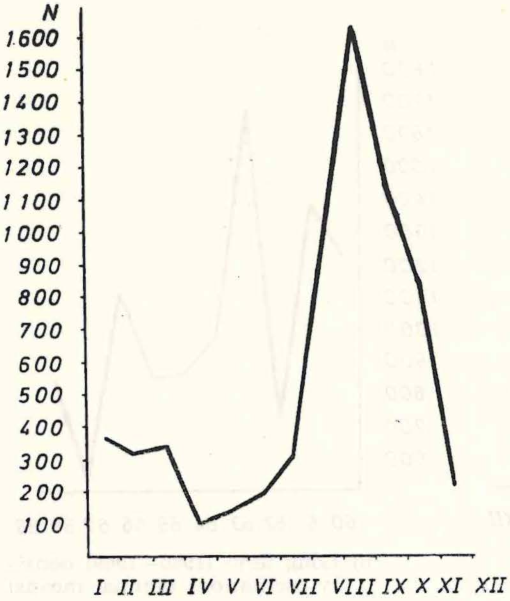
c) Relation between density and temperature at 10 m

d) Relation between density and salinity at 10 m

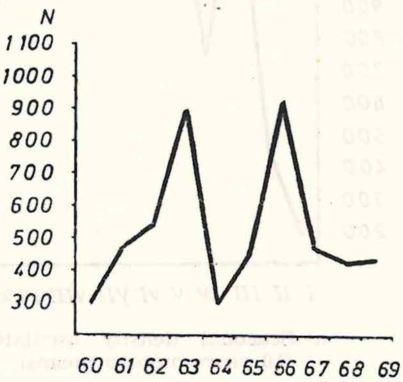
23. *Temora stylifera,* (Dana), 1848. — Occurs among the Kaštela Bay copepods throughout the year. It was not recorded from only 16 out of the 110 samples. On an average, it accounts for 8.4%, or from 0.9% in April to 19.8% in October in the total number of copepods.

It comes fourth among six best represented copepods. Together with *C. kröyeri* it is responsible for the autumn maximum in September and October (Fig. 5a).

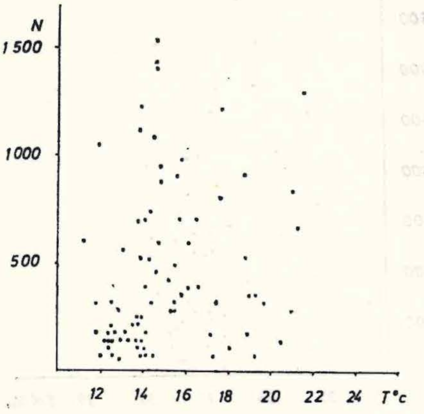
Fig. 4. *Centropages kröyeri*



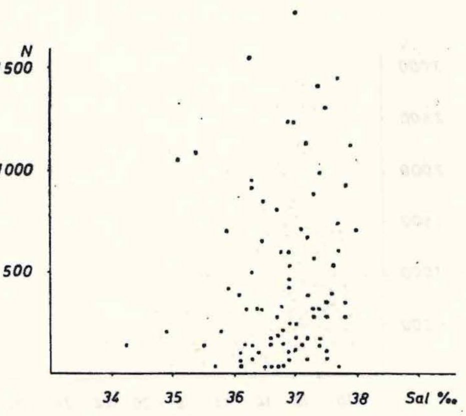
a) Seasonal density oscillations (10 years months means)



b) Long term (1960—1969) density oscillations (annual means)



