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# Long-term fluctuations of zooplankton in the middle Adriatic Sea (1960-1982)

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*Long-term (1960-1982) zooplankton fluctuations in the open middle Adriatic were studied on samples from the station Stončica. The groups: Copepoda, Appendicularia, Cladocera, Medusae/Siphonophora, Chaetognatha, Thaliacea, Mollusca, Decapoda and Polychaeta were analyzed for their numbers and relative abundance.*

*Percentages of each individual group in the total zooplankton were calculated and seasonal and long-term fluctuations observed.*

*Seasonal and long-term fluctuations of some groups were found to be dependent on the variations of temperature, salinity and phytoplankton quantity in the same month whereas some groups showed a time lag of about a month behind the environmental changes.*

## INTRODUCTION

The beginning of the research of the zooplankton quantities in the middle Adriatic may be traced back to the end of the thirties of this century. These early papers and some later ones reported on the shorter (a single year) studies of the quantities of individual zooplankton groups and their distribution in time and space (GAMULIN, 1939, 1948; HURE, 1955, 1961).

Systematic collections of zooplankton of the Kaštela Bay started as early as in 1954, and ever since the beginning of sixties, apart from the data on phyto and zooplankton, the data on all the other oceanographic parameters have been systematically collected from the transect Split-Gargano. Parallel observations of long-term data proved to be very important, not only from the viewpoint of accounting for the causes of some changes in the study area but also some forecasting attempts of the future state and development were made possible.

The long-term zooplankton data collected from the middle Adriatic so far have supplied information on the species composition and quantities of zooplankton and also the long-term fluctuations of these parameters (VUČETIĆ, 1965, 1969c, 1970, 1971b, 1977, 1980, 1984; VUČETIĆ and KAČIĆ, 1973; REGNER, 1973, 1975, 1976, 1977, 1982, 1985).

This paper reports on the quantitatively dominant zooplankton groups at Stončica station on the Split-Gargano transect. Particular attention was given to seasonal variations and to the changes in the quantities of individual groups over a longer time interval (23 years). It was attempted to realate the causes of these changes to some abiotic (temperature and salinity) and biotic (phytoplankton) factors in the same area.

## STUDY AREA

The station Stončica is located 4Nm southeast from the cape Stončica on the Vis Island,

43° 00' and 16°20"E (Fig. 1). The station is 107 m deep, with a sandy-detritic bottom mixed with mud. The station is strongly affected by the open sea, so that the temperature and salinity variations are smaller than at stations closer to the coast. In the 1952-1970 period the lowest surface temperature of 12.18°C was recorded in February and the highest, 25.42°C in September. In the same period the lowest salinity ($Sx10^{-3}$ = 36.13) was found at 60 m in August and the highest ($Sx10^{-3}$ = 39.02) at 100 m in April (BULJAN and ZORE-ARMANDA, 1966, 1979).

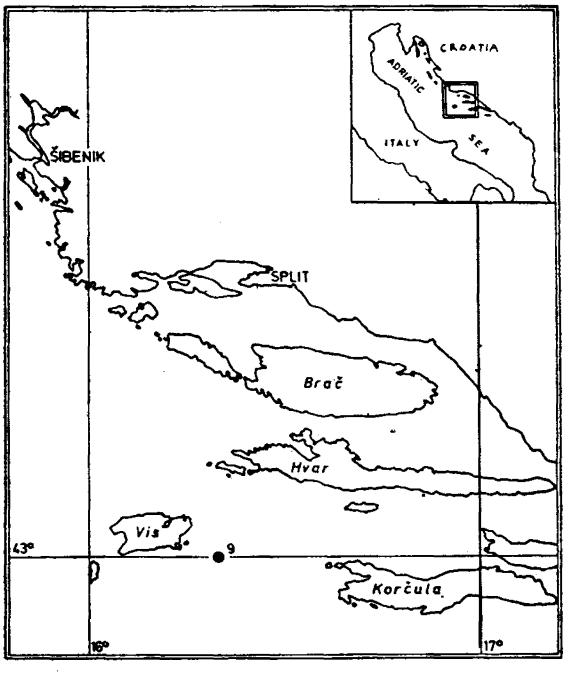


Fig.1. Study area - Stončica (station No 9)

The fluctuations of sea water density showed homogeneous water column in the colder part of the year, from December to April, and stratification in the warmer part, from May to November (BULJAN and ZORE-ARMANDA, op. cit.).

Sea water transparency is very high at this station, with an annual average of 25.8 m (1960-1982). The poorest transparency was recorded in March, increasing by September when it reaches its maximum value (BULJAN and ZORE-ARMANDA, op. cit.).

Currents are prevalently of NW direction in winter, N in spring, SE in summer and SW in autumn (BULJAN and ZORE-ARMANDA, op. cit.).

The studies carried out up to now showed the phytoplankton density at Stončica to be considerably lower than in the coastal area (PUCHER-PETKOVIĆ, 1963, 1964, 1968, 1971, 1979; PUCHER-PETKOVIĆ and MARASOVIĆ, 1982). The data for the 1961-1981 period show that the phytoplankton quantities are slightly higher in May and August (Fig. 2) and that the highest densities are recorded in autumn-winter (October - January).

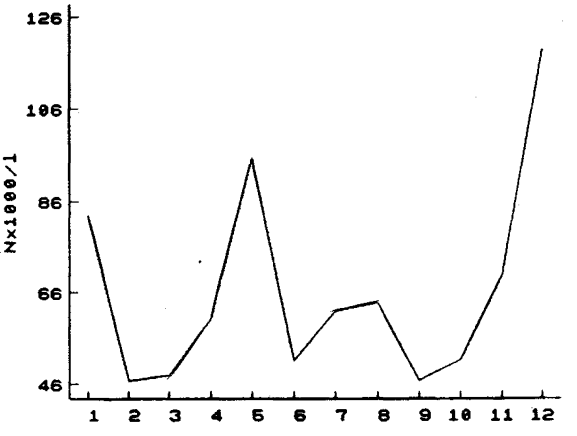


Fig.2. Phytoplankton-seasonal density fluctuations at Stončica (monthly means, 1961-1981)

Long-term studies (1961-1981) showed a trend of phytoplankton population density increase in this area (Fig. 3).

Preliminary measurements of primary production by the $^{14}C$ method were begun at Split-

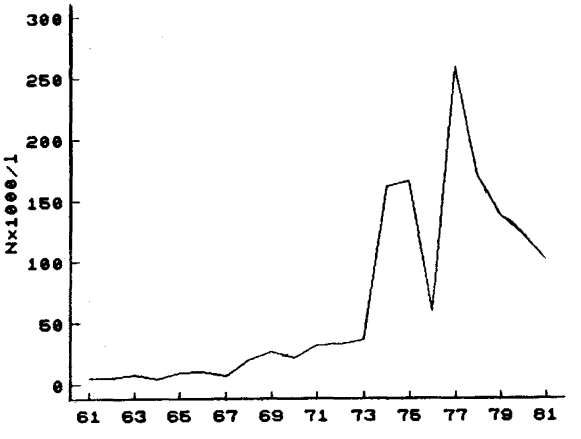


Fig.3. Phytoplankton -long-term density fluctuations at Stončica (annual means)

Gargano transect in 1962 (CVIIĆ, 1963) and systematic research has been carried out ever since the 1966 (PUCHER-PETKOVIĆ, 1969, 1971, 1974, 1979). Results show that the open water of the middle Adriatic are less productive than the coastal area. Annual mean primary production at Stončica was assessed at 57.4 $gCm^{-2}$ in the 1962-1979 period and at 96.3 $gCm^{-2}$ for the 1980-1983 period (PUCHER-PETKOVIĆ, 1974; PUCHER-PETKOVIĆ and MARASOVIĆ, 1982; PUCHER-PETKOVIĆ *et al.*, 1988) (Fig. 4).

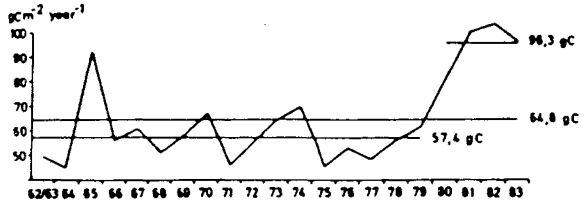


Fig.4. Long-term primary production fluctuations at Stončica (PUCHER-PETKOVIĆ *et al.*, 1988)

Zooplankton studies have shown that the total zooplankton density and biomass are also lower in the open middle Adriatic than in the coastal area (VUČETIĆ, 1961a, 1961b, 1963b, 1965, 1969a, 1970, 1971b, 1979, 1980, 1988). As shown by the monthly mean values for the 1960-1982 period, the zooplankton numbers are highest at Stončica in spring-summer, from March to September, when they considerably exceed 10.000 organisms per net haul (Fig. 5).

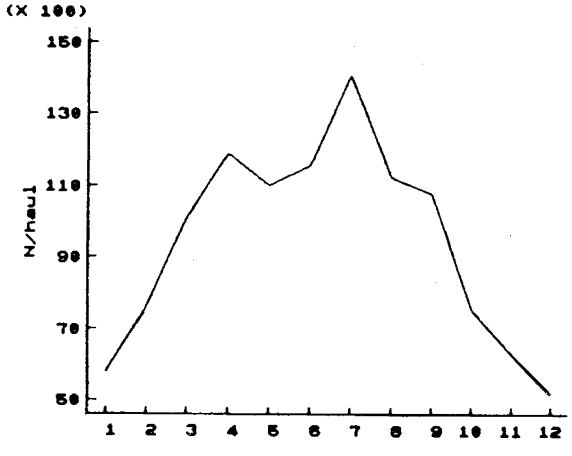


Fig.5. Zooplankton-seasonal density fluctuations at Stončica (monthly means, 1960-1982)

The observation of long-term variations of total zooplankton density in the 1960-1980 show a marked drop in the 1971, and significant increase in 1975, 1979 and 1980 (Fig. 6). In general, an increase tendency of the total zooplankton may be reported for the entire study period.

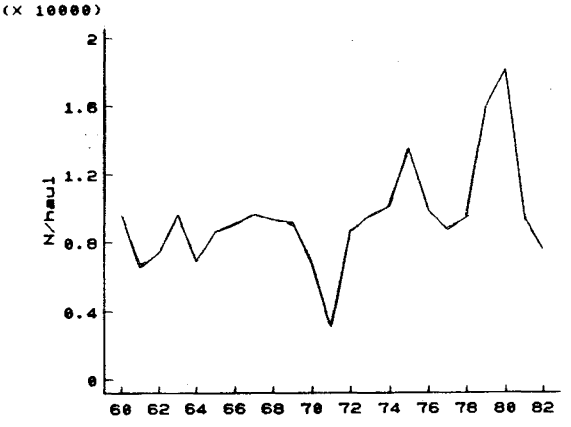


Fig.6. Zooplankton - long-term density fluctuations at Stončica (annual means)

Dry zooplankton weight measurements (VUČETIĆ, 1971a) show highest zooplankton biomass at this station in March and April (on the average 146 mg dry weight per net haul). In summer and autumn this value gradually decreases to be lowest in winter, 97 mg, (Fig. 7).

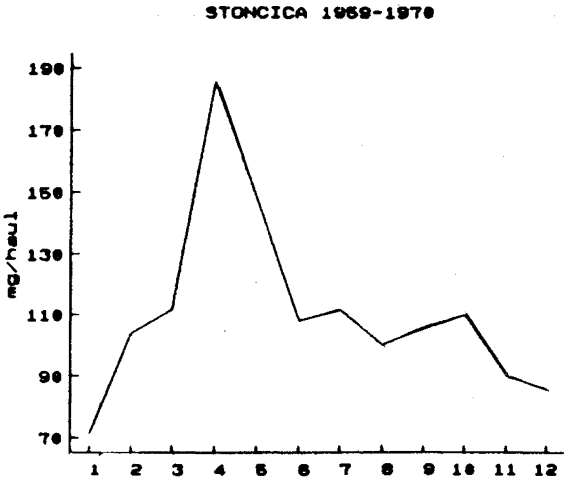


Fig.7. Seasonal zooplankton biomass fluctuations at Stončica (VUČETIĆ, 1971a)

The period 1959-1970 showed an increase in the 1960. 1962, 1966 and 1968 (VUČETIĆ, 1971a, 1988, VUČETIĆ and PUCHER-PETKOVIĆ, 1969) (Fig. 8).

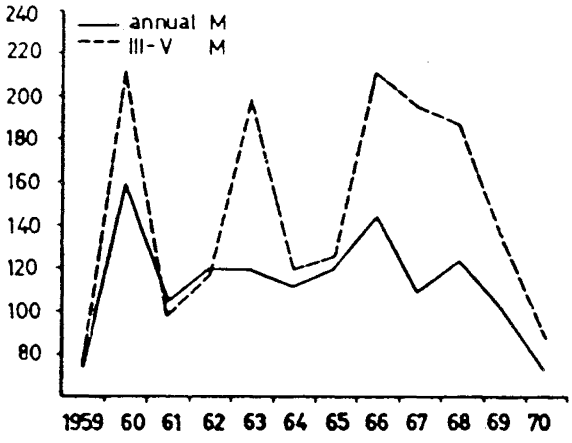


Fig.8. Long-term zooplankton biomass fluctuations at Stončica (dry weight mg haul$^{-1}$; VUČETIĆ, 1971a)

## MATERIAL AND METHODS

Zooplankton samples from station Stončica originated from the material collected during long-term research on the transect Split-Gargano. We took only the samples collected between 1960 and 1980 (VUČETIĆ, 1969a, 1971a, 1977 and 1980).

Samples were collected by vertical hauls from 100 m to the surface using Hensen net (mouth aperture 73 cm, mesh surface area 0.419 m$^2$, silk N$^0$ 3). Collections were performed during daylight at month intervals from r/v BIOS and PREDVODNIK. Samples were preserved in 4% formaldehyde.

The following groups were numerically analyzed: Copepoda, Appendicularia, Cladocera, Medusae/Siphonophora, Chaetognatha, Thaliacea, Mollusca, Decapoda and Polychaeta. Density of well represented groups was obtained by counting 1/20 of a sample and in the case of poorer represented groups the whole catch. Values were expressed as a number of specimens per haul and as a number of specimens in a cubic metre.

We also used the data on phytoplankton density in the same area and at the same time interval (PUCHER-PETKOVIĆ, 1963, 1964, 1968, 1971, 1979; PUCHER-PETKOVIĆ and MARASOVIĆ, 1982; PUCHER-PETKOVIĆ *et al.*, 1988).

Hydrographic data, that is monthly temperature and salinity values for both the surface (10 m) and bottom (75 m) sea water layers were collected simultaneously with net sampling (BULJAN and ZORE-ARMANDA, 1966, 1979; ZORE-ARMANDA *et al.*, 1988; ZORE-ARMANDA *et al.*, 1991). The relationship between the zooplankton groups, between zooplankton and phytoplankton and between zooplankton and abiotic environmental factors were examined by statistical methods (SPIEGEL, 1972; PETZ, 1985).

Seasonal distribution was studied from monthly means for 23 years (1960-1982) and long-term fluctuations from annual means and five-year running averages.

Seasonal density changes of individual zooplankton groups as affected by abiotic and biotic factors were determined by linear regression equations and calculating the correlation coefficients from 23-year annual means. Correlation coefficients and linear regression equation were also applied for long-term density changes of individual zooplankton groups as affected by environmental changes using absolute monthly means for the entire period covered by the study.

In both cases a correlation with a negative shift of one month was performed. All studied zooplankton groups were correlated to abiotic factors (temperature, salinity). However, only those zooplankton groups to which phytoplankton is believed to be principal food were correlated to phytoplankton.

## RESULTS

### *Distribution and species composition in the total zooplankton*

For the entire period of our study Copepoda dominated the zooplankton contributing 59.3% of the total counts, whereas Appendicularia formed 11.7%, Cladocera 9.3%, Medusae/Siphonophora 6.5%, Chaetognatha 5.7% and Thaliacea 5.3%. Other groups were moderately present in the collections: Mollusca 1.5%, Decapoda 0.5% and Polychaeta 0.1%. (All these values are means of all measurements, their seasonal and long-term variations will be presented further on).

Seasonal changes

The 23-year monthly means show that in January Copepoda are predominant constituting 60% of the total counts, followed by Appendicularia with 19.2%. The presence of Chaetognatha with 9% and Medusae/Siphonophora with 8.6% is rather significant. No values of other groups exceeded 1% (Table 1).

Table 1. Variations of seasonal presence (%) of dominant zooplankton groups (Stončica, monthly means 1960 - 1982)

| | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Copepoda | 60.0 | 63.4 | 64.0 | 77.4 | 72.2 | 61.6 | 42.1 | 47.0 | 49.3 | 60.0 | 61.0 | 60.0 |
| Appendicularia | 19.2 | 22.7 | 22.6 | 8.6 | 10.3 | 9.6 | 8.0 | 6.8 | 7.1 | 9.7 | 9.0 | 17.0 |
| Cladocera | 0.4 | 0.2 | 1.1 | 2.3 | 4.8 | 13.0 | 23.0 | 17.6 | 17.8 | 7.4 | 4.3 | 0.8 |
| Medusae/Siphonophora | 8.6 | 6.9 | 7.5 | 7.5 | 6.7 | 6.5 | 4.2 | 4.1 | 5.1 | 7.9 | 9.4 | 7.7 |
| Chaetognatha | 9.0 | 5.0 | 2.6 | 2.4 | 3.4 | 4.5 | 5.1 | 6.0 | 6.0 | 9.4 | 11.0 | 11.0 |
| Thaliacea | 0.7 | 0.7 | 0.6 | 0.5 | 0.9 | 3.1 | 15.6 | 15.7 | 9.3 | 2.9 | 1.8 | 1.3 |
| Mollusca | 0.8 | 0.6 | 0.9 | 0.5 | 0.8 | 0.8 | 1.4 | 2.2 | 4.2 | 2.1 | 2.0 | 1.6 |
| Decapoda | 0.9 | 0.9 | 0.6 | 0.4 | 1.0 | 0.4 | 0.3 | 0.5 | 0.2 | 0.6 | 0.5 | 0.7 |
| Polychaeta | 0.4 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.03 | 0.03 | 0.03 | 0.1 | 0.4 | 0.3 |

In February and March Appendicularia reached their maximum abundance in the total zooplankton. At the same time the abundance of Copepoda slightly increased and that of Medusae/Siphonophora and Chaetognatha decreased. Other groups are also very moderately present.

