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LONG - TERM INVESTIGATIONS OF COPEPODS (ZOOPLANKTON) IN THE COASTAL WATERS OF THE EASTERN MIDDLE ADRIATIC

VIŠEGODIŠNJA ISTRAŽIVANJA KOPEPODA (ZOOPLANKTON) U PRIOBALNIM VODAMA ISTOČNOG SREDNJEG JADRANA

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Copepods, the dominant group of net zooplankton organisms, were studied in the areas exposed to the pollution of agricultural, domestic and industrial effluents in the 1976-1988 period.

Relatively small depth at studied stations and the strong impact of human activities have caused some changes of the environment reflected upon composition, density and seasonal oscillations of copepod biomass. All these changes can be clearly related to progressive eutrophication of the eastern Adriatic coastal waters and increasing phytoplankton density.

INTRODUCTION

This review-paper describes some long-term results on copepods, the best represented group of net zooplankton.

As copepods respond quickly (R e g n e r , D., 1986, 1987, 1988a, 1988b, 1991) - both by composition and biomass to the changes of the environment they inhabit, they were studied in detail along eastern Adriatic coast in areas exposed to the strong impact of the land. Besides, some results from the open sea of the middle Adriatic were taken for comparison.

MATERIAL AND METHODS

Zooplankton samples were collected monthly or seasonally in front of Zadar, Šibenik, Split, Ploče and Dubrovnik (Gruž) harbours, in the Kaštela Bay and Vela Luka Bay. In the open sea the material was collected near Jabuka Pit and at station between Sušac and Palagruža islands.

Samples were taken by vertical hauls of "Hensen" plankton net (73/100, silk N°3) from bottom to surface.

STUDY AREA

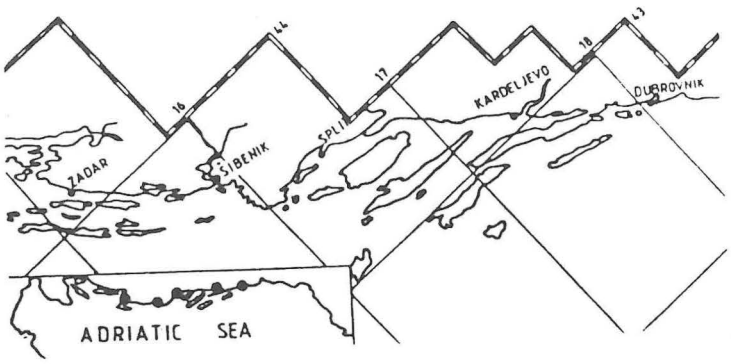

Fig. 1. Study area

Small depth of the coastal stations (Fig. 1) in front of the most important harbours in the middle Adriatic (which does not exceed 35 m), and the strong impact of the land, caused very high oscillations of all hydrographic factors throughout the year, according to the results of Stojanoski, Vukadin and Zvonarić (in Krstulović *et al.*, 1984). So, temperature varies from 14.04°C to 25.26°C with thermocline between 0 and 10 meters in July, and somewhat deeper in August.

Salinity varies between 21.12 ppt and 39.18 ppt, and the lowest values in front of Šibenik and Ploče show the fresh water impact at these two stations. In 1986 and 1987, salinity slightly increased in front of Zadar and Šibenik (Stojanoski, Vukadin and Zvonarić in Dujmov *et al.* 1988) (Fig. 2). Due to strong impact of the river Krka, sea water transparency is smallest at Šibenik station (Morović in Krstulović *et al.* 1984). In addition, coastal values are even seven times