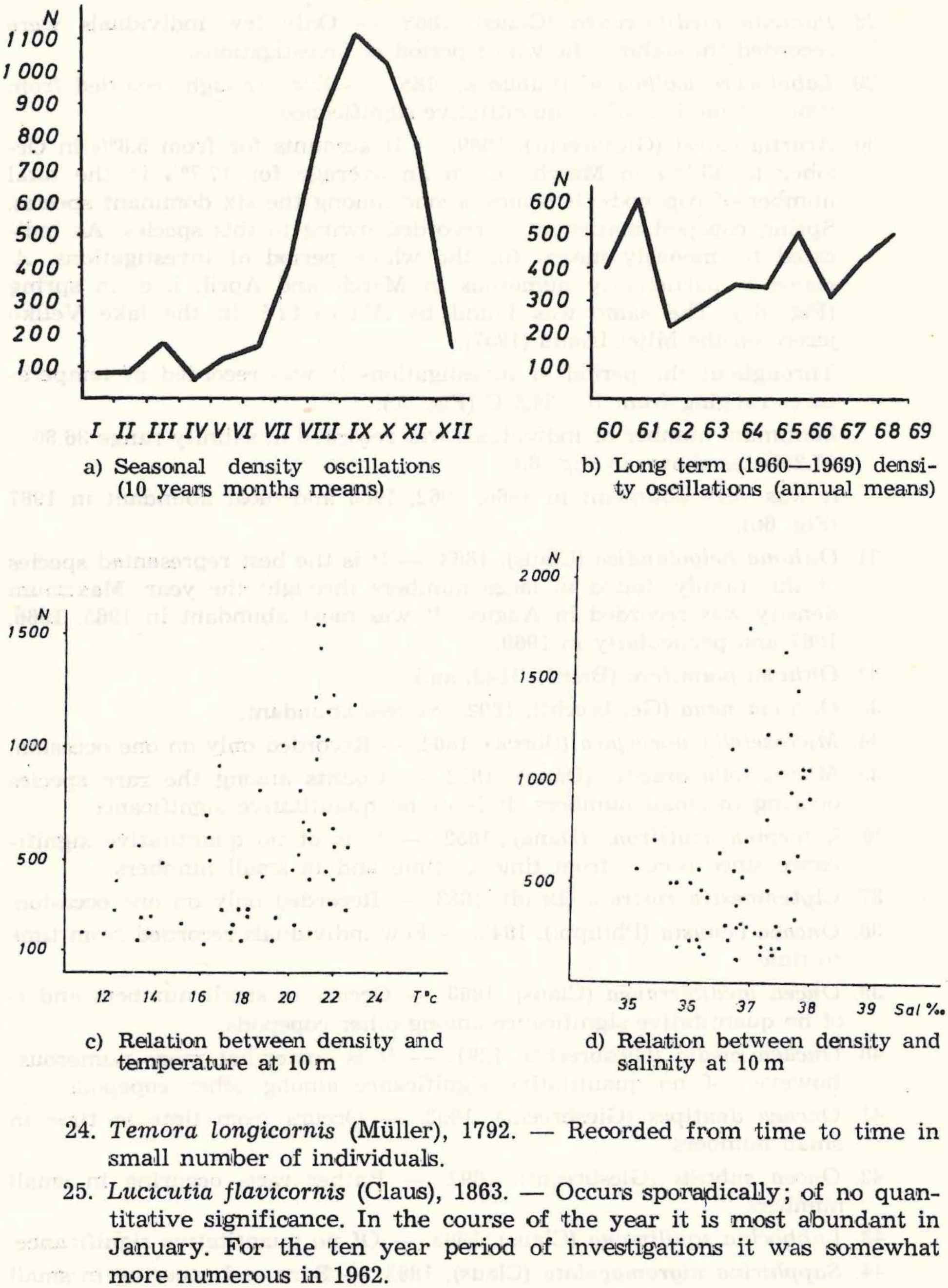
c) Relation between density and temperature at 10 m



d) Relation between density and salinity at 10 m

It was found within the temperature limits of 9.6—23.7°C (Fig. 5c). For the period of ten years *T. stylifera* was recorded at salinity range of 34.25—38.10‰ at 10 m depth. Maximum number of individuals was most frequently recorded between 37.0 and 38‰ (Fig. 5d). Annual means of the number of individuals do not show any considerable variations. It was more numerous in 1961, 1966, 1968 and 1969 (Fig. 5b).

Fig. 5. *Temora stylifera*



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24. *Temora longicornis* (Müller), 1792. — Recorded from time to time in small number of individuals.

25. *Lucicutia flavicornis* (Claus), 1863. — Occurs sporadically; of no quantitative significance. In the course of the year it is most abundant in January. For the ten year period of investigations it was somewhat more numerous in 1962.

26. *Candacia armata* (Böeck), 1872. — Larger numbers of individuals present from January to March; most numerous in April. It occurred in great abundances in 1960.

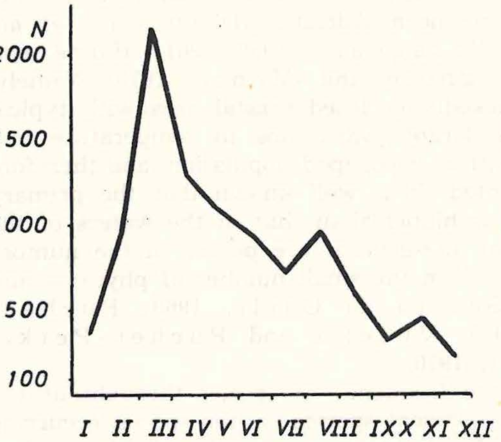
27. *Pontella lobiancoi* (Canu), 1888. — Occurs rarely, in small numbers.
28. *Pontella mediterranea* (Claus), 1863. — Only few individuals were recorded throughout the whole period of investigations.
29. *Labidocera wollastoni* (Lübbock), 1857. — Even though recorded from time to time it is of no quantitative significance.
30. *Acartia clausi* (Giesbrecht), 1889. — It accounts for from 5.8% in October to 33.1% in March, or on an average for 17.7% in the total number of copepods. It comes second among the six dominant species. Spring copepod maximum is recorded owing to this species. As indicated by monthly means for the whole period of investigations, *A. clausi* is particularly numerous in March and April, i. e. in spring (Fig. 6a). The same was found by Vučetić in the lake Veliko jezero on the Mljet Island (1957).