Considerable changes occur in April. Copepoda increased in numbers and with 77.4% reached their annual maximum on the total zooplankton with a considerable decline of Appendicularia abundance to as low as 8.6%. Cladocera presence slightly increased not yet being significant in the total zooplankton. Medusae/Siphonophora were found to be represented like in the preceding months. Three groups showed annual minimum in this month: Chaetognatha, Thaliacea and Mollusca, the latter two being so moderately present throughout the winter-spring.

Copepoda presence is still very high in May, Appendicularia, Chaetognatha and Cladocera abundance is slightly higher, whereas Medusae/Siphonophora abundance decreases. Decapoda reached maximum even though they did not constitute more than 1% in the total zooplankton. Neither of other groups exceeded 1%.

In June Copepoda presence decreased by as much as 11% with respect to th preceding month while Cladocera suddenly increased by even 9%. Appendicularia and Medusae/Siphonophora formed the same percentage proportion as in the preceding month. Constituting 3.1%, Thaliaceae became for the first time a little more significant in the total zooplankton counts. Other groups were still moderately present.

In July and August four groups show relatively high abundance: Copepoda (with annual minimum in July), Appendicularia (with annual maximum in August), Cladocera (with annual maximum in July) and Thaliacea (with annual maximum in both months). Medusae/Siphonophora proportion declines reaching annual minimum. Chaetognatha were slightly better represented with respect to June, whereas all other groups showed no changes.

In September Copepoda abundance in the total zooplankton slightly increased. Cladocera, Appendicularia and Chaetognatha abundance was approximately the same as in the preceding month. Thaliacea was considerably poorer represented and annual maximum abundance was recorded for Mollusca.

Most of the groups showed significant changes in October. Copepoda abundance increased by about 10%, whereas that of Cladocera decreased by the same figure. Appendicularia, Chaetognatha and Medusae/Siphonophora for-

med only a few percentages more than in the preceding months. Thaliacea presence declined significantly and Mollusca abundance was reduced. Decapoda and Polychaeta were still present in very low percentages.

The abundance of Copepoda, Appendicularia and Mollusca in the total zooplankton was in November the same as in October. Cladocera and Thaliacea abundance significantly decreased whereas that of Medusae/Siphonophora and Chaetognatha increased, both reaching their annual maximum. The abundance of other groups remained unchanged.

In December most of the groups constituted the same percentages in the total zooplankton as in November. Only Appendicularia abundance considerably increased, whereas that of Cladocera dropped below 1%.

## Long-term fluctuations

The observations of the fluctuations in the abundance of individual groups in the total zooplankton at Stončica from annual means for the 1960-1982 period, show that Copepoda dominated the zooplankton. Their abundance in the total zooplankton counts ranged from 56.7 to 68.3%, with the exception for the years 1975 and 1979, when this group was relatively poorly represented. The year 1980 should be particularly emphasized since Copepoda abundance in the total zooplankton was lowest (38.3%) and the year 1981, as well, when it was highest (77.2%) for the entire period of our study (Table 2).

Appendicularia constituted from about 15% of the total zooplankton counts from the beginning of the study period up to 1977. Maximum (17.1%) was recorded in 1975. However, this group formed no more than 6.4 to 8.2% between 1977 and 1982.

Similar was recorded for the groups Medusae/Siphonophora and Chaetognatha. From 1960 to 1976 Medusae/Siphonophora contributed between 4.7 and 12.7% of the total counts, whereas their contribution did not exceed 0.3-3.5% from 1977 to 1982. The year 1980 was

Table 2. Long-term variations in presence (%) of dominant zooplankton groups (Stončica, annual means 1960 - 1982 ——— minumum, ▬▬▬ maximum)

| | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Copepoda | 67.0 | 56.7 | 57.6 | 62.0 | 65.1 | 65.1 | 65.4 | 68.3 | 67.4 | 62.9 | 61.7 |
| Appendicularia | 9.9 | 13.2 | 12.0 | 11.4 | 14.8 | 15.0 | 15.9 | 14.5 | 15.6 | 15.3 | 14.6 |
| Cladocera | 4.5 | 6.9 | 6.8 | 5.0 | 3.0 | 1.0 | 3.0 | 2.8 | 3.0 | 5.3 | 3.4 |
| Medusae/Siphonophora | 5.8 | 9.8 | 10.0 | 12.7 | 6.2 | 5.9 | 5.7 | 5.0 | 5.8 | 6.2 | 6.6 |
| Chaetognatha | 7.6 | 8.1 | 8.9 | 5.4 | 5.2 | 4.0 | 7.2 | 6.5 | 6.0 | 6.5 | 9.6 |
| Thaliacea | 2.6 | 1.7 | 2.6 | 1.3 | 2.3 | 0.5 | 1.2 | 1.2 | 0.5 | 1.6 | 0.9 |
| Mollusca | 1.4 | 2.7 | 0.9 | 1.5 | 1.6 | 1.9 | 0.6 | 0.8 | 0.9 | 1.3 | 2.0 |
| Decapoda | 0.7 | 0.6 | 1.0 | 0.4 | 0.9 | 0.7 | 0.9 | 0.8 | 0.5 | 0.7 | 0.9 |
| Polychaeta | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.2 | 0.2 | 0.1 |

| | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Copepoda | 66.1 | 57.4 | 65.9 | 60.0 | 46.0 | 64.1 | 57.5 | 56.8 | 44.6 | 38.3 | 77.2 | 71.6 |
| Appendicularia | 13.7 | 12.3 | 13.7 | 14.4 | 17.1 | 12.1 | 8.2 | 6.4 | 5.4 | 8.2 | 8.7 | 6.5 |
| Cladocera | 2.4 | 13.5 | 2.8 | 4.4 | 6.5 | 10.5 | 27.4 | 24.4 | 22.7 | 10.2 | 9.5 | 17.4 |
| Medusae/Siphonophora | 4.7 | 6.9 | 6.3 | 6.6 | 10.5 | 8.0 | 0.3 | 3.5 | 3.5 | 10.6 | 2.5 | 1.3 |
| Chaetognatha | 8.8 | 6.9 | 7.0 | 6.8 | 4.4 | 3.3 | 5.5 | 4.3 | 4.8 | 4.5 | 3.2 | 2.0 |
| Thaliacea | 0.9 | 0.9 | 2.3 | 5.7 | 10.7 | 0.6 | 0.3 | 3.0 | 15.0 | 27.4 | 0.2 | 0.4 |
| Mollusca | 1.7 | 1.2 | 1.5 | 1.2 | 4.0 | 0.9 | 0.5 | 1.2 | 3.3 | 0.6 | 0.4 | 0.5 |
| Decapoda | 1.4 | 0.7 | 0.5 | 0.8 | 0.6 | 0.6 | 0.2 | 0.3 | 0.2 | 0.1 | 0.2 | 0.3 |
| Polychaeta | 0.3 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |

an exception, since this group constituted 10.6 %. Chaetognatha constituted 4.0-9.6% in the 1960-1974 and 2-5.5% from 1975 to 1982.

The situation was quite contrary in Cladocera, the abundance of which was markedly higher, 9.5-27.4% in the 1976-1982 than in the preceding years when it did not exceed 1.9-13.5%. Thaliacea contributed on the average from 0.2 to 5.7%, with the exception for the years 1975 (10.7%), 1979 (15.0%), 1980 (27.4% - maximum abundance) and 1981 (0.2% - minimum abundance).

No significant fluctuations in Mollusca, Decapoda and Polychaeta abundance in the total zooplankton were observed for the period of our study.

* * *

All the monthly values showed that Copepoda ranged from 8.5-95.8% throughout the period of our study /earlier reported range for the same station was 9.11-92% (REGNER, 1985a), Appendicularia from 0.07-42.9%, Cladocera from 0-61.2%, Medusae/Siphonophora from 0.1-29.6%, Chaetognatha 0.1-24.2%, Thaliacea 0-63.9%, Mollusca 0-17.3%, Decapoda from 0-2.5% and Polychaeta from 0-1.1%.

*Seasonal and long-term density fluctuations quantities*

Seasonal and long-term fluctuations in zooplankton counts at Stončica in 1960-1982 are given separately for each individual group, in a succession as to their relative abundance in the total zooplankton counts.

Copepoda

Copepoda are known as best represented group in the total zooplankton counts of all the world seas. In the Adriatic they increase in numbers proceeding from the north southwardly and from the coast offshore (GAMULIN, 1948, 1979; HURE, 1955,1961; VUČETIĆ,1957, 1961a, 1961b, 1963a, 1963c, 1966a, 1966b, 1970; REGNER, 1973, 1975, 1976, 1977, 1982, 1985; VUKANIĆ, 1975).

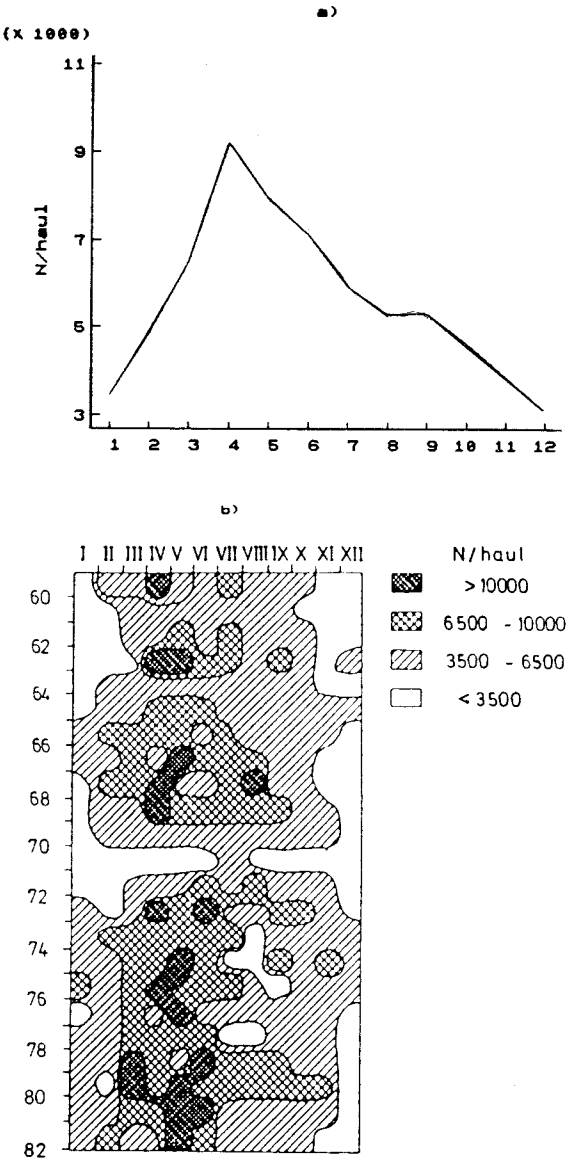


Fig.9. Copepoda (Stončica)
a) seasonal density fluctuations (monthly means 1960-1982)
b) contour diagram of long-term density variations

About 90 Copepoda species have been reported from Stončica by some recent investigations. *Mecynocera clausi, Clausocalanus jobei, Clausocalanus furcatus, Ctenocalanus vanus, Centropages typicus* and *Temora stylifera* were the most abundant species occurring in other parts of the Adriatic where they are also widely distributed and quantitatively dominant (REGNER, 1985).

The observations of seasonal variations in Copepoda counts at Stončica (1960-1982) pointed to their particularly high numbers from March to the end of July. In the years 1967 and 1968 high numbers were recorded by the end of August, in 1969 and 1979 up to the end of September and in 1980 they extended as far as the end of November. Maximum density was, as a rule, recorded in April or May (Fig. 9b) and low density mainly in November, December, January and February. However, low counts occurred only in August in 1974 and 1975, in September 1976 and in July and August 1978. Copepoda numbers were very low all 1971 round.

After monthly means for the entire period (23 measurements) it may be stated that Copepoda density increased, on the average, from January to April (when it reached a maximum of 9192 individuals per haul or 313 $m^{-3}$). Thereafter the density gradually declined to be represented in December by the lowest number of individuals (3093 per haul or 105 $m^{-3}$)(Fig. 9a).

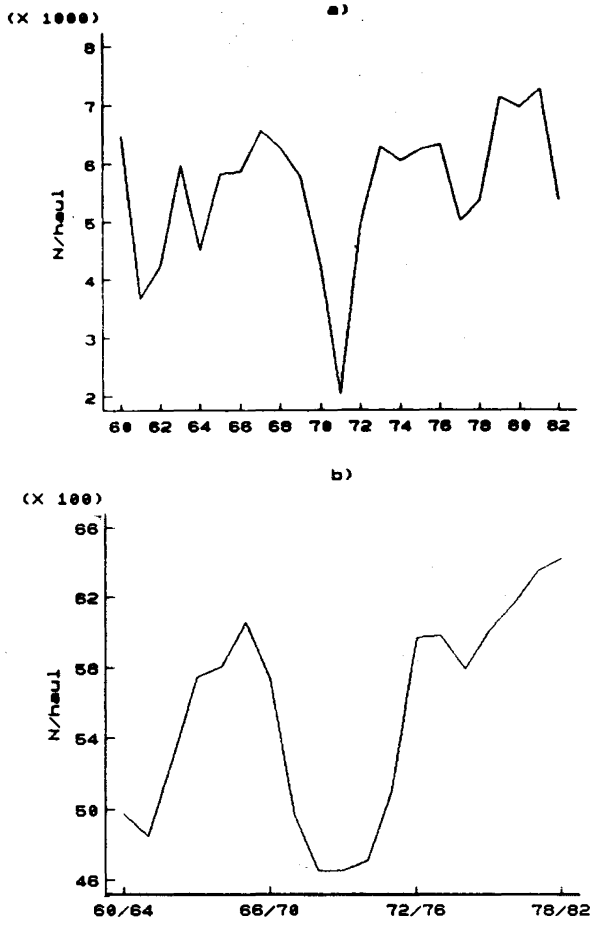


Fig.10. Copepoda -long-term density fluctuations at Stončica
a) annual means
b) five-year running averages

It was attempted to establish long-term density fluctuations from a long-term series (1960-1982) of annual means. Three periods of significant density declines may be observed apart from several (four) more poorly marked increeases in numbers (Fig. 10a).

The first significant density decrease was recorded in 1961. It was followed by a gradual increase up to 1964 when a marked decline occurred. The 1965-1969 is a period of gradual increase. In 1970 a signifiacnt drop was established, which proceeded through 1971, when the lowest value for the entire period was recorded (2038 specimens per haul or only 69 $m^{-3}$). Between 1972 and 1981 the highest annual mean density was observed (7282 specimens per haul or 248 $m^{-3}$), to be followed by a drop in 1982. Running averages mitigate these fluctuations and show two moderate density increases during the period of our study (Fig. 10b).

## Appendicularia

Up to now, a total of 27 species have been recorded from the Adriatic, 21 of which from the open middle Adriatic (GAMULIN, 1948; HURE, 1955, 1961; VUČETIĆ, 1957, 1961a, 1961b; VUKANIĆ, 1975; SKARAMUCA, 1979a, 1979b, 1979c, 1982a, 1982b, 1983). The species *Oikopleura longicauda, Oikopleura fusiformis, Oikopleura dioica, Fritillaria pellucida* and *Fritillaria borealis* were particularly numerous and formed 90.8% of Appendicularia in the Adriatic (SKARAMUCA, 1983).

Quantitatively, the abundance of Appendicularia in the total zooplankton gradually decreased from the north southwardly and from the coast offshore, whereas the fluctuations in the number of species are quite contrary.

The most important trait of this group is its ability to transfer energy from producers to consumers rapidly and directly. This means that Appendicularia feed on phytoplankton and at

the same time are the most important constituent of fish larvae food (VUČETIĆ and PUCHER-PETKOVIĆ, 1969). They were found to respond quickly to the primary production increase (VUČETIĆ, 1957).

Seasonal density fluctuations of Appendicularia at Stončica station in the 1960-1982 show that high quantities may mainly be recorded from the beginning of February to the end of June. High density occurred from January to the end of July in 1969, 1974, 1975 and 1980, from February to August in 1965, from January to the end of September in 1967 and from February to as far as the end of October in 1963. In 1973 the number of individuals was high and uniform all year round (Fig. 11b).

Even though the occurrence of maximum density varied from one year to another, still it may be said to occur in March.

Low counts were found in autumn-winter of all years, that is from the beginning of October to the end of January in the 1960-1976 and from the beginning of September to the end of December in the 1977-1982. The densities were very low almost throughout 1971.