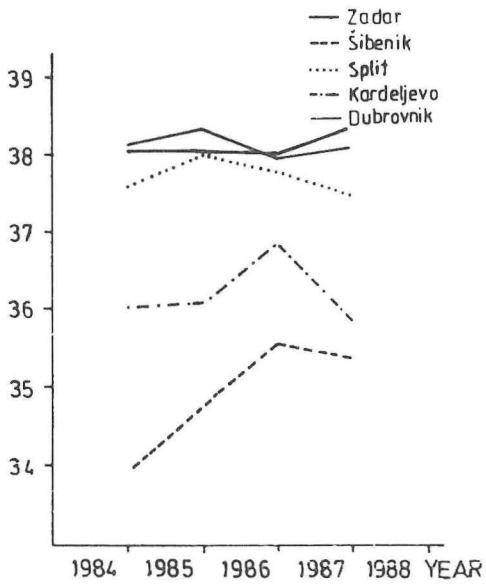

Fig. 2. Salinity of the sea (summer 1984 - summer 1987)

lower in comparison with those in the open sea. In 1986 and 1987 sea-water transparency decreased with the exception at the station in front of Zadar (M o r o v i ć , in D u j m o v *et al.*, 1988) (Fig. 3).

Furthermore, nitrate and phosphate levels have slightly increased at all investigated stations (S t o j a n o s k i , V u k a d i n and Z v o n a r i ć in D u j m o v *et al.*, 1988) (Fig 4) for the last three years.

In Kaštela Bay - Fig. 5 (which is exposed to the impact of the industrial wastes, agricultural wastes, food processing industry, shipyard, etc.), basic hydrographic parameters are very variable, too. Surface temperature ranges from 9.5 to 26°C, salinity from 34.74 to 38.27 ppt, and sea-water density from 24.72 to 28.48. Transparency of the sea has been reduced for the last ten years under the strong land effects (M o r o v i ć and D o m i j a n , 1991).

Vela Luka Bay (Fig. 6) is under the strong impact of human activities from the coast,as well, with the prevailing organic pollution in the eastern (shallower) part of the bay. Nevertheless, the outer part of the bay is under stronger influence of the open sea of the middle Adriatic (S t o j a n o s k i in D a d i ć *et al.*, 1991).

The Jabuka Pit and Palagruža are situated in the open waters of the middle Adriatic. High salinity (up to 38.99 ppt), high oxygen content (with 5-6 cm^3 /dm^3 mean values)

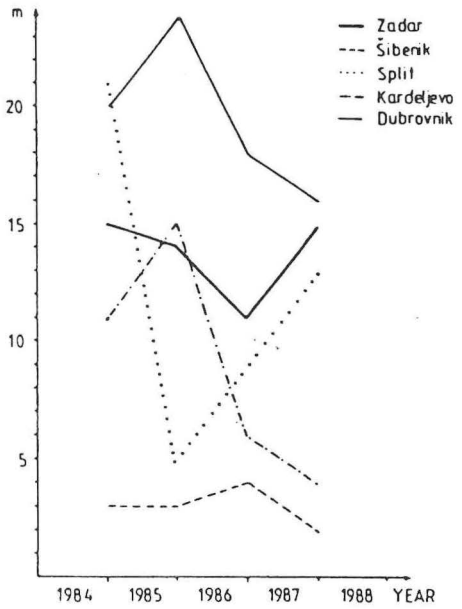

Fig. 3. Sea water transparency (July 1984 - July 1987)

and low nutrients (up to 0.063 mmol/m^3 PO_4 -P; 1.17 mmol/m^3 NO_3 - N) are the most important properties of this area (Fig. 7), as well as pretty high transparency (to 40-45 m) in comparison to the coastal sea.

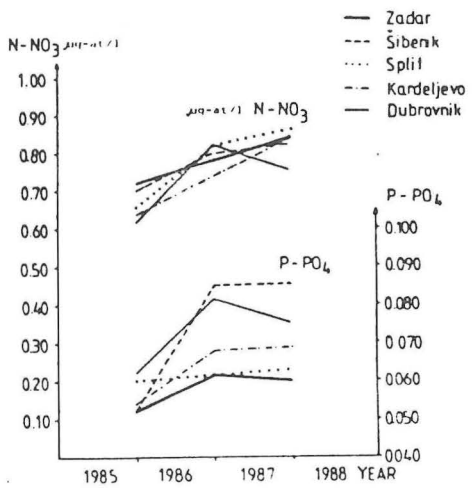

Fig. 4. Nitrate and phosphate levels (summer 1985 - summer 1987)