    Throughout the period of investigations it was recorded at temperatures ranging from 10—24,5°C (Fig. 6c).

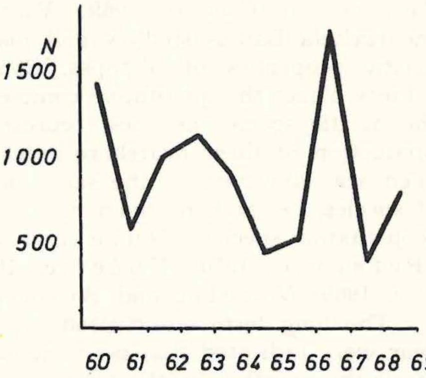
    Maximum number of individuals was recorded at salinity range 36.80—37.20‰, as shown in Fig. 6d.

    It was very abundant in 1960, 1962, 1963 and most abundant in 1967 (Fig. 6b).
31. *Oithona helgolandica* (Claus), 1863. — It is the best represented species of this family, found in large numbers throught the year. Maximum density was recorded in August. It was most abundant in 1965, 1966, 1967 and particularly in 1969.
32. *Oithona plumifera* (Baird), 1843, and
33. *Oithona nana* (Geisbrecht), 1892. are less abundant.
34. *Microsetella norvegica* (Böeck), 1864. — Recorded only on one occasion.
35. *Microsetella gracilis* (Dana), 1852. — Counts among the rare species ocuring in small numbers. It is of no quantitative significance.
36. *Euterpina acutifrons* (Dana), 1852. — It is of no quantitative significance since occurs from time to time and in small numbers.
37. *Clytemnestra rostrata* (Brad), 1883. — Recorded only on one occasion.
38. *Oncaea venusta* (Philippi), 1843. — Few individuals recorded from time to time.
39. *Oncea mediterranea* (Claus), 1863. — Occurs in small numbers and is of no quantitative significance among other copepods.
40. *Oncaea media* (Giesbrecht), 1891. — It is somewhat more numerous; however of no quantitative significance among other copepods.
41. *Oncaea dentipes* (Giesbrecht), 1892. — Occurs from time to time in small numbers.
42. *Oncea subtilis* (Giesbrecht), 1892. — Rather rare, occuring in small numbers
43. *Lubbockia squilimana* (Claus), 1863. — Of no quantitative significance.
44. *Sapphirina nigromaculata* (Claus), 1863. — Rare and occuring in small numbers.
45. *Sapphirina* sp. Few individuals of *Sapphirina* genus found from time to time in 1964, 1965, 1966 and 1967.

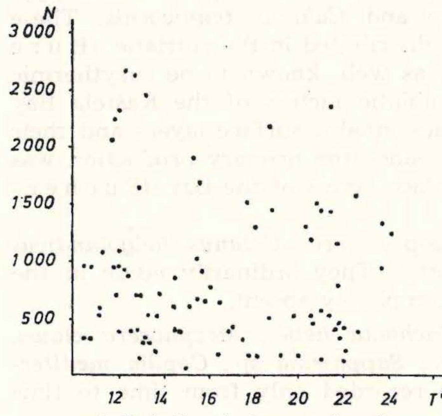
Fig. 6. *Acartia clausi*



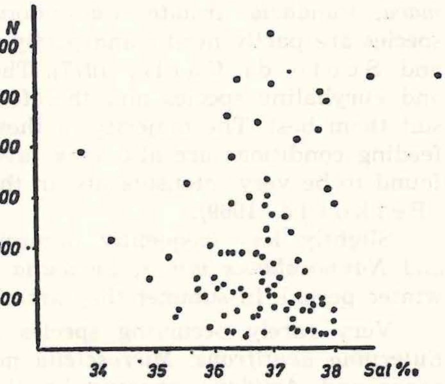
a) Seasonal density oscillations (10 years months means)



b) Long term (1960—1969) density oscillations (annual means)



c) Relation between density and temperature at 10 m



d) Relation between density and salinity at 10 m

46.—53. *Corycaeide*. Out of the eight species of this genus, *Corycaeus typicus* (Kröyer), 1849, is quantitatively best represented particularly during the warmer part of the year, as well as *Corycaeus brehmi* Steuer, 1910.