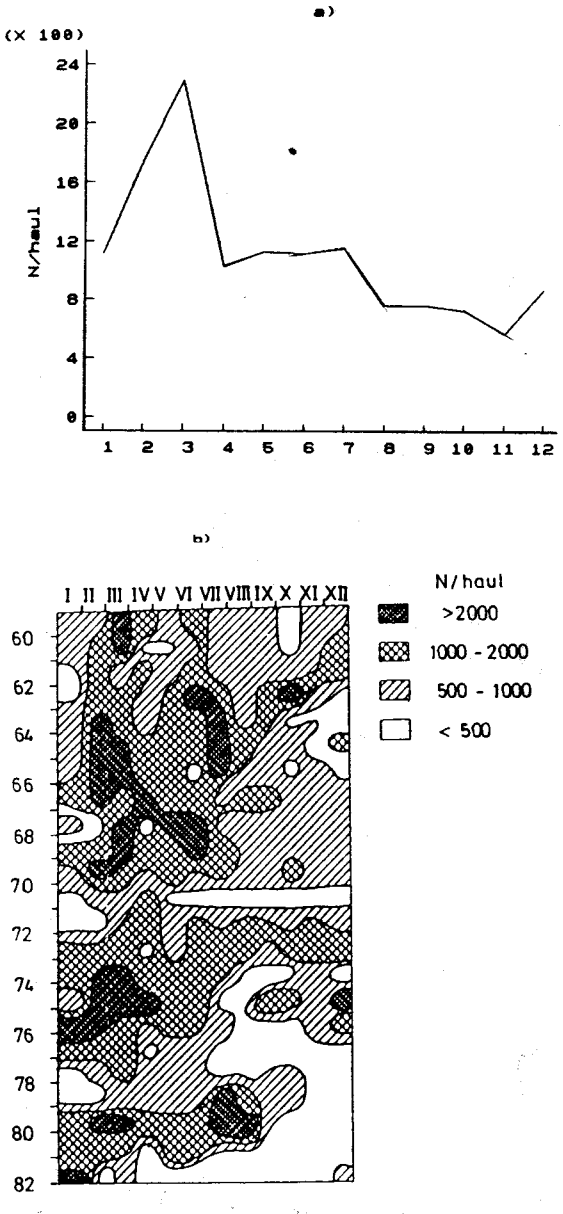


Fig.11. Appendicularia (Stončica)
a) seasonal density fluctuations (monthly means 1960-1982)
b) contour diagram of long-term density variations

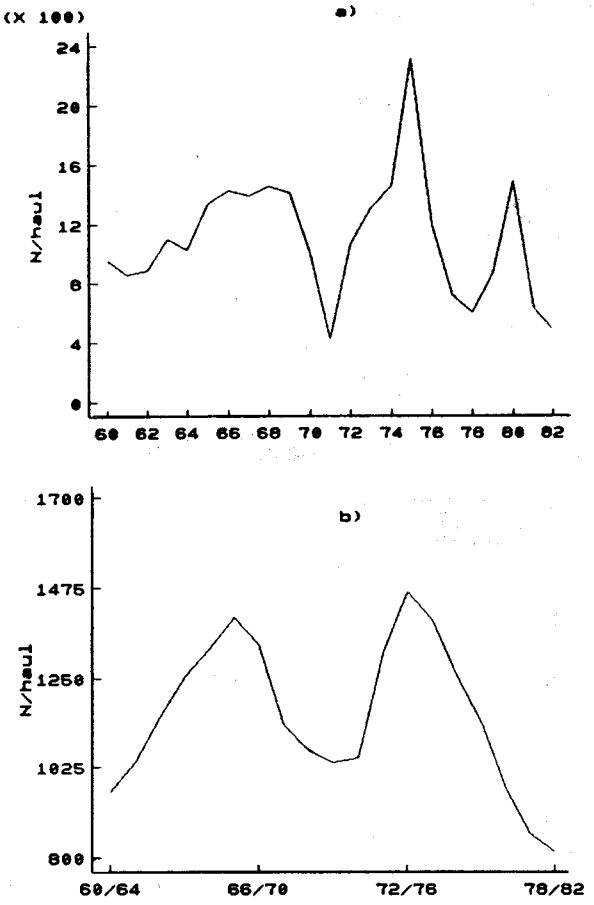


Fig.12. Appendicularia long-term density fluctuations at Stončica
a) annual means
b) five-yeae running averages

In general, Appendicularia quantities increase from December to March (when the highest number of 2289 individuals per haul, or 78 $m^{-3}$ was recorded) to decrease gradually to November (the lowest mean values - 569 individuals per haul or 19 $m^{-3}$)(Fig. 11a).

As shown by long-term fluctuations of annual means, there occurred several marked increases and drops during the period of our study (Fig. 12a). From the beginning, that is between 1960 and the end of 1969, the density gradually increased with respect to the mean value for the entire study period. A slight quantity decline was recorded in 1970 and a marked one in 1971, when the lowest Appendicularia density of 423 individuals per haul, or 14 $m^{-3}$, occurred. From 1972 up to 1975 the density of this group suddenly increased, to reach its maximum in 1975: 2318 individuals per haul or 79 $m^{-3}$. From 1976 to 1978 the density suddenly dropped once again. The third density increase occurred in the 1979-1980 period and a drop in 1981-1982.

Running averages showed two periods with an increase trend, each followed by an intesive density decline (Fig. 12b).

## Cladocera

Six Cladocera species have been known in the Adriatic. All of them were also found in the open middle Adriatic (GAMULIN, 1948; HURE, 1955; 1961; SPECCHI, 1969; VUKANIĆ, 1975; VUČETIĆ, 1980; BENDER, 1984). Species diversity and quantities of this group decreased gradually from the north southwardly, an from the west eastwardly. In some areas this group makes up a bulk of zooplankton during the warmer part of the year (BENDER, 1984).

Higher density of this group was observed mainly to occur between April (May) as far as to October (November). Within this interval maximum densities were recorded from July to September in 1960 and 1963, in July and August 1969 and 1972 and from June to september in the 1975-1982 (Fig. 13b).

This period of very high counts was followed by a sudden drop so that very low values occurred in the 1960-1971, as early as at the

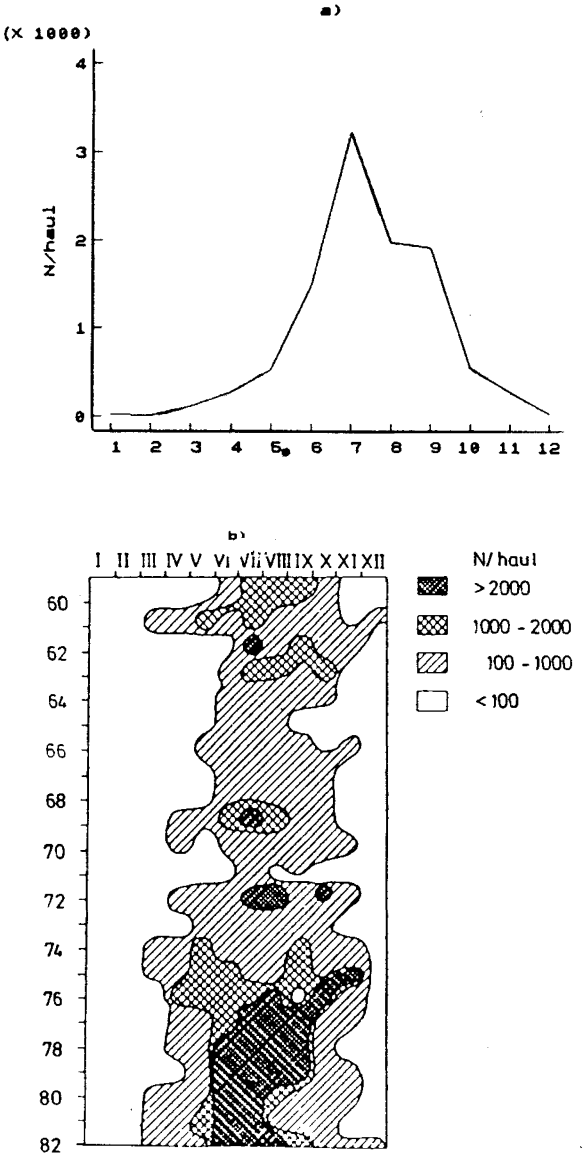


Fig.13. Cladocera (Stončica)
a) seasonal density fluctuations (monthly means 1960-1982)
b) contour diagram of long-term density variations

beginning of November, an in all the years from December to mostly the end of March. Low density extended to the end of April in 1966, 1971, 1973 and 1979, to the end of May in 1960, 1963-1965 and 1967-1968, to be recorded up to the end of June in 1971.

As shown by monthly means for the entire study period higher density was recorded in the warmer part of the year with maximum values

in July (3232 specimens per haul or 11 $m^{-3}$) However, the presence of this group was almost negligible in the colder part of the year (the lowest number of individuals was recorded in February: 12 per haul or 0.4 $m^{-3}$) (Fig. 13 a).

An analysis of long-term fluctuations showed a slight density increase in the 1960-1962, followed by a sudden drop in 1963-1965, an increase in 1966-1969 and another drop in 1970-1971. The lowest mean density was recorded in 1971: 73 specimens per haul or 2 $m^{-3}$. In 1972 their counts significantly increased to drop considerably in 1973. A new increase occurred in the 1974-1979, with the highest density in 1979: 3636 individuals per haul or 124 $m^{-3}$. Density declined once again in 1980-1981 followed by a slight increase in 1982 (Fig. 14a).

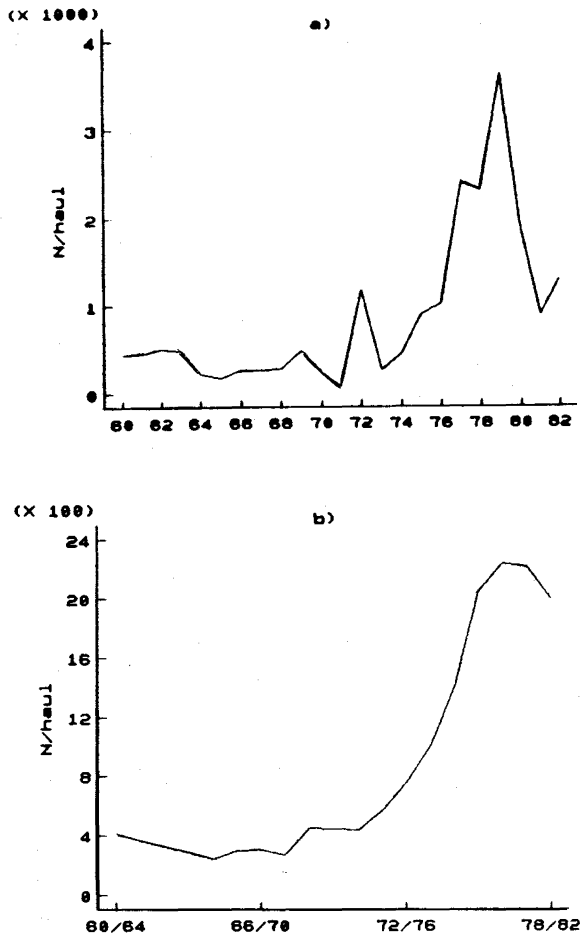


Fig.14. Cladocera -long-term density fluctuations at Stončica
a) annual means
b) five-year running averages

Running averages show a pronounced density increase tendency somwhere from the middle of the study period on (Fig. 14b).

## Medusae/Siphonophora

Of 75 hydromedusan species recored from the Adriatic by now, 12 were found in the open middle Adriatic. The species *Rhopalonema velatum, Liriope tetraphylla, Aglaura hemistoma* and *Laodicea undulata* are most common. The number of species decreases from the north southwardly, whereas the quantities increase. Apart from a larger number of species recorded from the channels, the group counts were also higher there than in the open sea (BABNIK, 1948; GAMULIN, 194, 1979; HURE, 1955, 1961; VUČETIĆ, 1957, 1961a, 1961b; BENOVIĆ, 1973; VUKANIĆ, 1975).

A total of 23 Siphonophora species have been recorded from the Adriatic, 16 of which occur in the open middle Adriatic. The most frequent species are: *Muggiaea kochi, Eudoxoides spiralis, Lensia subtilis, Chelophyles appendiculata* and *Sulculeolaria chuni.* As distinct from other groups the density of the group increases parallel to the increase in the number of species proceeding from the north southwardly (GAMULIN, 1948, 1968, 1979, 1982b, HURE, 1955, 1961; VUČETIĆ, 1961a, 1961b).

From the early beginning of the research along the transect Split-Gargano, these two groups have always been treated together, therefore we did the same in this paper.

The period 1965-1970 showed higher density from January to April and the years 1960-1964, 1973-1976 and 1980-1982 all year round with almost no departures. Lower density was recorded in January and February 1968 and 1979, and throughout 1971, 1977, 1978 and 1982 (Fig. 15b).

The diagram of monthly means for the entire study interval shows higher density from March to June, a decrease from July to August, another slight increase from September to November and once again a decrease in December, January and February (Fig. 15a). The lowest monthly mean density occurred in December:

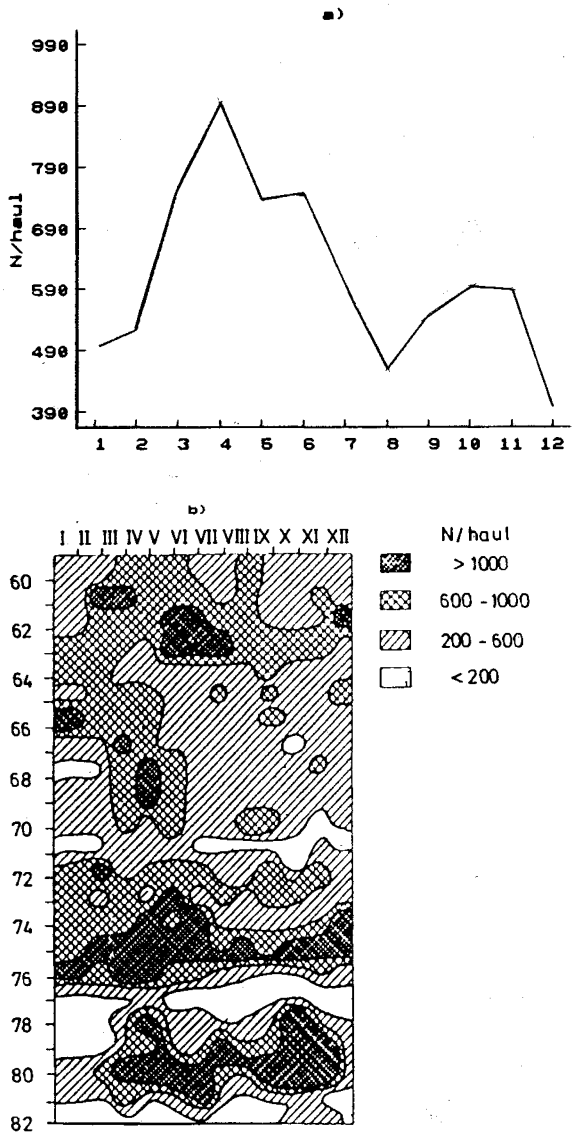


Fig.15. Medusae/Siphonophora (Stončica)
a) seasonal density fluctuations (monthly means 1960-1982)
b) contour diagram of long-term density variations

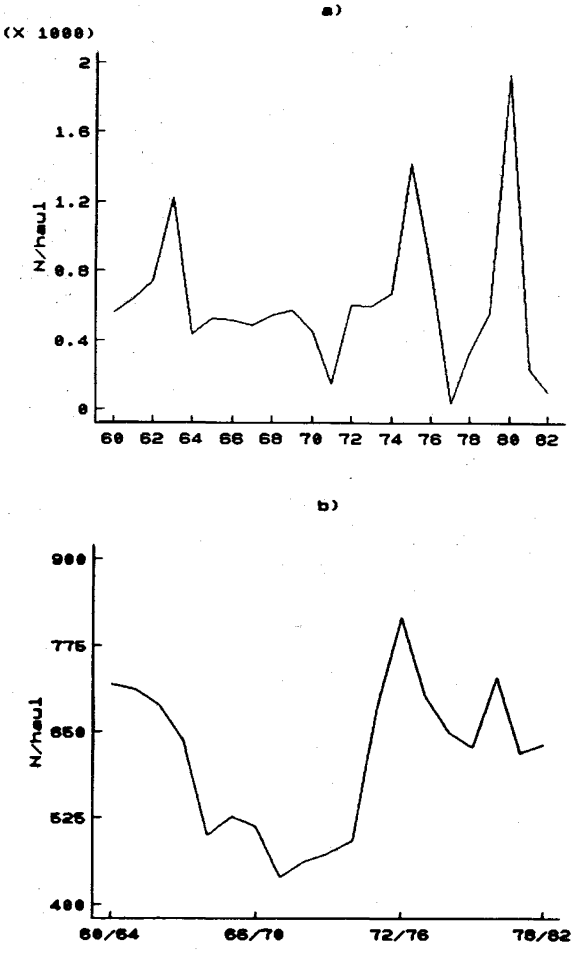


Fig.16. Medusae/Siphonophora -long-term density fluctuations at Stončica
a) annual means
b) five-year running averages

399 specimens per haul or 14 $m^{-3}$, and the highest one in April: 897 per haul or 31 $m^{-3}$. The observations of long-term fluctuations (Fig. 16a) show an increase in Medusae/Siphonophora counts in the 1960-1963, followed by a sudden drop in 1964. The density increased once again in the 1965-1969 and dropped in 1970-1971, rised in 1972-1975 and decreased thereupon. The lowest annual mean density was found in 1977: 30 specimens per haul or 1 $m^{-3}$. A new increase occurred in 1978 extending by 1980 when the highest mean density was recorded: 1929 specimens per haul or 66 $m^{-3}$. The years 1981-1982 again showed a decrease.

Running averages gave a quantity drop about the middle of the study period and an increase at its end.