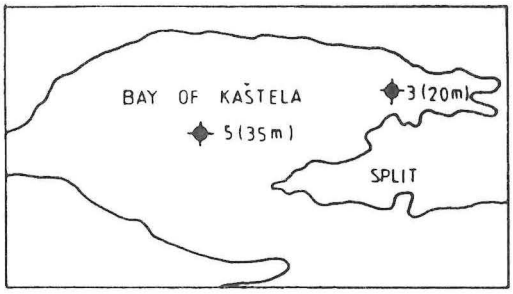

Fig. 5. The Bay of Kaštela

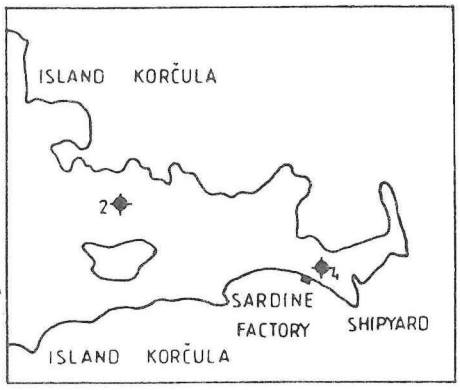

Fig. 6. The Vela Luka Bay

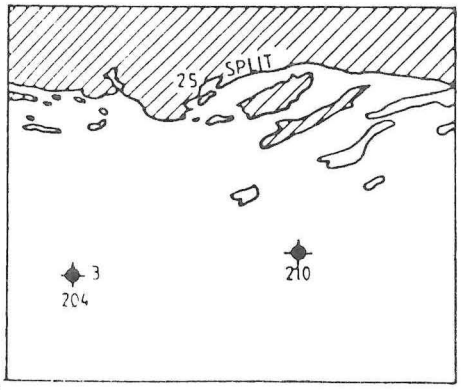

Fig. 7. The open waters of the middle Adriatic

RESULTS AND DISCUSSION

More than 60 copepod species were found during long-term investigations of copepods in front of the most important harbours in the middle Adriatic (R e g n e r , D. 1987, 1991). Species composition was similar at all studied stations, with prevalence of neritic copepods such as *Acartia clausi*, *Centropages typicus*, *Centropages kroyeri*, *Temora stylifera*, *Paracalanus parvus* and *Ctenocalanus vanus*. The periodical appearance of pelagic copepods: *Neocalanus gracilis*, *Eucalanus elongatus*, *Clausocalanus parapergens*, *Clausocalanus pergens*, *Lucicutia flavicornis*, *Euterpina*

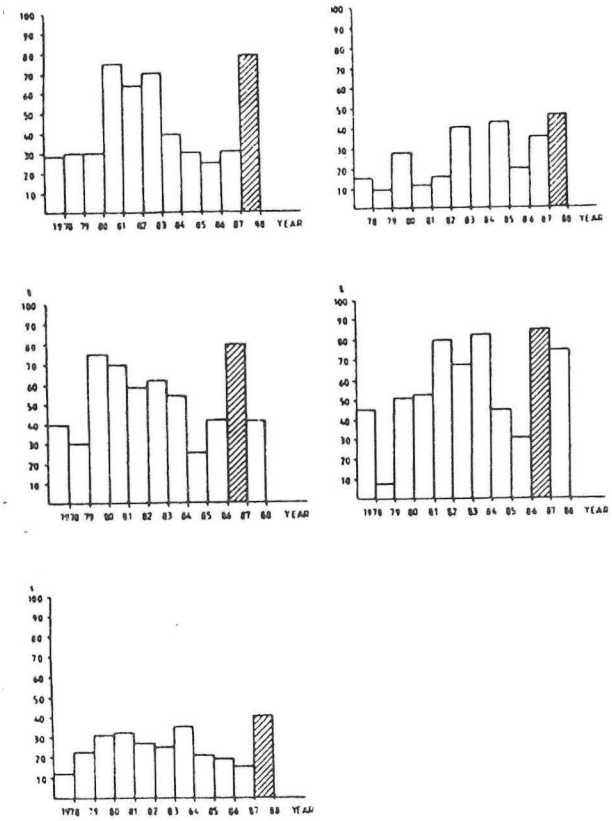

Fig. 8. The maximum percentage of *Acartia clausi* (July 1978 - July 1988)

acutifrons, Clytemnestra rostrata etc. is caused by periodical incoming of water masses from the open sea -particularly strong in winter (Z o r e - A r m a n d a *et al.*, 1974).