54. *Caligus rapax* (M. Edwards) is the skin parasite of a large number of fishes. It was recorded from the Kaštela Bay exclusively in winter.

3. DISCUSSION OF RESULTS

a. Seasonal changes in the copepod composition

The results of the ten year investigations of the Kaštela Bay copepods, brought out in the preceeding part, show that, as far as qualitative composition of copepod community is concerned, this area is similar to the other neritic areas in the Adriatic, such as: the Bay of Boka Kotorska (Gamulin, 1938; Vukanić, 1971), shallow northern Adriatic (D'Ancona *et al.*, 1959; Battaglia, Mozzi and Varagnolo, 1958, 1961; Hure and Scotto di Carlo, 1969; Varagnolo and Monte, 1970). Namely, the Kaštela Bay is shallow and markedly enclosed coastal area with typical neritic properties of biotopes. Considerable variations in temperature and salinity affect the qualitative composition of copepod population, and therefore the neritic species are best represented. It is well known that the primary production of these nearshore areas is higher than that in the waters of the open sea. However, at the same time these areas are poorer in the number of species, i.e. high production is based on the small number of phyto — and zooplankton species (Hure and Scotto di Carlo, 1969; Pucher-Petković, 1970; Vučetić, 1965; Vučetić and Pucher-Petković, 1969; Vučetić and Regner, 1970).

The long term observations of the frequency of species throughtout the year were indicated that permanently present species i.e. the species occurring in all the months are the following: *Centropages typicus, Acartia clausi, Centropages kröyeri, Temora stylifera, Clausocalanus arcuicornis, Paracalanus parvus, Clausocalanus furcatus, Ctenocalanus vanus, Isias clavipes, Diaixis pygmaea, Candacia armata, Calocalanus pavo* and *Calanus tenuicornis.* These species are partly neritic and partly widely distributed in the Adriatic (Hure and Scoto di Carlo, 1977). They are, as well, known to be eurythermic and euryhaline species and therefore the abiotic factors of the Kaštela Bay suit them best. The majority of these species inhabit surface layers and their feeding conditions are also very favourable since the primary production was found to be very intensive just in these surface layers of the Bay (Pucher-Petković, 1969).

Slightly less frequently occurring copepods are: *Calanus helgolandicus* and *Nannocalanus minor, Lucicutia flavicornis.* They ordinarily occur in the winter period. In summer they are almost completely absent.

Very rarely occurring species are: *Euchaeta hebes, Mecynocera clausi, Euterpina acutifrons, Microsetella norvegica, Sapphirina sp., Copilia mediterranea* and *Aetideus armatus,* i.e. they are recorded only from time to time as individual specimens.

The summer conditions of the Kaštela Bay, characterized by the intensive heating of water almost to the bottom are probably not favourable for the development of the population of *Calanus helgolandicus* known as a rare species. As established for the lake Veliko jezero on the Mljet Island, *Calanus helgolandicus* keeps in summer below the thermocline, in the bottom layer with the temperature of 15—18°C. It does not, however, cross the thermocline by night, either (Vučetić, 1966). Vučetić suggests that this is the reason why the stagnation in reproduction occurs. Namely, the spawned eggs sink too quickly down to the bottom where perish.

Gamulin (1939) states that the occurrence of species *Calanus helgolandicus, Nannocalanus minor* and *Lucicutia flavicornis* in the Kaštela Bay in winter may be due to the winter winds and inflow of water in deeper layers. All three species are well represented in the deeper layers of the channel area waters and they probably occur there owing to the depth properties of the water layers they inhabit. There is an agreement between these data and the most recent ones of Zore-Armanda *et al.* (1974) according to which there is an increased inflow of the open sea water into the Kaštela Bay in winter. Similarly, the periodical occurrence of species *Euchaeta hebes* and *Copilia mediterranea* may be in connexion with the periodically intensified inflow of more saline water from the open Adriatic into the deeper layers of the Kaštela Bay.