## Chaetognatha

A total of 10 species have been reported for the Adriatic by now. The number and density of species are smaller in the northern Adriatic than in the other Adriatic parts. All ten

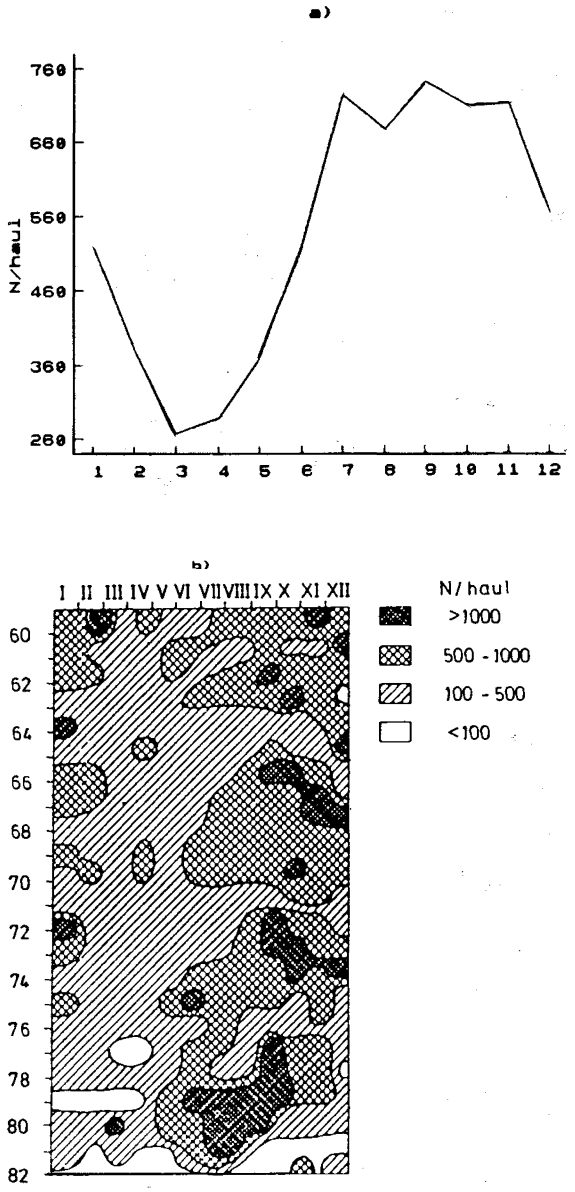


Fig.17. Chaetognatha (Stončica)
a) seasonal density fluctuations (monthly means 1960-1982)
b) contour diagram of long-term density variations

species occur in the open middle Adriatic, of which the following are particularly abundant: *Sagitta inflata, Sagitta minima, Sagitta setosa, Sagitta serratodentata* and *Sagitta lyra* (GAMULIN, 1948, 1979, 1982a; HURE , 1955, 1961; VUČETIĆ, 1957, 1961a, 1961b, 1961d, 1963a, 1969b, 1969c). Some species of this group are recognized as good plankton indicators, that is they are characteristic of a defined water mass type pointing to the distribution and movement of different water types (VUČETIĆ, 1961d, 1963a, 1969b, 1969c).

For the period 1960-1982 high density occurred at Stončica mostly from July to December: in January in 1960-1962, 1964, 1966-1967, 1969, 1972-1973 and 1975. Low density was mainly recorded between January and May, only occasionally in June and July (1960, 1964-1968, 1971-1973). Markedly poor counts were found for the first four months in 1979 and almost all year round in 1971 and 1982 (Fig. 17b).

Monthly mean values for the entire period show that the increase mainly starts in May and extends by September when the highest mean density is recorded (743 specimens per haul or

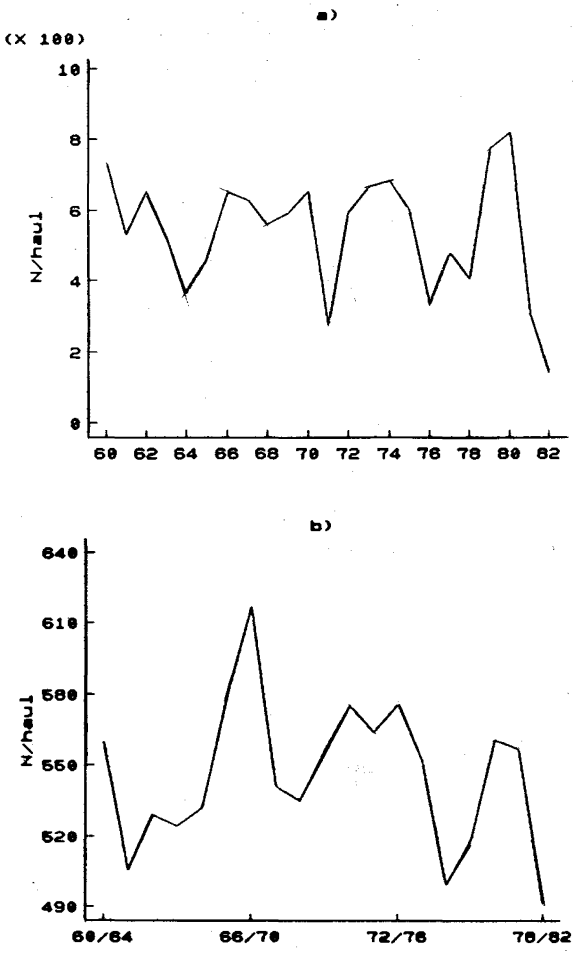


Fig.18. Chaetognatha - long-term density fluctuations at Stončica
a) annual means
b) five-year running averages

24 m$^{-3}$). It remains at that level up to the end of the year. Their counts gradually decline mainly from January to March, when the lowest monthly mean density was found: 267 specimens per haul or 9 m$^{-3}$ (Fig. 17a).

Long-term fluctuations reveal several marked drops and increase of this group density for the period of our study (Fig. 18a). Their numbers gradually decreased in the 1960-1964, followed by an increase up to 1970 and thereupon suddenly dropped in 1971. Another increase was recorded in the 1972-1974 and another drop in 1975-1976. From 1977 on the density increased to reach maximum mean value in 1980: 821 specimen per haul or 28 m$^{-3}$. From 1981 on the density declined again and the smallest annual mean number of specimens, 147 per haul or 5 m$^{-3}$, was recorded in 1982.

Running averages could not give more pronounced trends of either an increase or decrease in numbers (Fig. 18b).

Thaliacea

A total of nine Thaliacea species have been recorded from the Adriatic up to now. All of them occur in the open middle Adriatic, as well, where the following species occur in significant quantities: *Doliolum nationalis, Doliolina mülleri, Thalia democratica and Salpa fusiformis,* whereas *Salpa maxima* and *Pyrosoma atlanticum* were rarely recorded in extremely small numbers (GAMULIN, 1948, 1979; HURE, 1955, 1961; KATAVIĆ, 1977, 1979, 1982).

Seasonal density variations of this group were considerable at Stončica for the period of our study (1960-1982). The highest density mostly occurred in the warmer part of the year, from May to October. In the 1960-1963 period Thaliacea were well represented all year round. The termination of high densities and the time of the occurrence of lower densities differ from one year to another. In some years it happens in the colder part: from August to May 1964, 1965, 1971 and 1977, from September to March 1966 and 1968, from September to December 1967, from October to June 1982, from November to March 1969 and 1972, from December to May 1975-1976 and 1978-1981, and in January and February 1970, 1973 and 1974.

As shown by monthly means for the entire period the highest density was recorded between May and October with a maximum of 2195 specimens per haul or 75 m$^{-3}$ in July. For the rest of the year the presence of Thaliacea is

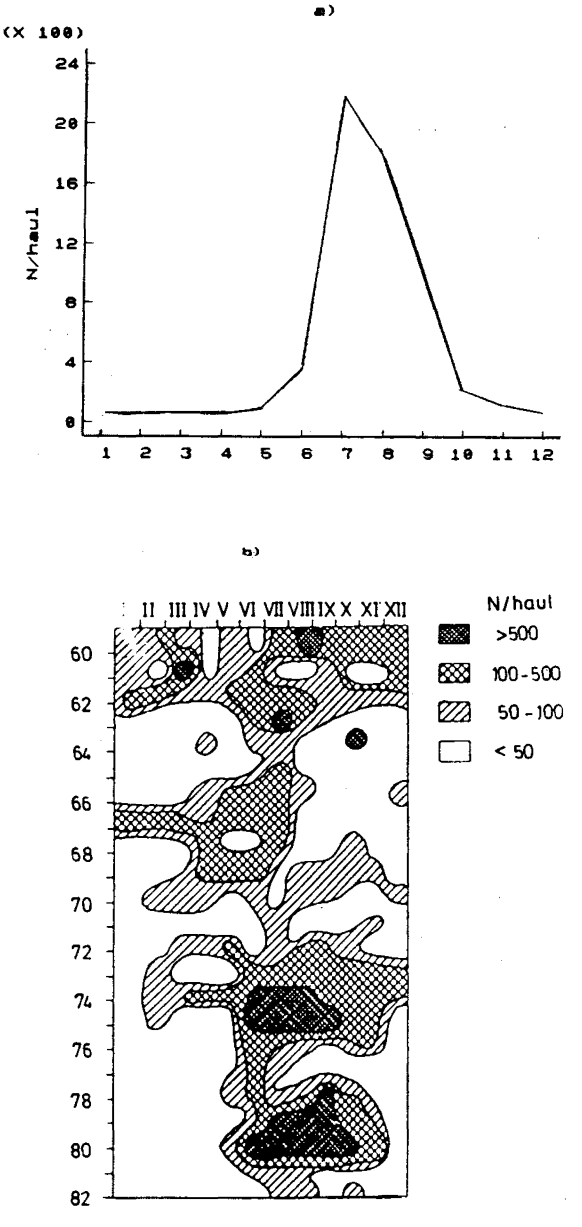


Fig.19. Thaliacea (Stončica)
a) seasonal density fluctuations (monthly means 1960-1982)
b) contour diagram of long-term density variations

almost insignificant, and the lowest density of 40 specimens per haul or 1 $m^{-3}$ was found in January (Fig. 19a).

Long-term variations show that between 1960 and 1971 their numbers slightly decreased. A sudden increase appeared in 1972-1975 followed by a marked drop in 1976-1977. The lowest density was recorded in 1977, 22 specimens per haul or 0.7 $m^{-3}$.

Thaliacea quantities were suddenly increased in 1978 and proceeded to increase up to 1980, reaching maximum values of 4979 per haul or 169 $m^{-3}$. Another considerable drop in counts was recorded in the 1981-1982 (Fig. 20a).

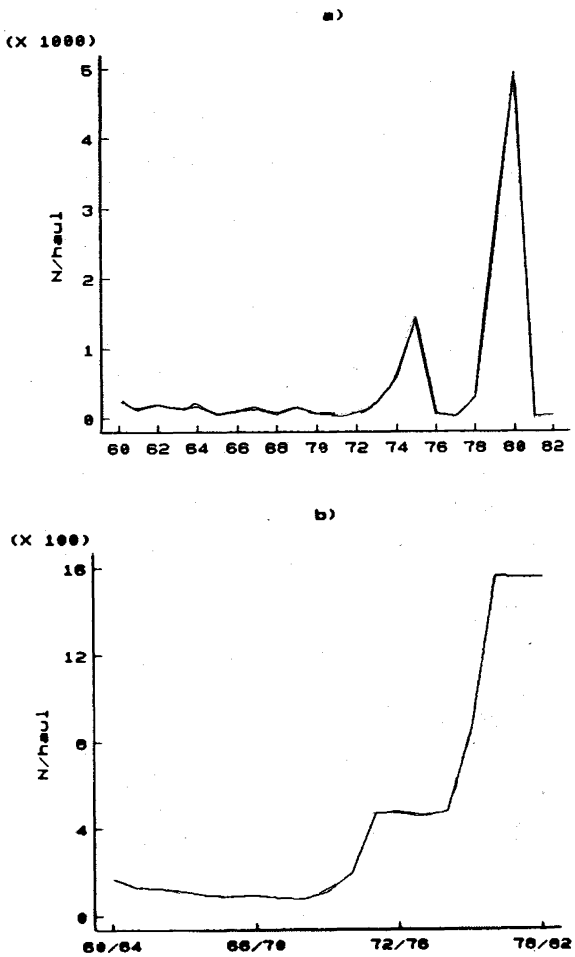


Fig.20. Thaliacea -long-term density fluctuations at Stončica
a) annual means
b) five-year averages

Mollusca

This zooplankton group is mainly comprised of the larvae of benthic organisms, the most numerous of which are those of Lamellibranchiata and Gastropoda. Of adults found in the material only gastropods of the Pteropoda group were recorded.

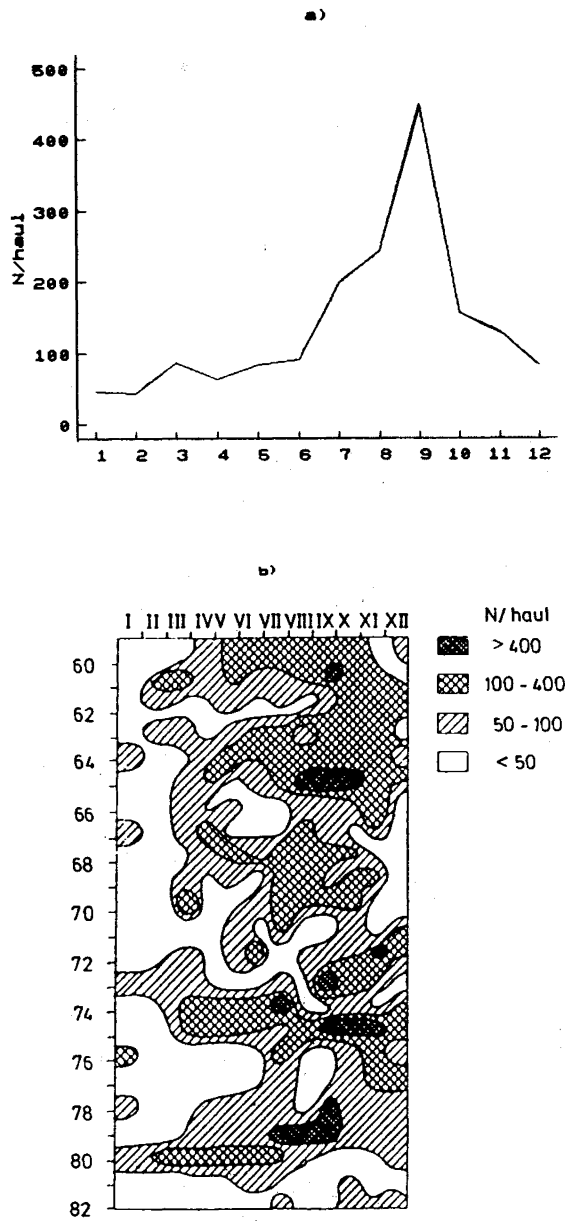


Fig.21. Mollusca (Stončica)
a) seasonal density fluctuations (monthy means 1960-1982)
b) contour diagram of long-term density variations

This group occurred in highest quantities during the warmer part of most of the studied years, most frequently between May and October, and as far as to December in the 1962-1965 and 1972-1977. Lower densities were mainly found from January to March, by August in 1962, up to June in 1976-1977, all year round in 1966, 1971, 1977, 1981 and 1982 (Fig. 21b).

Monthly means show that density gradually increased from March to July, followed by a sudden increase in August and September, when the highest density was found, 449 specimens per haul or 15 $m^{-3}$. A sudden decline occurred from October extending to February when the lowest monthly mean number of individuals was recorded, 44 per haul or 1 $m^{-3}$ (Fig. 21a).

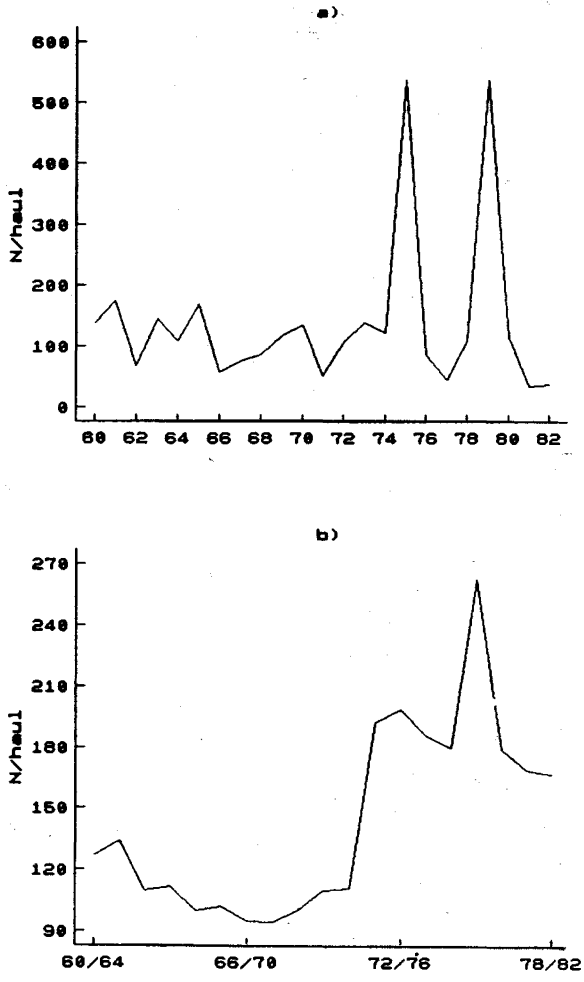


Fig.22. Mollusca -long-term density fluctuations at Stončica
a) annual means
b) five-year running averages

From long-term fluctuations of Mollusca density it appears that there were several marked increases and drops during the period of our study (Fig. 22a). The density decreased in the 1960-1962, followed by an increase in the 1963-1965 and another sudden decrease in 1966. From 1966 on Mollusca quantities gradually increased by 1970, to suddenly drop thereupon in 1971. Marked increase was recorded between 1972 and 1975. In 1976 the decrease was once again very sudden extending through 1977, to increase intensively in 1978 and 1979. The highest annual mean density was noticed in 1979 with 538 specimens per haul or 18 $m^{-3}$. Upon so marked rise in numbers a sudden drop occurred in 1980 to proceed by the end of the study period. In 1981 the lowest counts were recorded, 81 per haul or 3 $m^{-3}$.

Running averages showed a tendency of density increase somwhere around the end of the study period (Fig. 22b).

## Decapoda

The Decapoda group includes mainly different developmental stages of decapod crustaceans. Of adults, the species *Lucifer acestra* was most common.