The smallest number of species was found in summer, during the prevailing W direction of the surface current which moves the surface water towards the open sea.

Among all these species, *Acartia clausi* was markedly dominant throughout the 15-year period. Maximum percentage of this species amounts to more than 85 % of the total copepods. In long-term period it even showed an increase trend in 1987 and 1988 (R e g n e r , D., 1991) (Fig. 8). This phenomenon is in agreement with permanent increasing of phytoplankton density along the eastern coastal Adriatic (P u c h e r - P e t k o v i ć , in press).

Simultaneously, the density of copepods (biomass expressed as the number of specimens/m^3) showed the trend of increase, too, with the highest values for the past years (Fig. 9).

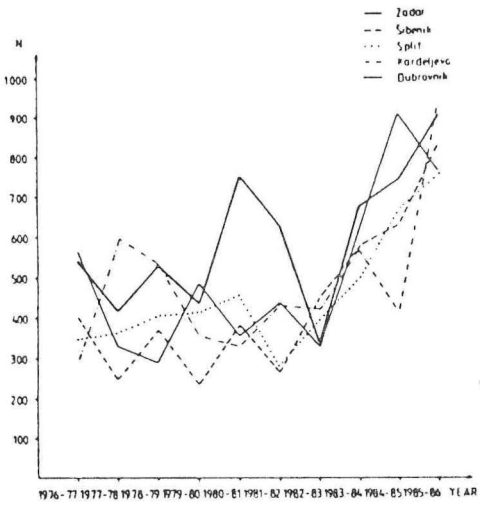

Fig. 9. The copepod density (annual mean values) in the 1976 - 1986 period

Such changes in the ratio between copepod species, with markedly increased percentage of *Acartia clausi*, as an increase in density, we can clearly connect with the progressive eutrophication of the eastern Adriatic coastal waters and higher phytoplankton density.

In the Vela Luka bay, about 35 copepods species were found. Maximum number of species was recorded from the entrance to the bay, exposed to the strongest impact of the open sea. Nevertheless, the species composition is pretty diverse in the inner part of the bay, with some pelagic species, besides these of neritic origin. So, the presence

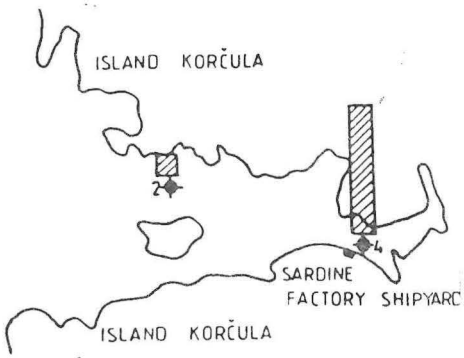

Fig. 10. The biomass of copepods ($N°/m^2$) in Vela Luka Bay

of copepods: *Lucicutia ovalis*, *Lucicutia flavicornis*, *Mecynocera clausi*, *Euchaeta hebes*, *Heterorhabdus pappiliger* and some other predominantly pelagic species showed the mixing of coastal and pelagic influences in the entire study area. Dominant copepods were: *Acartia clausi* - making up to 93% in July, *Centropages kroyeri* (up to 50% in autumn), *Temora stylifera*, *Labidocera wollastoni* etc. Besides the high percentage of

A. clausi in summer, the eutrophication effects of human activities are felt in the inner part through an unexpectedly high biomass for such shallow stations (Fig. 10). This phenomenon is obvious at station 4 (15 m depth) particularly in summer.