Total number of copepod species shows the following seasonal variations during the year:

Table 1 — Seasonal mean values of the number of copepod species

Seasons:	spring (III, IV, V)	summer (VI, VII, VIII)	autumn (IX, X, XI)	winter (XII, I, II)
mean value of the number of species	18	14	16	17

With respect to seasons larger number of copepod species is recorded in the winter-spring period, and smaller number during the warmer part of the year. This account is also in close agreement with the system of currents in the Kaštela Bay, which carries the water masses of the open sea into the bay during the winterspring period, whereas the outgoing flow is intensified in summer (Zore-Armanda *et al.*, 1974).

b. Quantitative seasonal changes

Observations of the total number of copepods show two density maxima in the course of the year: spring and summer ones. Of those, the higher maximum is recorded in March and lower ones in August and September. Variations in the copepod numbers in the course of the year are given in the following table on the basis of the ten year means for individual months:

Table 2. — Seasonal density oscillations (10 year months means)

Months:	Number of individuals per catch
January	2564
February	3959
March	6583
April	4924
May	4732
June	4612
July	4168
August	5666
September	5695
October	5154
November	4373
December	1956

As shown by the Table 2, the number of copepods decreases from August to December when winter minimum is recorded. Afterwards, the density increases until March. Gamulin (1939), after a year of observations, finds winter copepod minimum to occur in the same month and in the same area. Gamulin's data on the maximum number of copepods agree with those reported in this paper as to the seasons. However, as far as months are concerned these two accounts differ in some respect, what may be understood since the mean data from the period of ten years are used in this paper. Namely, the data from individual years somewhat differ from the average ones. Thus in the spring seasons of 1963 and 1964 density maxima did not occur in March but in April. The other data agree mainly with the mean values given, with some slight differences.

This seasonal trend of the copepod density occurs also as a consequence of the changes of ecological (abiotic and biotic) factors of environment. Hydrographic properties of the Kaštela Bay, e.g. the abiotic factors, are one of the causes of seasonal increases and decreases in the density of the number of copepods during the year. Thus, Vučetić (1965) finds the increased standing crop of the total Kaštela Bay zooplankton as well as the increased density of the population of *Calanus helgolandicus* species in 1961. In this year, however, the lowest quantities of precipitations were recorded for this area.

Temperature data from the Kaštela Bay show, further, that maximum surface values are recorded in August, and minimum ones in February (Buljan, 1968), and that these variations in temperature during the year vary within the interval of 15°C, only extremely of 18°C. Since the maximum numbers of copepods were recorded both in March and August, temperature, if used isolated from other factors, seems not to be of any considerable significance for the variations in the total number of all copepod species. However, temperature exerts double effect on species taken individually. On the one side, it directly affects the biology and physiology of species, and on the other, indirectly, the quality and quantity of the food available in the sea (i.e. phytoplankton). As far as the direct influence of temperature is concerned, the species *Calanus helgolandicus* has already been mentioned. It has been stated that during homothermy in autumn and winter this species is found in the lakes of the Mljet Island in all the layers (Vučetić, 1966). However, by heating of the surface water the night shifting towards the surface, observed earlier, is reduced and individuals concentrate below the thermocline. Thermocline would, therefore, be a factor of importance for the vertical distribution of species and copepod migrations. The diurnal migration of *Ctenocalanus vanus* in summer, when the anothermic stratification of layers occurs, is established to be also controlled by thermocline (Hure, 1961). The species *Paracalanus parvus* and *Centropages kröyeri* are found to keep in the surface layers not crossing the thermocline (Vučetić, 1961).

Since the vertical migration of copepods is not only controlled by temperature but by the light as well, the investigations of the species *Calanus helgolandicus* (Vučetić, 1957) show that in summer, during the most intensive light, the individuals concentrate in the deepest layers at noon. Later on, when the light is reduced, they return to the surface layers if not hindered by the occurrence of thermocline.

Further, changes of the salinity variations are rather considerable in the course of the year (above 10‰). They are due to a number of factors: drainage of the land waters, precipitations and submarine springs. These changes may also be said to influence both: the species individually, and the total number of all the copepods. It was found, for example, that markedly minimum salinity values on the surface coincided with the minimum number of all the specimens.

On the other side, the quality and quantity of available food may be one of the biotic factors of external environment crucial for the fluctuations of density. The above mentioned most frequently occuring copepod species in the Kaštela Bay material are mainly herbivorous. This assumption has been supported by the most recent results of investigations of feeding of the quantitatively dominant copepod species of the Kaštela Bay (Homen, B. and D. Regner, 1977; Marasović and D. Regner, 1979).

Of the less numerous species the following may be listed as herbivore: *Calanus helgolandicus* (Gaudy, 1962; Vučetić, 1966), *Calanus minor* (Gaudy, 1962) and others. Many of the omnivore species, as well as those which facultatively mix the food, i.e. in the case of shortage of one kind of food they take another, should be added to these species.

Further, according to the data of Gaudy (1962) for the Bay of Marseilles the curves of the variations in density of the species *Acartia clausi, Centropages typicus* and *Temora stylifera* throughout the year are very similar to the variations in phytoplankton density, and even more the occurrence of individual generations coincides with the maximum phytoplankton density.