No regular pattern of seasonal quantity fluctuations of this group at Stončica could be discovered for the period of our study (Fig. 23b). High numbers occurred in quite different months. Very low quantities were recorded in all months in the 1977-1981 period.

Seasonal variations in numbers are somewhat different as shown by long-term monthly means (Fig. 23a). The numbers decreased from January to April, a marked increase occurred in May, when the highest mean density was found, 107 specimens per haul or 4 $m^{-3}$. Thereupon density decreased by the end of the year. The lowest mean density of 22 specimens per haul or 0.7 $m^{-3}$ was obtained for September.

Long-term fluctuations show several marked increases and declines in number in 1960-1976 (Fig. 24a). The most pronounced density drop occurred in 1977 and the density recorded

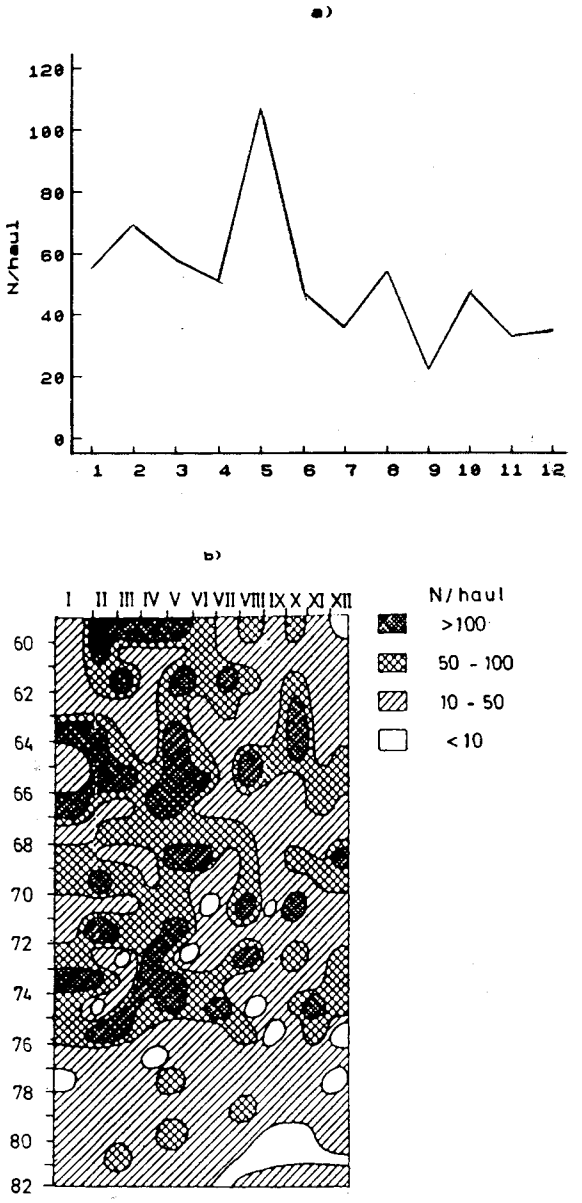


Fig.23. Decapoda (Stončica)
a) seasonal density fluctuations (monthly means 1960-1982)
b) contour diagram of long-term density variations

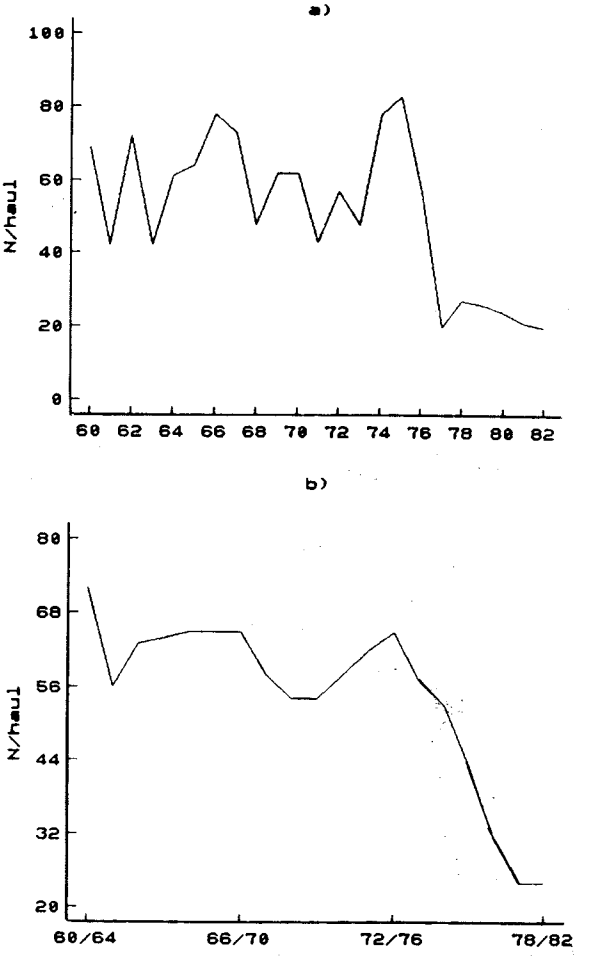


Fig.24. Decapoda -long-term density fluctuations at Stončica
a) annual means
b) five-year running averages

then is the lowest mean density for the entire period (20 individuals per haul or 0.7 $m^{-3}$). Thereupon there was no significant increase by the end of the study period. The highest density was recorded in 1975: 83 specimens per haul or 3 $m^{-3}$. Annual mean was 61 individuals per haul in the 1960-1976, whereas it was not more than 23 specimens per haul in the 1977-1982.

In general an increase tendency is recorded for the first half of the study period and a decline tendency in the second half (Fig. 24b).

## Polychaeta

As shown by the research carried out up to now, 20 species of pelagic Polychaeta have been mainly recorded from the middle and southern Adriatic. A total of seven species have been found in the open middle Adriatic waters, of which *Tomopteris elegans* was quantitatively most important (GAMULIN, 1948, 1979; HURE, 1955, 1961; ZEI, 1956).

Polychaeta group was relatively poorly represented in the material from the open middle

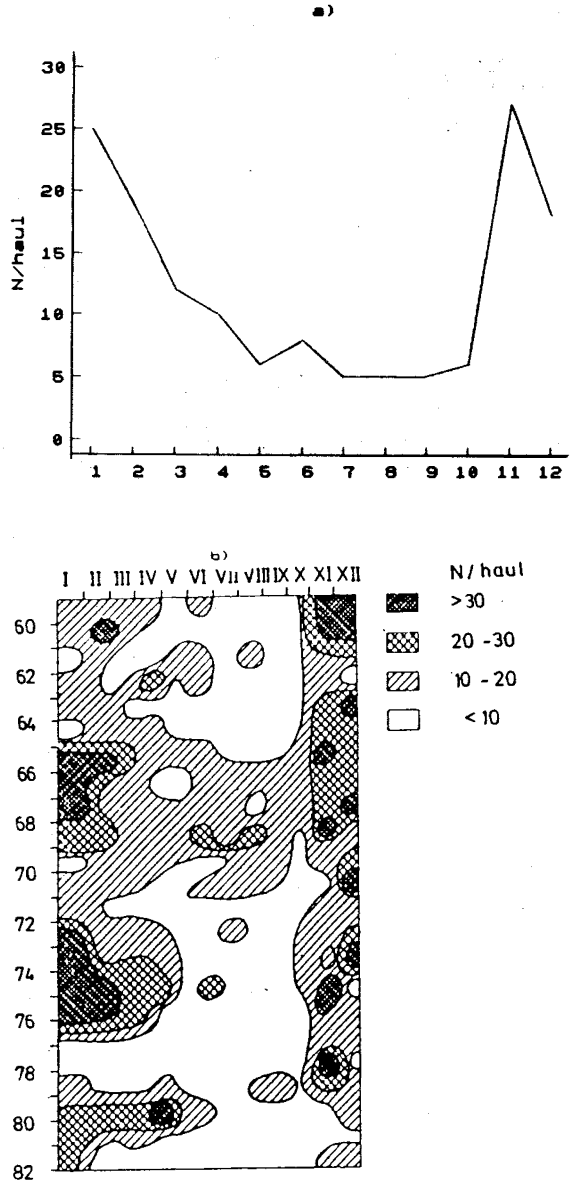


Fig.25. Polychaeta (Stončica)
a) seasonal density flucttuations (monthly-means 1960-1982)
b) contour diagram of long-term density variations

Adriatic. The specimens most frequently belonged to the genus *Tomopteris*.

Seasonal variations in 1960-1982 showed the highest densities in the colder part of the year, that is from November to February, with maximum in one of these four years (Fig. 25b). In most of the years the density was very low between March and October. The period 1966-1970 was the only exception since the numbers were somewhat higher than normally in that period of the year.

The diagram of monthly means for the entire period shows higher density from November to March and density decrease from April to October (Fig. 25a). The highest monthly mean density occurred in November (27 specimens per haul or 1 $m^{-3}$), and the lowest in July, August and September (5 individuals per haul or 0.2 $m^{-3}$).

Long-term fluctuations show that the numbers slightly decreased in the 1960-1963. An increase was recorded in 1964, proceeding with slight fluctuations by 1969. Another not so marked drop occurred in the 1970-1972, followed

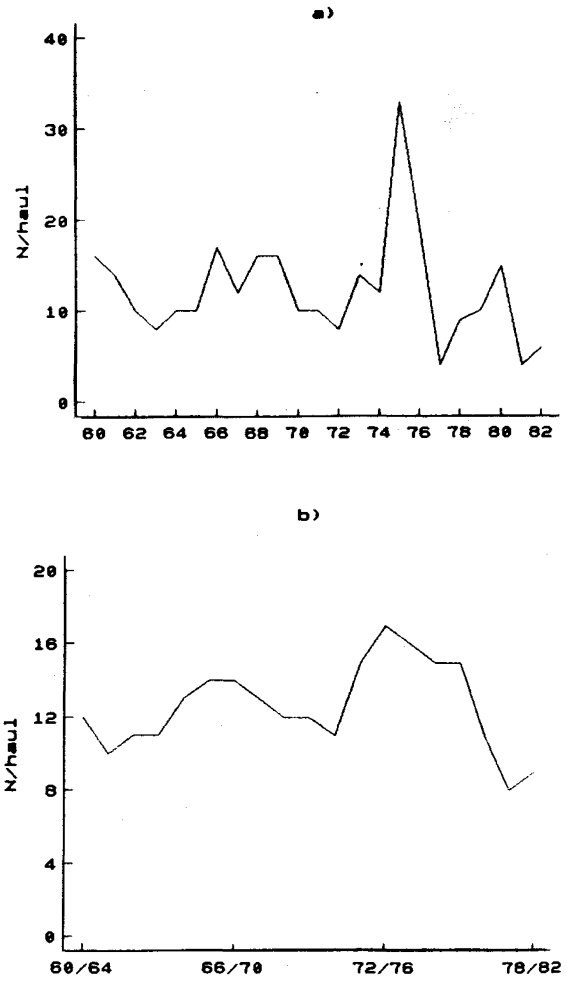


Fig.26. Polychaeta -long-term density fluctuations at Stončica after:
a) annual means
b) five-year running averages

by a significant increase in numbers with the maximum of 33 individuals per haul or 1 $m^{-3}$ in 1975. Thereupon, in 1977 a sudden decrease was found and the lowest annual density recorded, 4 specimens per haul or 0.1 $m^{-3}$. The Polychaeta counts slightly increased in the 1978-1980 followed by a new decline in 1981-1982 (Fig. 26a).

The first half of the study period is characterized by an increase tendency and the second by a decrease tendency (Fig. 26b).

## DISCUSSION

*Seasonal variations in zooplankton quantities as affected by abiotic and biotic factors*

The data collected during the long-term investigations at station Stončica suggest that the quantities and various groups and species of zooplankton (holoplanktonic and meroplanktonic) are highly variable depending on the season and associated environmental changes particularly those affecting direct reproduction. Some years also showed similar seasonal variations.

This study conducted at Stončica also observed the occurrence of maximum and minimum values of densities of dominant groups and thus revealed which of them have the same seasonal occurrence.

So between spring months of March and July, Copepoda, Appendicularia, Medusae/Siphonophora and Decapoda reach their maximum showing a defined similarity with the results of some earlier studies in the same area. Apart from Copepoda spring maximum (GAMULIN, 1979; REGNER, 1973) recorded during this study an autumn one was also reported (REGNER, 1973). Annual spring, summer and autumn maxima were also reported for the 1970-1974 surveys (REGNER, 1985).

Maximum Appendicularia densities were found in February, March and April. This does not agree with the earlier (single year) research of the same area mentioning summer-autumn maximum (SKARAMUCA, 1982a, 1982b, 1983).

GAMULIN (1968, 1979, 1982b) reported the largest numbers of Siphonophora in the open middle Adriatic between February and April. Hydromedusae also occurred in highest numbers during the colder part of the year, some species being dominant in September and October and some from November to spring and some from March to May (BENOVIĆ, 1973; GAMULIN, 1979).

A year-round occurrence of some decapod crustaceans larvae was reported as well the occurrence of some only during a defined periods of the year (HURE, 1955; KURIAN, 1956). The largest quantity of larvae was recorded from the open middle Adriatic waters from May to September (VUČETIĆ, 1970).

At the end of spring Cladocera, Chaetognatha, Thaliacea and Mollusca are at the start of their gradual development to reach their peak development (Cladocera, Thaliacea and Mollusca) in summer, from July to the end of September. Seasonal maximum of Cladocera and Thaliacea coincided in time with the Copepoda minimum. These results support those for the northern Adriatic (KATAVIĆ, 1979). Seasonal variations of Cladocera described in the present study conforms to the earlier accounts of Cladocera from this area (SPECCHI, 1969; BENDER, 1984). These results contrast with ours in that absolute maximum occurs in September or October and not in July. Seasonal fluctuations of Thaliacea numbers are also in agreement with the reports of some other authors for the same area (GAMULIN, 1979; KATAVIĆ, 1982). Earlier studies of Mollusca in the plankton mainly dealt with the Pteropoda group, of which the species *Creseis acicula,* occurred most frequently, being present in the open middle Adriatic all year round, whereas other species were found from autumn to spring (GAMULIN, 1979).

Cladocera, Thaliacea and Mollusca are also abundant at the beginning of autumn, whereas larger quantities of Chaetognatha are present all autumn through (September-December). Earlier studies of Chaetognatha in this area also showed increase in their density in this period of the year (HURE, 1955, 1961; VUČETIĆ, 1961d; GAMULIN, 1979, 1982a).

Higher Polychaeta density was recorded at the end of autumn persisting throughout winter (by March). Seasonal variations of Polychaeta with maximum values in winter are consistent with the earlier published reports on this area, when ZEI (1956) found that pelagic Polychaeta occurred in the colder part of the year with a peak in March, and GAMULIN (1979) that the species *Tomopteris elegans,* which constituted 57.7% of all pelagic Polychaeta of the material collected then, occurred more frequently from February to April than during the warmer part of the year.

## Seasonal changes in zooplankton and their control by seasonal temperature variations

Described fluctuations in numbers of individual zooplankton groups, apart from being due to some interrelations within each individual group, may also be caused by some of ecological factors. It is well known that, as an ecological factor, temperature affects reproduction limiting the timing of the occurrence and peaks of some species in a particular marine area. Therefore seasonal temperature variation in the study area is related to seasonal fluctuations in the numbers of each zooplankton group worked out (Figs. 28, 29, 30, 31; Table 3).

As to the hydrography of the study area in the 1960-1982 period, sea surface (10 m) te mperature ranged from 13.47°C in March to 23.01°C in August. In the bottom layer (75 m) the lowest monthly mean temperature (13.59°C) was also recorded in March and the highest in November (17.32°C) (Fig. 27) (BULJAN and ZO-RE-ARMANDA, 1966, 1979; ZORE-ARMANDA *et al.,* 1991).

It was observed that the numbers of Cladocera (Fig. 28a), Chaetognatha (Fig. 28b), Thaliacea (Fig. 28c) and Mollusca (Fig. 28d) significantly ($p<0.01$) increased with sea surface (10 m) temperature increase. On the contrary, a decrease in numbers of all the other groups was recorded with temperature increase, even though it was statistically significant ($p<0.05$) in only Appendicullaria and Polychaeta.

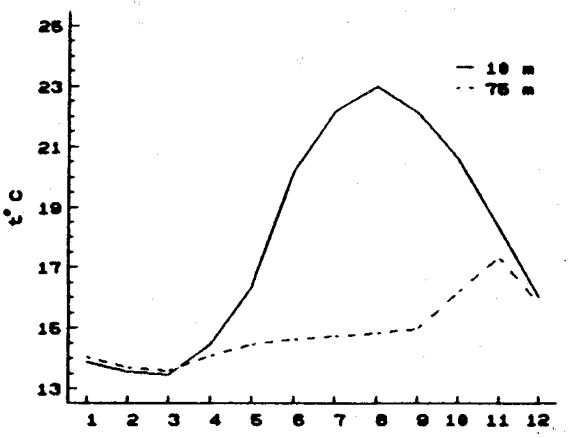


Fig.27. Seasonal sea water temperature variations at Stončica (monthly means for 1960-1982 after BULJAN and ZORE-ARMANDA, 1966, 1979; ZORE-ARMANDA *et al.,* 1988)

Similar relationship was obtained relating the numbers of individual groups to surface temperature of the preceding month. The correlation between temperature and Chaetognatha and Mollusca was statistically significant ($p<0.01$) (Fig. 29), and temperature was slightly less poorly correlated to Copepoda, Appendicularia, Medusae/Siphonophora and Decapoda numbers ($p<0.05$) /Table 3, r(1)/.