Similar results were found in the Kaštela Bay after red-tide events have become rather frequent. So, the percentage of *Acartia clausi* increased from ten percent in the eastern part of the bay to almost twice that value in the middle of the bay - in three year period only (Table 1).

Table 1. Percentage of *Acartia clausi* in the Kaštela Bay

	Station 3	Station 5
July 1982-1985	60 %	35 %
July 1988	70 %	65 %

In the long-term period the biomass of copepods expressed as density, showed the trends of increase from 1970 to 1988 (Table 2).

Table 2. The biomass of copepods (number/m^3) at station 5

July 1970-74	188
July 1982-83	350
July 1988	484

All these results can be clearly connected with the progressive eutrophication of the eastern Adriatic coastal waters, and the increasing phytoplankton density, especially in summer.

At stations Jabuka and Palagruža (open waters of the middle Adriatic) about 50 copepod species were found (R e g n e r , D., in Z o r e - A r m a n d a *et al.*, 1988). Even though this number is smaller than expected, we can explain it with seasonal sampling of zooplankton material in 1986 and 1987. Among present copepods, *Ctenocalanus vanus*, the most wide-spread Adriatic species, dominated with about 11%. In addition, *Acartia clausi* was present with 6%, *Clausocalanu jobei* with 4.6%, *Centropages typicus* with 4.4%, etc. From time to time only a few specimens of: *Clausocalanus mastigophorus, Calocalanus plumulosus, Clausocalanus parapergens, Haloptilus longicornis, Lucicutia flavicornis, Macrosettela gracilis, Scolecithucella*

dentata, Corycaeus flaccus and some other predominantly pelagic species occurred as a consequence of the dynamics of water masses and mixing of coastal and open-sea waters at studied stations.

The number of copepods per m^3 is pretty low - about $112/m^3$ - what is quite usual for open waters of the middle Adriatic (R e g n e r , D., in Z o r e - A r m a n d a *et al.*, 1988).

CONCLUSIONS

Having in mind all the results mentioned above, it can be concluded:

1. The recent results from the coastal sea of the eastern Adriatic have shown progressive changes under the influence of eutrophication, such as an increase trend of *Acartia clausi* percentages and increasing copepod biomass.

2. In the Vela Luka bay (channel region) the eutrophication effects of human activities can be seen in the upper part of the bay through unexpectedly high biomass.

3. No changes have yet been recorded from the open middle Adriatic.

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VIŠEGODIŠNJA ISTRAŽIVANJA KOPEPODA (ZOOPLANKTON) U PRIOBALNIM VODAMA SREDNJEG JADRANA

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KRATKI SADRŽAJ

U radu se donose rezultati višegodišnjih istraživanja kopepoda iz priobalnih voda ispred luka Zadra, Šibenika, Splita, Ploča i Dubrovnika kao i Kaštelanskog i Velolučkog zaljeva, uz usporedbu sa nekim rezultatima iz otvorenog mora srednjeg Jadrana.

Višegodišnja istraživanja skupine kopepoda (1976-1988) ispred naših najvećih luka pokazuju uznapredovale promjene pod utjecajem eutrofikacije koje se očituju kroz povišenje gustoće kopepoda, pojavu neuobičajenog ljetnjeg maksimuma, te veoma visoki postotak kopepoda *Acartia clausi* medju ostalim kopepodima.

Iste posljedice ustanovljene su i u Kaštelanskom zaljevu, a djelomično i na unutrašnjoj postaji u Velolučkom zaljevu gdje su pod utjecajem kopna zabilježene neuobičajeno visoke vrijednosti biomase.

Istovremeno, na otvorenom moru srednjeg Jadrana nađen je uobičajeni sastav, neizmjenjeni ritam sezonskih oscilacija gustoće, kao i uobičajene vrijednosti biomase kopepoda.

Navedeni rezultati ukazuju prema tome na promjene u skupini kopepoda prouzročene utjecajem eutrofikacije samo u priobalnom području istočno-jadranske obale, dok u otvorenom srednjem Jadranu još uvijek nisu zapažene.