Quantitative studies of the Adriatic phytoplankton carried out up to now (Ercegović, 1936) indicate that the nearshore water phytoplankton of the central Adriatic goes through four stages during the year: I) stage of winter bloom; II) stage of winter-summer decrease; III) stages of spring bloom; and IV) stage of summer-autumn stagnation. The data of Pucher-Petković, (1966, 1975), however, show that the more productive period of the year could not, for the Kaštela Bay, be limited to a shorter time interval. In the majority of cases it covers spring and summer »in the period from March to July or even August« what is in close agreement with the spring-summer maximum number of copepods. In the winter period, however, lower values of primary production are obtained (if not taken per time unit due to the shorter photosynthetic day) as well as the great abudance of phytoplankton.

However, it has already been established for zooplankton (from the data on dry weight — Vučetić, 1965d) that winter is the period with the lowest values, which is also confirmed with the present data referring to copepods density. The occurrence of the larger number of phytoplankton organisms in winter may appear controversal. However, this may be understood as the result of the low consumption of phytoplankton by zooplankton which is known to be present in minimum abundances at that time.

After Pucher-Petković (1968) the majority of primary organic matter is produced in the upper 10 metres of the sea water in the Kaštela Bay. This is due to the fresh water inflows from the land which bring nutrients. Thus, this accounts for the fact that copepods found in this material mainly belong to the surface species. As to the other species their diurnal-night migrations are well known. Thus Vučetić, 1966 states that »owing to the fact that during the period of increased light there is no phytoplankton available in the deeper layers inhabited by zooplankton during the day, they move for food to the surface by night.«

It may also be of significance to mention that herbivore copepods *Acartia clausi* and *Centropages typicus* are mainly responsible for the spring maximum of copepod density, whereas *Centropages kröyeri, Temora stylifera* and *Centropages typicus* are responsible for the summer one.

Percentage presence of the most frequent, and at the same time as far as the number of individuals is concerned, quantitatively dominant species *Centropages typicus, Temora stylifera, Acartia clausi, Centropages kröyeri, Clausocalanus arcuicornis* and *Paracalanus parvus* is given in Fig. 7. As seen, their interrelation change by months (circle diameters show the total numbers of individuals of all the species).

The relationship between dominant species and the total density of all the individuals is given in Fig. 8. It may be seen that their values determine the shape of the curve of the copepod density.

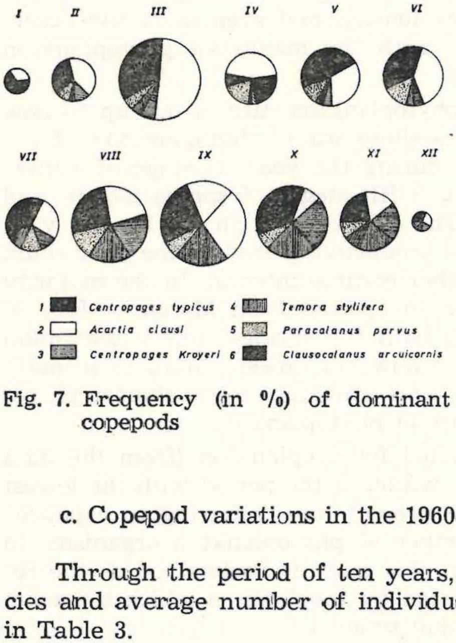


Fig. 7. Frequency (in %) of dominant copepods

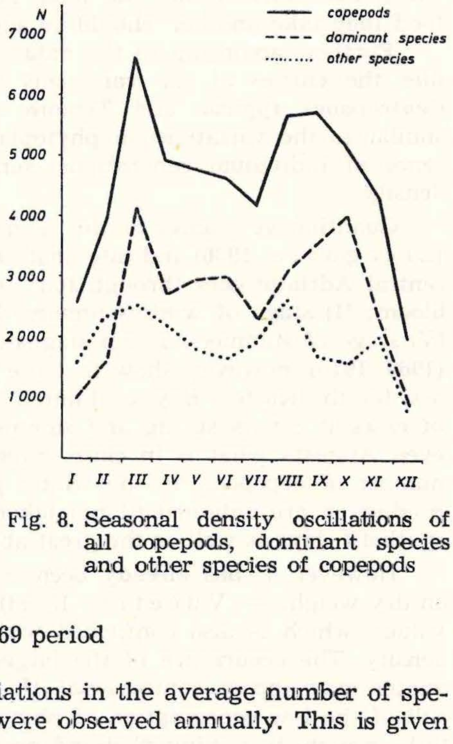


Fig. 8. Seasonal density oscillations of all copepods, dominant species and other species of copepods

c. Copepod variations in the 1960—1969 period

Through the period of ten years, variations in the average number of species and average number of individuals were observed annually. This is given in Table 3.