Table 3. Seasonal variations in zooplankton numbers as affected by sea water temperature (Stončica, monthly means 1960 - 1982; —— corr. coef. >95% or $p<0.05$, —— corr. coeff. >99% or $p< 0.01$; r (0) = coeff. of correlation between the data of the same month, r (1) = coeff. of correlation between zooplankton and temperature of the preceding month)

| | temperature | | | |
|---|---|---|---|---|
| | 10 m | | 75 m | |
| | r (0) | r (1) | r (0) | r (1) |
| Copepoda | –0.06 | –0.58 | –0.48 | –0.80 |
| Appendicularia | –0.60 | –0.72 | –0.74 | –0.55 |
| Cladocera | 0.84 | 0.54 | 0.03 | –0.10 |
| Medusae/Siphonophora | –0.24 | –0.61 | –0.32 | –0.70 |
| Chaetognatha | 0.83 | 0.96 | 0.70 | 0.57 |
| Thaliacea | 0.77 | 0.57 | 0.01 | –0.03 |
| Mollusca | 0.76 | 0.77 | 0.23 | 0.10 |
| Decapoda | –0.43 | –0.61 | –0.46 | –0.50 |
| Polychaeta | –0.58 | –0.18 | 0.23 | 0.49 |

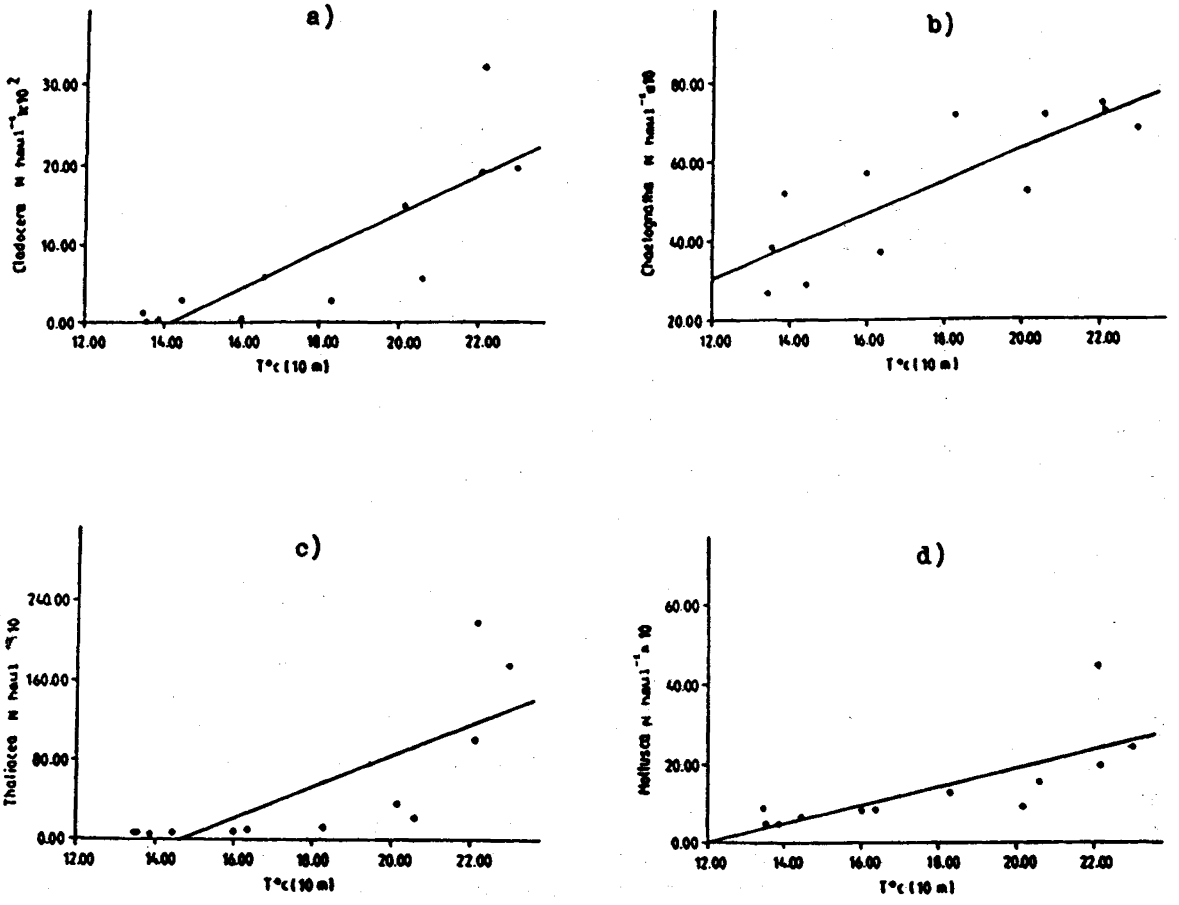


Fig.28. Regression lines for seasonal relationship between the numbers of a) Cladocera, b) Chaetognatha, c) Thaliacea, d) Mollusca and sea surface temperature in the some month (Stončica, monthly means 1960-1982)

Chaetognatha numbers increased with the bottom temperature increase ($p<0.05$) and Appendicularia numbers decreased ($p<0.01$; Fig. 30). No statistically significant correlation between bottom temperature and numbers of other groups was found (Table 3).

A comparison of the numbers of individual groups with bottom layer temperature in the preceding months showed statistically significant decrease in numbers with temperature increase only for Copepoda ($p<0.01$; Fig. 31) and Medusae/Siphonophora ($p<0.05$) /Table 3, r(1)/.

As found earlier from a shorter data series (1970-1974) Copepoda showed a very marked positive relationship to surface layer temperature (REGNER, 1982, 1985). The disagreement between those data and ours may be due to the fact that no comparison was made of the seasonal relationships between the numbers and temperature for each separate year but of the average of 23 years during which period maximum and minimum numbers occurred in quite different months.

Thaliacea and Cladocera showed a strong correlation with temperature increase in the sea surface layer and very poor (though positive) correlation with bottom temperature. Earlier studies also showed that the numbers of both Cladocera (FONDA-UMANI, 1980; BENDER, 1984) and Thaliacea (BRACONNOT, 1970, 1971) were affected by temperature increase.

It was shown earlier that the peak numbers of Polychaeta coincided with the lowest annual temperature (ZEI, 1956) which we found, as well.

Negative correlation with temperature was recorded for Appendicularia and positive for Mollusca in both sea water layers.

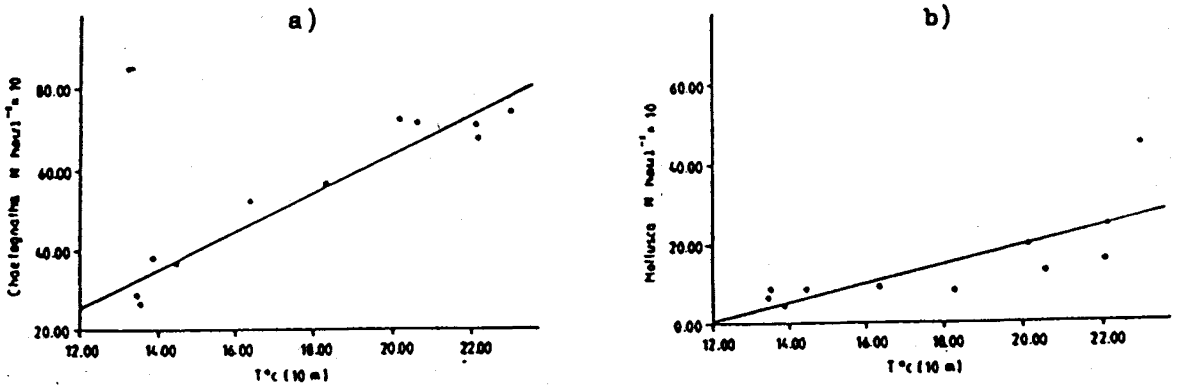


Fig.29. Regression lines for seasonal relationship between the numbers of
a) Chaetognatha,
b) Mollusca and sea surface temperature in the preceding month (Stončica, monthly means 1960-1982)

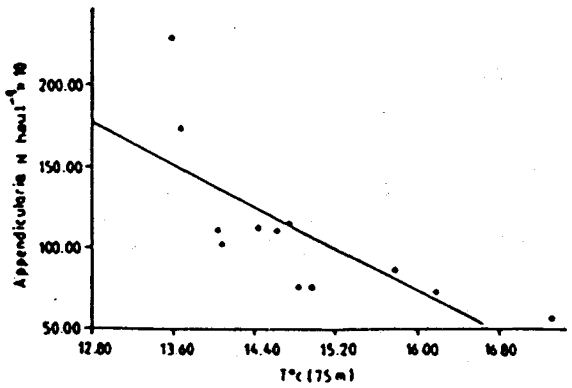


Fig.30. Regression lines for seasonal relationship between the numbers of Appendicularia and bottom layer temperature in the same month (Stončica, monthly means 1960-1982)

## Seasonal changes of zooplankton and their control by seasonal salinity variations

Seasonal salinity variations are not so marked as temperature variations at Stončica. However, it may be stated that salinity decreases in the surface layer between the beginning of the year and July ($Sx10^{-3}$ = 38.06), gradually increasing by September reaching annual peak ($Sx10^{-3}$ = 38.46). Bottom salinity varies much less with the maximum $Sx10^{-3}$ = 38.50 in March and minimum $Sx10^{-3}$ = 38.67 in September (Fig. 32) (BULJAN and ZORE-ARMANDA 1966, 1979; ZORE-ARMANDA *et al.*, 1991).

We found that the quantities of Chaetognatha, Mollusca and Polychaeta increased with

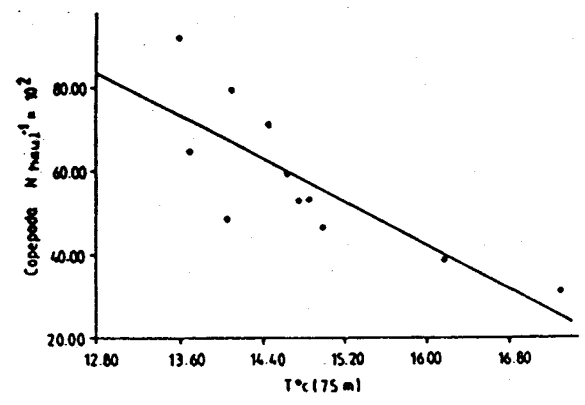


Fig.31. Regression lines for seasonal relationship between the numbers of Copepoda and bottom layer temperature in the preceding month (Stončica, monthly means 1960-1982)

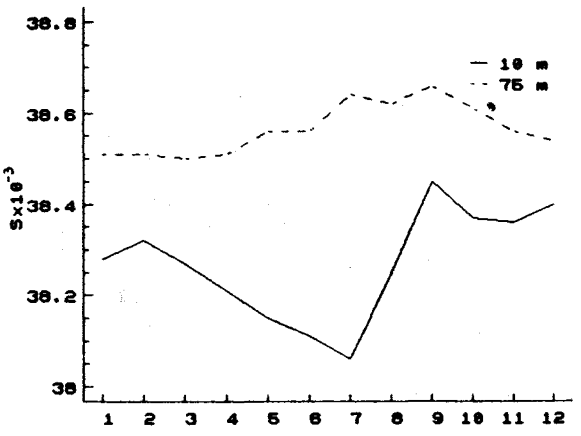


Fig.32. Seasonal sea water salinity variations at Stončica (monthly means for 1960-1982) after BULJAN and ZORE-ARMANDA, 1966, 1979; ZORE-ARMANDA *et al.*, 1988)

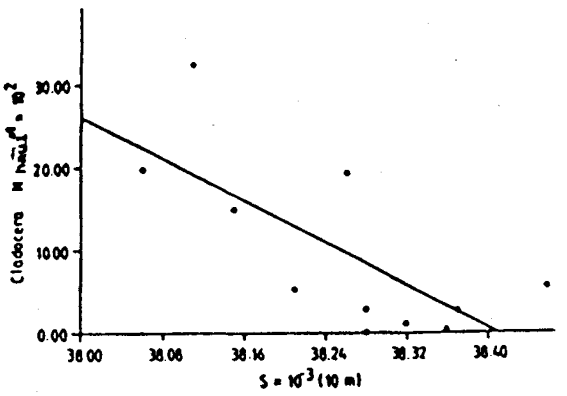


Fig.33. Regressiona lines for seasonal relationskip between the numbers of Cladocera and sea surface salinity in the some month (Stončica, monthly means 1960-1982)

surface salinity increase and quantities of all the other groups decreased (Table 4). It is important to point out that this relationship was significant only in Copepoda ($p<0.05$).

REGNER (1985) also found a negative, even though not significant, correlation between the Copepoda numbers and salinity.

The comparison of group quantities with the surface salinity in the preceding month showed positive relationship only for Polychaeta, and negative for all the other groups /Table 4, r(1)/. However, the correlation coefficient was significant only for Thaliacea ($p<0.05$) and Cladocera ($p<0.01$; Fig. 33). BENDER (1984) found no correlation between Cladocera and surface salinity.

Quantities of Cladocera (Fig. 34a), Chaetognatha (Fig. 34b), Thaliacea (Fig. 34c) and Mollusca (Fig. 34d) significantly increased ($p<0.01$) with the bottom salinity increase. Some species of Chaetognatha groups are well known as indicators of intermediate Mediterranean water (VUČETIĆ, 1961d, 1963a, 1969b, 1969c), richer in nutrients and of higher sa-

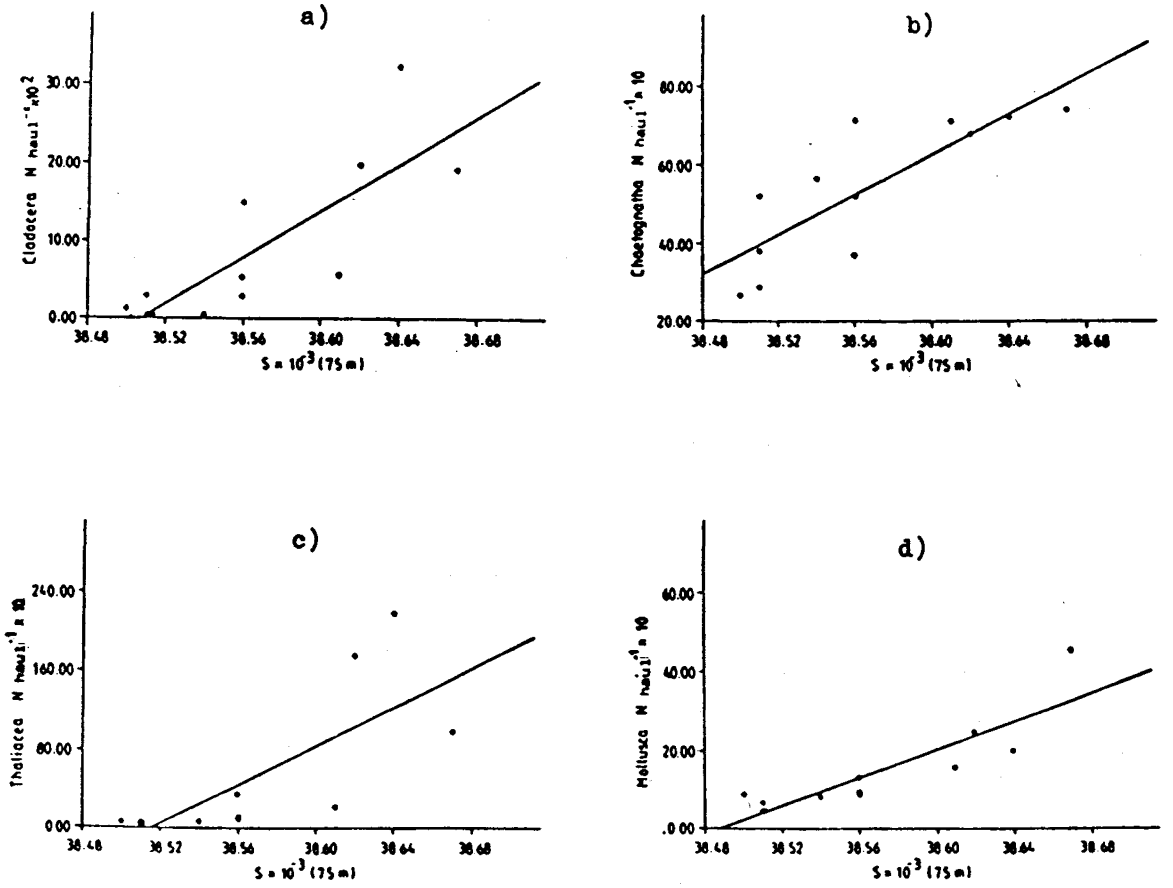


Fig.34. Regression lines for seasonal relationskip between the numbers of a) Cladocera, b) Chaetognatha, c) Thaliacea, d) Mollusca and bottom layer salinity in the same month (Stončica, monthly means 1960-1982)

Table 4. Seasonal variations of zooplankton numbers as affected by sea water salinity (Stončica, monthly means 1960-1982;—— corr. coef. >95% or p< 0.05, —— corr. coef. >99% or p<0.01; r (0) = coeff. or correlation between data for the same month, r(1) = coeff. of correlation between zooplankton and salinity of the preceding month

| | salinity | | | |
|---|---|---|---|---|
| | 10 m | | 75 m | |
| | r (0) | r (1) | r (0) | r (1) |
| Copepoda | –0.62 | –0.38 | –0.11 | –0.58 |
| Appendicularia | –0.24 | –0.03 | –0.57 | –0.69 |
| Cladocera | –0.42 | –0.77 | 0.81 | 0.34 |
| Medusae/Siphonophora | –0.50 | –0.03 | –0.31 | –0.55 |
| Chaetognatha | 0.27 | –0.06 | 0.84 | 0.89 |
| Thaliacea | –0.33 | –0.72 | 0.76 | 0.37 |
| Mollusca | 0.33 | –0.24 | 0.89 | 0.63 |
| Decapoda | –0.42 | –0.15 | –0.43 | –0.51 |
| Polychaeta | 0.36 | 0.51 | –0.59 | –0.16 |

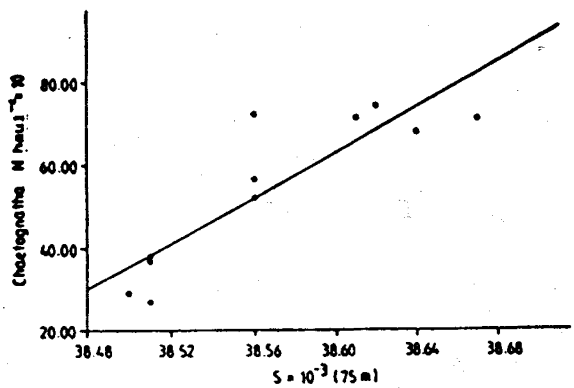


Fig.35. Regression lines for seasonal relationship between the numbers of Chaetognatha and bottom layer salinity in the preceding month (Stončica, monthly means 1960-1982)

linity. So the positive correlation between this group numbers and bottom salinity may be accounted for by this water type presence. A decrease in numbers with salinity increase was recorded for Copepoda, Appendicularia, Medusae/Siphonophora, Decapoda and Polychaeta. It was statistically significant ($p<0.05$) for only the last group.

Positive correlation between the group numbers and bottom salinity of the preceding month was found for Cladocera, Chaetognatha, Thaliacea and Mollusca, and negative one in all the other groups. The correlation was statistically significant in Chaetognatha ($p<0.01$; Fig. 35), Copepoda, Appendicularia and Mollusca ($p<0.05$) /Table 4, r(1)/.

## Seasonal changes of zooplankton and their control by seasonal phytoplankton density variations

It is presumed that very high phytoplankton production in a particular area will be followed by the occurrence of very high zooplankton concentrations, with a defined phase lag. It has frequntly been confirmed by some researches, even though quite a different situation could be recorded. So, high concentrations of zooplankton were sometimes recorded from the waters with low phytoplankton concentrations or very dense phytoplankton populations were followed by very little zooplankton (STEEMANN NIELSEN, 1937; RILEY and BUMPUS, 1946; TETT and EDWARDS, 1984).

The coincidence in time of phyto- and zooplankton fluctuations was not recorded from the middle Adriatic, either. It was observed that with great abundance of phytoplankton, zooplankton quantities were sometimes high and sometimes low (ERCEGOVIĆ, 1936; GAMULIN, 1939; HURE, 1955, 1961; VUČETIĆ, 1957, 1961c, 1965, 1970, 1971a, 1971b; PUCHER-PETKOVIĆ, 1966, 1969, 1970, 1971; PUCHER-PETKOVIĆ and VUČETIĆ, 1969; VUČETIĆ and PUCHER-PETKOVIĆ, 1969; KARLOVAC *et al.*, 1974).

The highest phytoplankton concentrations are recorded from this area in autumn-winter, from October to January, and considerable quantities occur also in May and August. Seasonal fluctuations of phytoplankton was compared to seasonal fluctuations of Copepoda, Appendicularia, Cladocera and Thaliacea (Fig. 36).

Maximum numbers of Appendicularia occur in the study area in February or March, those of Copepoda in April or May and those of Cladocera and Thaliacea in July, that is after phytoplankton maximum. At the time of winter phytoplankton maximum, minimum numbers

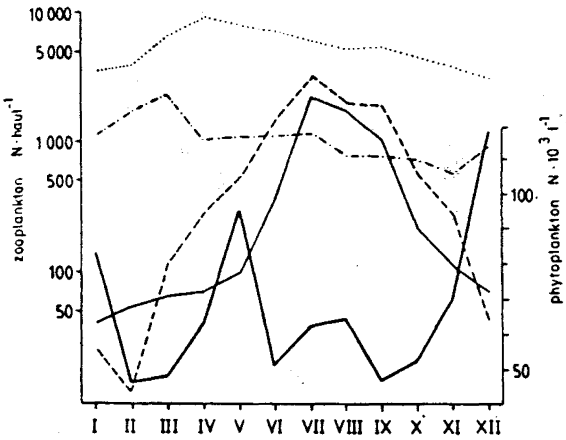


Fig.36. Stončica-seasonal fluctuations of phyto and zooplankton (herbivore) density (monthy means 1961-1981)
..... Copepoda
- - - - - Appendicularia
---------- Cladocera
——— Thaliacea
▬▬▬ phytoplankton

were recorded for all four zooplankton groups. The correlation between monthly mean numbers of those groups and phytoplankton density also showed that an increase in zooplankton numbers coincided with the phytoplankton density decrease (Table 5).

Table 5. Seasonal variations of herbivore zooplankton as affected by phytoplankton density (Stončica, monthly means 1961-1982; r(0) = coeff. or correlation between data for the same month, r(1) = coeff. of correlation between zooplankton and phytoplankton density of the preceding month.

| | phytoplankton | |
|---|---|---|
| | r (0) | r (1) |
| Copepoda | –0.30 | –0.09 |
| Appendicularia | –0.32 | 0.09 |
| Cladocera | –0.29 | 0.02 |
| Thaliacea | –0.21 | –0.11 |

During the growth, zooplankton gradually reduces the phytoplankton density by grazing which may result in an inverse relationship between them (HARVEY *et al.*, 1935; STEEMANN NIELSEN, 1937; CLARKE, 1939; RILEY and BUMPUS, 1946). In addition zooplankton organisms respond to changed feeding conditions not that fast as phytoplankton (generation time is longer in zooplankton than in phytoplankton). Therefore the correlation between zooplankton numbers and phytoplankton quantity in the preceding month was examined. Inverse and negative correlation was again found for Copepoda and Thaliacea /Table 5, r(1)/. However, rather poor but positive correlation was found for Appendicularia and Cladocera /Table 5, r(1)/. It was reported earlier that Appendicularia respond most readily to a production increase (VUČETIĆ, 1957; VUČETIĆ and PUCHER-PETKOVIĆ, 1969; PUCHER-PETKOVIĆ and VUČETIĆ, 1969) (Table 5).

It should be emphasized that neither the correlation between monthly mean numbers of zooplandton groups and phytoplandton density in the same month nor the correlation between the zooplankton numbers and phytoplankton density in the peceding month were statistically significant.

*Long-term variations of zooplankton quantities as affected by abiotic and biotic factor changes*

Long-term fluctuations of the structure and quantity of zooplankton obtained from annual mean values for the 1960-1982 period (Figs. 9-26) show three intervals with poorer increase in numbers for Copepoda, of which the poorest was the 1977-1981 one. In Appendicularia two periods with the density exceeding the average were recorded, 1965-1969 and 1973-1976, and a slightly poorer increase in 1980. Cladocera, Thaliacea and Mollusca showed a very marked density increase somewhere from the middle of the observed period. This, to a certain extent applies to Polychaeta and Medusae/Siphonophora even though the latter group was well represented at the beginning of the study period. Chaetognatha showed no marked departures from the mean. Decapoda decreased to a considerable extent in 1977 so that the mean for the 1960-1976 period was 61 specimens per haul, and in 1977-1982 did not exceed 23. This might be related to temperature decrease below the mean which occurred from 1973 on (Fig. 37).

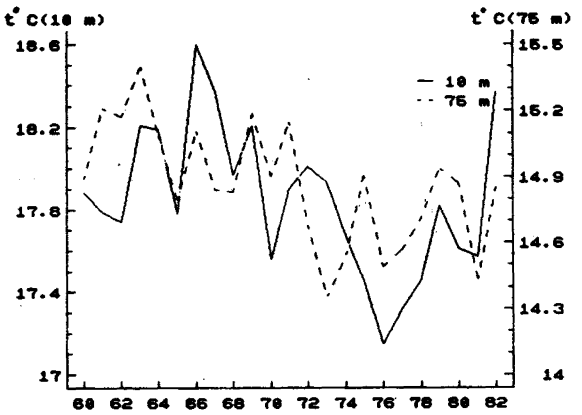


Fig.37. Long-term sea water temperature variations at Stončica (monthly means for 1960-1982; after BULJAN and ZORE-ARMANDA, 1966, 1979; ZORE-ARMANDA *et al.*, 1988)

The observations of zooplankton quantity variations by individual years showed that:

- 1971, quantity of almost all the groups suddenly and marlkedly decreased, with the exception of Decapoda and Polychaeta which show no changes.
- 1975, a pronounced increase in Mollusca, Polychaeta, Appendicularia, Thaliacea and Medusae/Siphonophora density was recorded.
- 1977, most of the groups shows very marked sudden density drop, Cladocera and Chaetognatha slightly increased in density, with the exception of Copepoda which showed no marked density variations.
- 1981 and 1982, density drop was pronounced in all studied groups.

Long-term density variations of individual zooplankton groups were attempted to be related to temperature, salinity and phytoplankton density changes.

## Impact of long-term temperature variations

Studies of the sea water temperature variations (1960-1982) showed a trend of slight decrease in both the surface and bottom layer (Fig. 37). The highest temperature of the surface layer (10 m) (18.74°C) was recorded in 1968 and the lowest (14. 35°C) in 1973. Bottom layer (75 m) highest temperature (15.40°C) was found in 1963 and lowest (14.35°C) in 1973 (BULJAN and ZORE-ARMANDA, 1966; 1979; ZORE-ARMANDA *et al.*, 1991).

Relating the numbers of zooplankton to temperature of the same month (Table 6) showed a significant ($p<0.01$) drop in numbers of Appendicularia (Fig. 38a) and Decapoda (Fig. 38c) whit temperature increase in both sea water layers.

Table 6. Long-term variations of zooplankton numbers as affected by sea water temperature (Stončica, monthly means 1960-1982; —— corr. coeff. > 95% or $p<0.05$, ——— corr. coeff. >99% or $p< 0.01$; r(0) = coeff. of correlation between data for the same month, r(1) = coeff. of correlation between zooplankton and temperature of the preceding month

| | temperature | | | |
|---|---|---|---|---|
| | 10 m | | 75 m | |
| | r (0) | r (1) | r (0) | r (1) |
| Copepoda | –0.03 | –0.29 | –0.29 | –0.45 |
| Appendicularia | –0.27 | –0.32 | –0.31 | –0.23 |
| Cladocera | 0.37 | 0.26 | –0.01 | –0.06 |
| Medusae/Siphonophora | 0.06 | –0.13 | 0.01 | –0.11 |
| Chaetognatha | 0.32 | 0.39 | 0.25 | 0.19 |
| Thaliacea | 0.18 | 0.13 | –0.01 | –0.02 |
| Mollusca | 0.24 | 0.22 | 0.07 | 0.01 |
| Decapoda | –0.16 | –0.24 | –0.13 | –0.12 |
| Polychaeta | –0.27 | –0.12 | 0.14 | 0.30 |

Cladocera, Thaliacea and Mollusca showed statistically significant ($p<0.01$) increase in numbers with temperature increase in the surface layer but not with the temperature increase in the bottom layer. Only Chaetognatha showed significant quantity increase ($p<0.01$) with temperature increase in both the surface and bottom layers. Polychaeta numbers astatistically significantly decreased with surface temeprature increase ($p<0.01$) as well as significantly increased in number with battom temperature increase ($p< 0.01$). The numbers of Copepoda significantly ($p<0.01$) dropped with bottom temperature increase (Fig. 40).

Medusae/Siphonophora showed no significant dependence on the sea water temperature variations.

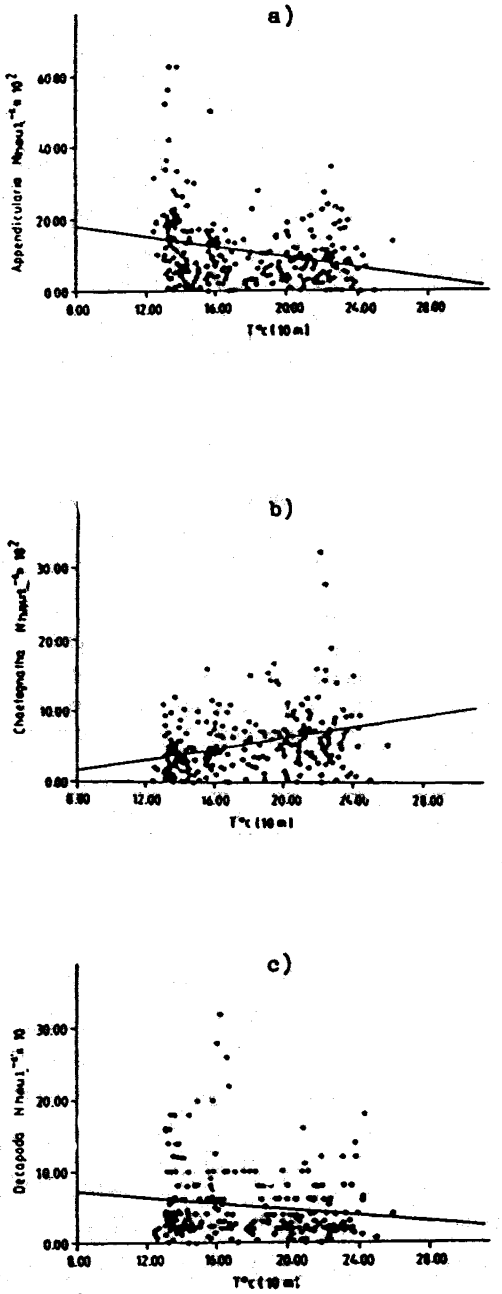


Fig.38. Regression lines for long-term relationship between the numbers of a) Appendicularia, b) Chaetognatha, c) Decapoda and sea surface temperature in the same month (Stončica, 276 monthly data, 1960-1982)

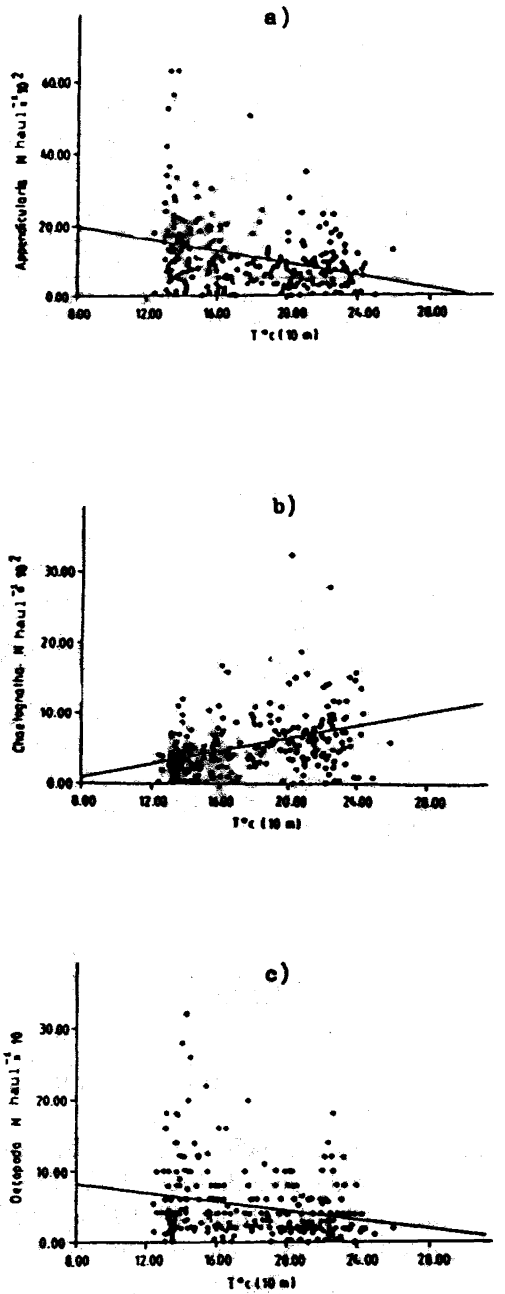


Fig.39 Regrassion lines for long-term relationship between the numbers of a) Appendicularia, b) Chaetognatha, c) Decapoda and sea surface temperature in the preceding month (Stončica, 276 monthly data, 1960-1982)

Relating the numbers of zooplankton to temperature of the preceding month gave no different results, with the exception of Copepoda the numbers of which significantly ($p<0.01$) decreased with surface temperature increase (Figs. 39, 41; Table 6, r/1/).

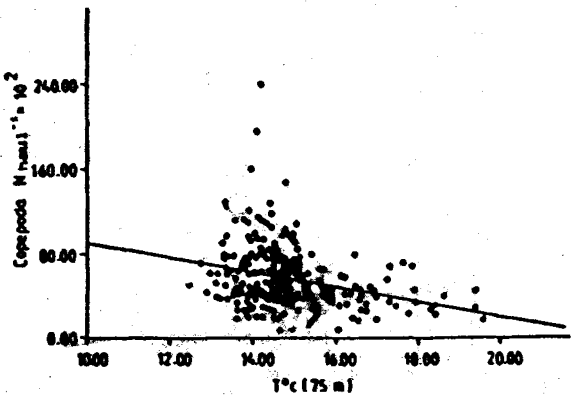


Fig.40 Regression lines for long-term relationship between the numbers of Copepoda and bottom layer temperature in the some month (Stončica, 276 monthly data, 1960-1982)

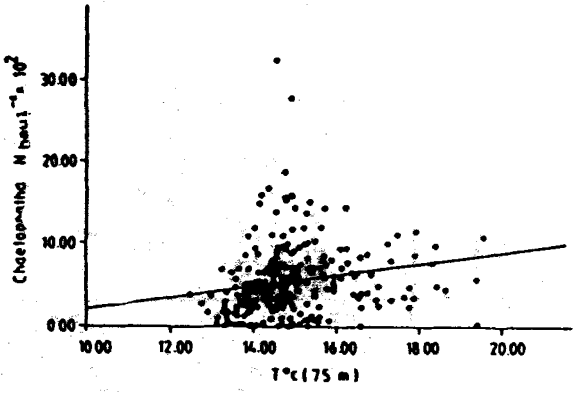


Fig.41 Regression lines for long-term relationship between the numbers of Chaetognatha and bottom layer temperature in the preceding month (Stončica, 276 monthly data, 1960-1982)

## Impact of long-term salinty variations

Salinity oscillations were rather great during the study period, 1960-1982. The highest surface (10 m) salinity ($Sx10^{-3}$ = 38.59) was recorded in 1981, and the lowest ($Sx10^{-3}$ = 37.93) in 1960. The highest bottom (75 m) salinity ($Sx10^{-3}$ = 38.78) occurred in 1968 and 1969 and the lowest ($Sx10^{-3}$ = 38.29 in 1960 (Fig. 42) (BULJAN and ZORE-ARMANDA, 1966, 1979: ZORE-ARMANDA *et al.*, 1991). So the annual mean salinity values in both the surface and bottom layer were lower at the beginning (1960-1961) of the study period than during the remainder of it.