As indicated by the results brought out, considerable variations in the annual mean values of copepods (from 3000 to 6000 individuals per haul) were found in the ten year period. Marked increases of the total number of copepods occurred in 1960, 1963/64 and 1967.

Similar variations in the Kaštela Bay zooplankton were also shown in some earlier papers. In the 1954—1964. period V u č e t i ć (1965) establishes the variations in the dry weight of zooplankton, as well as the fluctuations of the number of copepod *Calanus helgolandicus,* number of the sardine and anchovy eggs and fish larvae. The data from the mentioned paper agree with the data on the variations in the total number of copepods from the present paper. Differences between individual years were established both for zooplankton an for copepods. Thus, the increase in the number of copepods we found may be added to the earlier found increase of total zooplankton (dry weight) in 1960 an 1964.

Table 3 — Everage number of copepods by years

Year	Number of species	Aver. nr. of individuals/catch
1960.	19	6035
1961.	16	4763
1962.	16	4165
1963.	18	5907
1964.	19	5127
1965.	20	3606
1966.	18	3905
1967.	17	5337
1968.	16	3007
1969.	16	3896

In 1959 and 1960 the decrease in the numerical values of phytoplankton recorded coincided with the general increase of zooplankton. Pucher-Petković (1968) suggests that this reduction is due to the large quantities of precipitations in that year wich reduced the sea transparency. However, marked increase in the density of zooplankton in that period, recorded for copepods as well, may not be related to the primary production since there is no data available for that year. Reduced number of phytoplankton may be the consequence of the intensified consumption of phytoplankton by zooplankton organisms. The paper of Zore-Armanda (1969) shows that in 1960 the differences between the winter and summer sea temperatures were lower than in other years (16.4°C in 1960 compared to 17.6° in 1961; 18.0°C in 1962; 20.3°C in 1963 etc.). These conditions are likley to be favourable to the reproduction of copepods. Therefore an increase in the density of copepods estabilished in this paper, was recorded in 1960.

Later studies of variations in phyto- and zooplankton in the same area (Vučetić and Pucher-Petković, 1969) also confirm the marked increase of values in 1965 and 1966. Authors related these results to the hydrographic data (Buljan, 1969) which indicate the change of hydrographic properties of the Adriatic water. Namely, Buljan, (1969) estabilishes the intensified dynamics of water masses in the central Adriatic in 1963, 1964 and 1965. This dynamics caused the changes in the hydrographic properties of the Adriatic water, which were manifested as the enrichment by organic processes, smaller ranges of annual temperatures and an increase in the maximum salinity values, Increased inflow of Intermediate Mediterranean Water (ingressions) to which the authors attribute the changes described, was more intensive in those years. This exerted a positive effect on organic production in the central. Adriatic (Pucher-Petković, and Vučetić, 1969). Marked increase in the density of the Kaštela Bay copepods in 1963/64, which is in agreement with the earlier results of the studies of hydrography, phyto- and zooplankton indicates that these different production parameters are closely dependent on one another.

The interrelations of phytoplankton and zooplankton are established from the data from 1967 when the quantities of both groups obviously increased. Namely, in 1967 and particularly in 1968 Pucher-Petković (1970) finds the primary production and phytoplankton density to be increased in the Kaštela Bay. The author accounts this for by the markedly favourable local abiotic factors. As mentioned above, the numerousity of copepods was considerably increased in that year, as well.

According to all that has been said, both seasonal and multiannual fluctuations of copepod densities may be best brought into connexion with the seasonal and multiannual variations in phytoplankton of the area studies. There is no intention on our side to state that the changes of biotic factors are more significant for the fluctuations of copepods than are the abiotic factors, since it may be said with certainty that the state of both phyto- and zooplankton groups is the result of the complex activity (influences) of both biotic and abiotic environmetal factors. At the same time, this seems to be main reason why it was easier to notice and observe the realitions between phytoplankton and copepods which are their direct predators, than to observe their relations with the total zooplankton where the whole series of different predator-prey relations count.

4. CONCLUSIONS

1. Analyses of the frequency of copepods in the Kaštela Bay in 1960—1969 period show that, aut of 54 determined species 13 species are present throughout the year. These are: *Centropages typicus, Acartia clausi, Centropages kröyeri, Clausocalanus arcuicornis, Temora stylifera, Clausocalanus furcatus, Ctenocalanus vanus, Isias clavipes, Paracalanus parvus, Diaixis pygmea, Candacia armata, Calocalanus pavo* and *Calanus tenuicornis*. More rarely occurring species are: *Calanus helgolandicus, Nannocalanus minor* and *Lucicutia flavicornis*. They occur only in the winter period. The occurrence of the rest of species, found periodically, is accounted for by the dynamics of water masses i.e. by the inflow of the channel area water during a determined period of the year.
2. During the year the number of species varies from 14 in December to 20 in March. For the period of ten years these variations range from 16 to 20. Maximum number of species was recorded in 1965.
3. Annual trend of the total number of specimens of all the species shows two maxima: spring one in March and summer one in August and September. Minimum density is found in winter — in December.
4. As to the density of individuals the best represented species are: *Centropages typicus, Acartia clausi, Centropages kröyeri, Temora stylifera, Paracalanus parvus* and *Clausocalanus arcuicornis.*
5. Seasonal fluctuations of the number of copepods in individual years coincide with the variations in phytoplankton what confirm that the most numerous species are mainly herbivorous.

6. The multiannual variations in the copepod density were observed in the period of investigations. The increase of density was recorded in 1960, 1963, 1964, and 1967. The increase found in 1963, 1964 and 1967 probably occurred owing to the increase in phytoplankton density and primary production in that area in those years.

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SEZONSKE I VIŠEGODIŠNJE FLUKTUACIJE KOPEPODA U KAŠTELANSKOM ZALJEVU (1960—1969)

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KRATKI SADRŽAJ

U ovom radu doneseni su rezultati istraživanja planktonskih kopepoda iz zooplanktonskog materijala sakupljenog u toku kompleksnih istraživanja Kaštelanskog zaljeva započetih 1954. godine (Vučetić, 1967, 1969 a, b; 1970).

Obrađeni uzorci obuhvaćaju period od 1960. do 1969. godine, a uzimani su u jednomjesečnim intervalima. Sakupljanje je izvršeno vertikalnim potezima (35—0 m), Hensenovom mrežom (73/100, N°3), po dnevnom svjetlu.

Rezultati istraživanja pokazali su da su po brojnosti kopepodi dominantna skupina u zooplanktonu. Od vrsta, čije se fluktuacije brojnosti i frekvencu pojavljivanja pratilo kroz desetogodišnji period, trajno su bile prisutne slijedeće: *Centropages typicus, Acartia clausi, Centropages kröyeri, Ctenocalanus vanus Isias clavipes, Paracalanus parvus, Diaixis pygmaea, Candacia armata, Calocalanus pavo* i *Calanus tenuicornis.* Rjeđe su nađeni kopepodi: *Calanus helgolandicus, Nannocalanus minor* i *Lucicutia flavicornis.*

Pojava ostalih rijetkih vrsta, koje su samo povremeno nađene, protumačena je nadolaskom vode iz kanalnog područja.

U toku godine nađeno je od 14 (u prosincu), do 20 (u ožujku) vrsta kopepoda. Kroz desetogodišnje razdoblje broj vrsta kopepoda kretao se između 16 i 20, a najveći broj vrsta bio je nađen u 1965. godini.

Kao brojno najzastupljenije vrste, čije oscilacije brojnosti diktiraju gustoću cijele skupine kopepoda, javljaju se: *Centropages typicus, Acartia clausi, Centropages kröyeri, Temora stylifera, Paracalanus parvus* i *Clausocalanus arcuicornis* .Zbog značaja koji ove vrste imaju među ostalim kopepodima, kretanje njihove brojnosti pokušalo se ispitati u odnosu na promjene osnovnog hidrološkog faktora — temperature. Utvrđeno je pri tom da se sa maksimumom broja primjeraka javljaju u ljetnje-jesenskom periodu *Centropages typicus, Centropages kröyeri* i *Temora stylifera,* dok su u zimsko-proljetnom periodu najbronije vrste *Acartia clausi* i *Centropages typicus.*

Godišnji tok ukupne brojnosti svih vrsta pokazao je dva maksimuma: proljetnji u ožujku i ljetnje-jesenski u kolovozu i rujnu. Minimum je nađen zimi, u prosincu.

Ispitivanje višegodnišnjih fluktuacija ukupne gustoće kopepoda pokazalo je poraste u 1960, 1963, 1964, te 1967. godini. Ove poraste kvantiteta kopepoda pokušalo se dovesti u vezu sa istovremenim porastom primarne produkcije i obiljem fitoplanktona na ispitivanom području u 1963, 1964. i 1967. godini. Za 1960. godinu nije se moglo ustanoviti direktnu sličnost kretanja toka fitoplanktona i zooplanktona. Moglo bi se pretpostaviti da su manje razlike između zimske i ljetne temperature mora u ovoj godini pogodovale razmnožavanju kopepoda pa se to možda odrazilo na povišenje gustoće ove skupine.