Most of the groups decreased in numbers with salinity increase (Table 7), but in a small number of cases this decrease was statistically significant.

Cladocera showed the strongest correlation to salinity; the correlation was positive and statistically significant with the salinity of the bottom layer of both the same and the preceeding month and slightly poorer ($p<0.05$) and inverse correlation between their numbers and surface salinity of the same month. Some earlier scien-

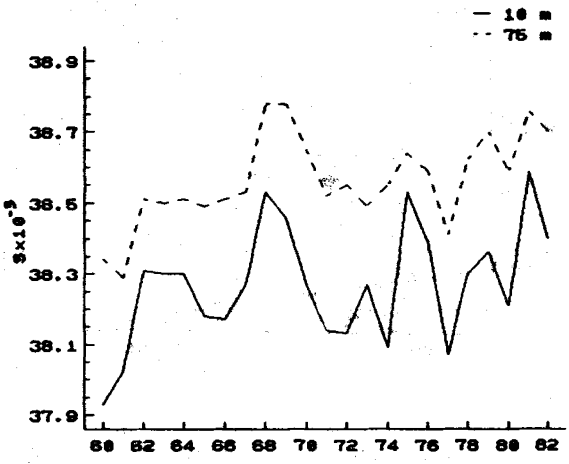


Fig.42 Long-term salinity variations at Stončica (monthly means; after BULJAN and ZORE-ARMANDA, 1966, 1979; ZORE-ARMANDA *et al.*, 1988)

Table 7. Long-term variations of zooplankton numbers as affected by sea water salinity (Stončica, monthly means 1960-1982; —— corr. coeff. > 95% or $p<0.05$, —— corr. coeff. >99% or $p< 0.01$; r(0) = coeff. of correlation between data for the same month, r(1) = coeff. of correlation between zooplankton and temperature of the preceding month

| | salinity | | | |
|---|---|---|---|---|
| | 10 m | | 75 m | |
| | r (0) | r (1) | r (0) | r (1) |
| Copepoda | –0.06 | –0.06 | 0.07 | –0.03 |
| Appendicularia | –0.09 | 0.02 | –0.05 | –0.04 |
| Cladocera | –0.12 | –0.11 | 0.21 | 0.16 |
| Medusae/Siphonophora | 0.00 | 0.07 | –0.02 | –0.07 |
| Chaetognatha | –0.04 | –0.13 | 0.03 | 0.10 |
| Thaliacea | –0.05 | –0.21 | 0.10 | 0.08 |
| Mollusca | 0.05 | –0.03 | 0.13 | 0.12 |
| Decapoda | –0.08 | –0.01 | –0.13 | –0.10 |
| Polychaeta | 0.05 | 0.07 | –0.11 | –0.01 |

tists reported Cladocera found in the Adriatic to be markedly euryhaline (FONDA-UMANI, 1980; BENDER, 1984). Presumably, the relationship between this group and salinity is due to the nutrient levels or phytoplandton quantity.

Mollusca significantly increased in number with salinity increase of the bottom layer ($p<0.05$). It is rather interesting that seasonal correlation between Chaetognatha and bottom salinity increase was very significant and positive. However, their long-term relationship showed a negative and somewhat poorer correlation with only the surface layer salinity of the preceding month (Table 7, r/1/). Similar applies to the Thaliacea group. Seasonal relation of Decapoda was reported not to affected by salinity, but the long-term observations proved them to decrease significantly ($p<0.05$) with only bottom salinity increase in the same month.

Presumably, the correlation between zooplankton and temperature and salinity variations could have been better accounted for if the variations in water mass dynamics had been taken into account.

## Impact of long-term variations in phytoplankton density

The observations of annual mean values for the 1961-1981 period showed that the fluctuations in the number of some herbivore zooplankton group follow the density fluctuations of some phytoplankton populations. This and particularly the fact that long-term fluctuations in zooplankton biomass were of the same order of magnitude as the changes in primaty production, was reported for the middle Adriatic earlier (VUČETIĆ, 1961c, 1965, 1969a, 1970, 1971 a, 1971b; PUCHER-PETKOVIĆ, 1969; PUCHER-PETKOVIĆ and VUČETIĆ, 1969; KARLOVAC *et al.*, 1974).

Our results show that the trend of increase in numbers of Thaliacea and Cladocera coincided broadly with the increase in phytoplankton density throughout the period of our study, as distinct from Appendicularia for which this could not be establishhed in this way (Figs. 43, 44). As to the Thaliacea an annual shift or lagging behind the changes in phytoplankton density.

A comparison of annual mean values showed no coincidence between the variations in Copepoda numbers and variations in phytoplankton density. However, a rather poor trend of increase in Copepoda numbers was recorded during an intensive phtyplankton increase (Fig. 43).

Calculations of correlation between phyto and zooplankton from their individual monthly values for all the study period, gave positive correlation between the numbers of Copepoda, Cladocera and Thaliacea and phytoplankton density both for the same and for the preceding month. Statistically significant correlation was obtained only for Cladocera (Table 8). Appendicularia were positively correlated with the increase in phytoplankton density in the preceding month and negatively with the increase in phytoplankton density in the same month. This corelation however, was not statistically significant.

Table 8. Long-term variations of zooplankton numbers as affected by phytoplankton density (Stončica, monthly means 1960-1982;—— corr. coeff. > 95% or $p<0.05$, —— corr. coeff. >99% or $p< 0.01$; r(0) = coeff. of correlation between data for the same month, r(1) = coeff. of correlation between zooplankton and temperature of the preceding month

| | phytoplankton | |
|---|---|---|
| | r (0) | r (1) |
| Copepoda | 0.09 | 0.04 |
| Appendicularia | –0.10 | 0.04 |
| Cladocera | 0.17 | 0.22 |
| Thaliacea | 0.06 | 0.05 |

These correlations, calculated from individual monthly values for the entire period, presumably gave no actual image, since date were not filtered to eliminate seasonal differences. When annual mean values were grouped analyzed parameters showed better pronounced relations.

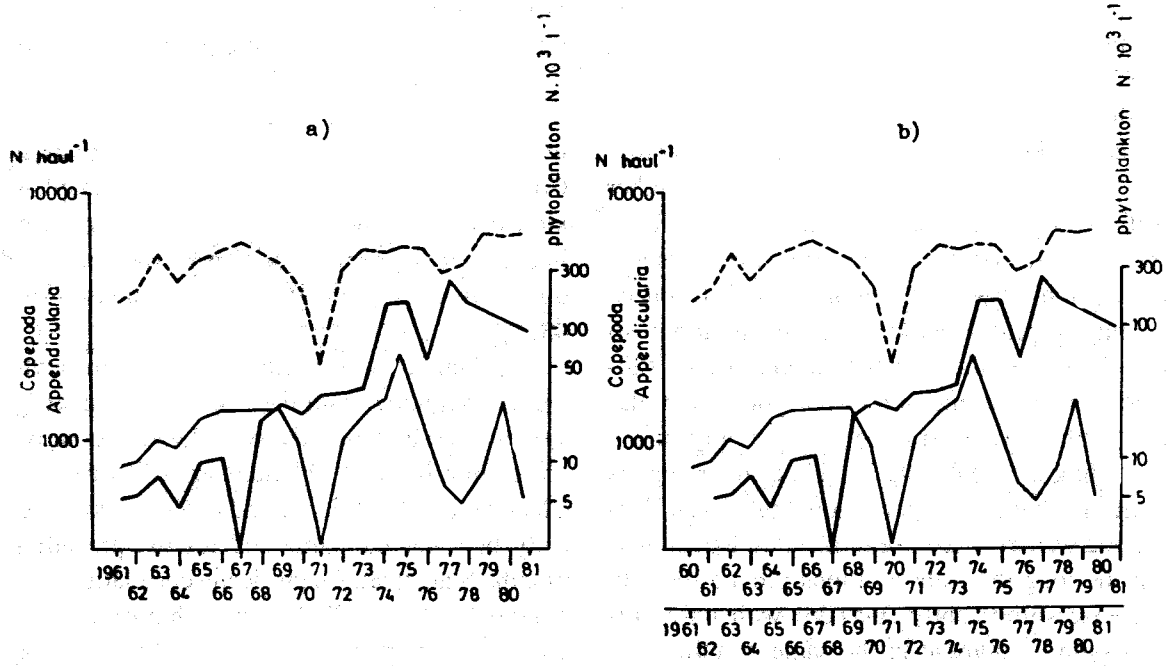


Fig.43 Stončica -long-term fluctuations of Copepoda and Appendicularia density in relation to phytoplankton fluctuations (a) in the same year, (b) in the preceding year (Stončica, annual means, semilogarithmic scale)

- - - - - - Copepoda

——— Appendicularia

——— phytoplankton

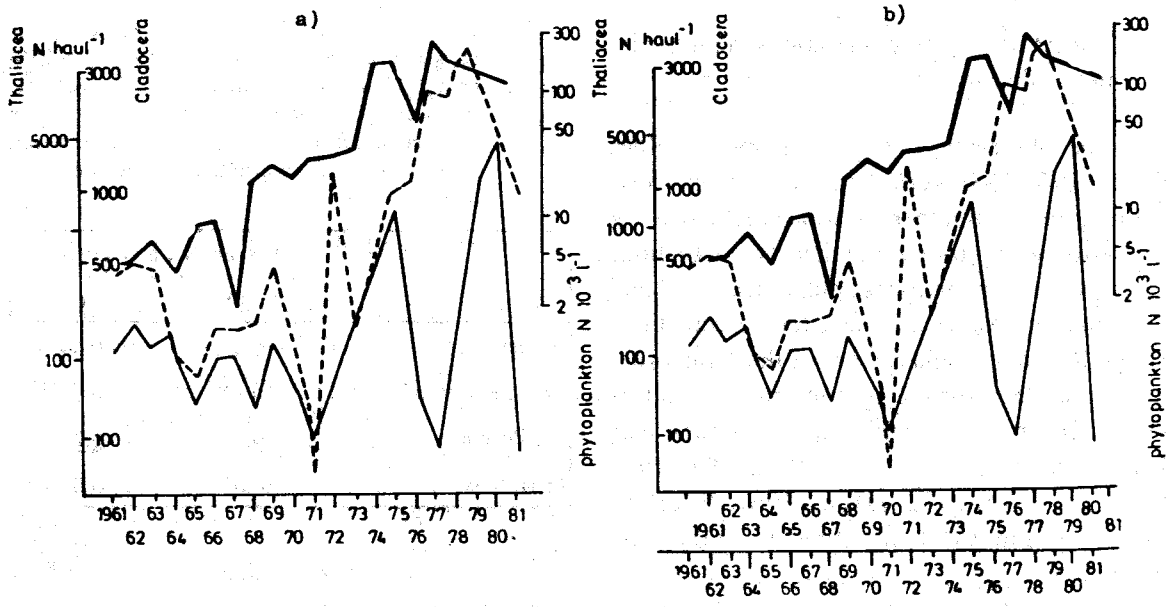


Fig.44 Stončica - long-term fluctuations of Cladocera and Thaliacea density in relation to phytoplankton fluctuations (a) in the same year, (b) in the preceding year (Stončica, annual means) semilogarithmic scale.

---------- Cladocera

——— Thaliacea

——— phytoplankton

Cladocera

Thaliacea

phytoplankton

## CONCLUSIONS

Long-term (1960-1982) study of fluctuations in zooplankton density at Stočnica station showed the following:

1. Zooplankton was dominated by the following groups and in the following succession: Copepoda with 59.3% (9.11-92), Appendicularia with 11.7% (0.07-42.9%), Cladocera with 9.3% (0-61.2%), Medusae/Siphonophora with 6.5% (0.1-29.6%), Chaetognatha with 5.7% (0.1-24.2%), Thaliacea with 5.3% (0-63.9%), Mollusca with 1.5% (0-17.3%), Decapoda with 0.5% (0.-2.5%) and Polychaeta with 0.1% (0-1.1%). In the 1977-1982 period the share of the groups Appendicularia, Medusae/Siphonophora and Chaetognatha was considerably reduced with respect to the preceding years, whereas the share of Cladocera increased. A decrease in the proportion of Copepoda group in the total zooplankton occurred in the years 1975, 1979 and 1980 coinciding in time with a marked increase in the share of Thaliacea group.

2. Seasonal observations of density fluctuations confirmed earlier reported regular patterns that the highest number of Copepoda, Medusae/Siphonophora and Decapoda occurred in spring, Cladocera, Thaliacea and Mollusca in summer, Chaetognatha in autumn and Polychaeta in winter. Only Appendicularia showed some difference with maximum in spring and not in autumn as found by some earlier (a single year) study in the same area (SKARAMUCA, 1982a, 1982b, 1983). Most of the groups showed the smalest number in winter with the exception of Chaetognatha which peaked in spring and Polychaeta in summer.

2a. Seasonal fluctuations of zooplankton density as affected by sea water temperature variations showed a mareked increase in the numbers of Cladocera, Chaetognatha, Thaliacea and Mollusca. At the same time the quantities of Appendicularia and Polychaeta were statistically significantly dicreased. An increase in bottom layer temperature was accompanied by a marked increase in only the Chaetognatha numbers and by a pronounced decrease in only the Appendicularia.

Relating the zooplankton values to the temperature of the preceding month, Chaetognatha and Mollusca markedly increased in numbers and Appendicularia and Decapoda de-creased with the increase of surface layer temperature. In addition, Copepoda and Medusae/Siphonophora numbers decreased with temperature increase in both sea water layers.

2b. The study of seasonal relationship between zooplankton numbers and surface salinity was significantly inversely proportional in only Copepoda group.

Variations in the number of zooplankton group was more significantly related to bottom salinity, since significant increase in numbers was recorded for Cladocera, Thaliacea, Chaetognatha and Mollusca, and significant decrease in Polychaeta.

Comparing these numbers to the surface salintity in the preceding month, a significant decrease in the numbers of Cladocera and Thaliacea was obtained. The increase of Chaetognatha and Mollusca along with the drop of Copepoda and Appendicularia were significantly related to the bottom salinity increase.

2c. Maximum numbers of prevalently herbivore zooplankton groups occured after seasonal maximum of phytoplankton with a defined phase lag which is lowest in Appendicularia, slightly higher in Copepoda and the highest in Cladocera and Thaliacea.

3. The observations of long-term variations (from annual means) in the 1960-1982 period showed a rather poor trend of increase in Copepoda. The number of Appendicularia, Decapoda and Polychaeta showed an increase trend for the first half of this period and a decrease trend for the second half. Marked density increase tendency was found for Cladocera and Thaliacea from the middle of the period on and for Mollusca at the end of this period. The Medusae/Siphonophora group showed a quantity drop about the middle and quantity increase at the end of the period. Chaetognatha showed no greater quantity variations.

A pronounced density increase of most of the studied groups was recorded only in the 1957 and slightly more pronounced drops in 1971, 1977, 1981 and 1982.

3a. The analyses of long-term fluctuations in the numbers of the groups as affected by the

sea water temperature variations (using all the monthly values for the entire study period) showed the number of Chaetognatha to increase significantly with the increase of both surface and bottom temperature whereas it significantly dropped in Appendicularia and Decapoda. Thaliacea, Cladocera and Mollusca responded by an increase in number to the surface temperature increase. The Polychaeta numbers decreased with the surface temperature increase and increased with the bottom temperature increase, whereas Copepopda decreased in numbers with the bottom temperature increase.

Relating the numbers of individual groups to temperature variations in the preceding month gave no defferent results, with the exception of Copepoda and Medusae/Siphonophora decrease with surface temperature increase.

3b. The decrease in numbers was recorded in most of the groups to follow the surface salinity increase, but this decrease was significant only in Cladocera. Salinity increase in the bottom layer was accompanied by a statistically significant increase in the Cladocera and Mollusca and decrease in Decapoda numbers. Relating these numbers to the salinity of the preceding month, they significantly decreased in Chaetognatha and Thaliacea with surface salinity increase and significantly increased in Cladocera and Mollusca with bottom salinity increase.

3c. Long-term variations in the numbers of herbivore zooplankton group as affected by phytoplankton density were studid from annual means. It was found that Cladocera and Thaliacea numbers significantly increased. Thaliacea also showed better overlapping and a defined year lag (Fig. 44b). Copepoda showed no marked coincidence with the phytoplankton density variations even though their numbers slightly increased, whereas Thaliacea showed no increase at all.

Positive correlations between Copepoda, Cladocera and Thaliacea density and phytoplankton density both for the same and for the preceding month were obtained from individual monthly measurements throughout the study period. The correlation was positive between the numbers of Appendicularia and phytoplankton density in the preceding month and negative between these values for the same month. This correlation was statistically significant only in Cladocera.

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# Fluktuacije zooplanktona u periodu 1960-1982. u području otvorenog srednjeg Jadrana

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## KRATKI SADRŽAJ

Zooplanktonski uzorci obrađeni u ovom radu dio su materijala sakupljenog tijekom dugoročnih istraživanja na profilu Split-Gargano. Korišten je materijal iz razdoblja 1960-1982, uziman na postaji Stončica u otvorenom srednjem Jadranu, a obrađene su skupine Copepoda, Appendicularia, Cladocera, Medusae/Siphonophora, Chaetognatha, Thaliacea, Mollusca, Decapoda i Polychaeta.