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Can signs of eutrophication be found in the mesozooplankton of Seili, Archipelago Sea?

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Abstract

In this study, we evaluate whether it is possible to distinguish the effects of eutrophication from other, i.e. hydrographical, factors affecting zooplankton. We illustrate our arguments with examples from an old set of zooplankton data which includes 9-year records on mesozooplankton and hydrography collected from Seili, off the south coast of Finland. The present study shows that hydrographic changes override or mask, at least in the time period studied, possible eutrophication effects.

Introduction

What will happen to the Baltic Sea's zooplankton as eutrophication increases? How can the role played by eutrophication in the change be weighed among the many other factors affecting the system, especially if the other factors are of paramount importance for biological processes? Findings from long-term monitoring of rising nutrient concentrations in the water of the Baltic Sea have been published, e.g. by NEHRING (1979) and FONSELIUS (1980) (review by NEHRING et al. 1987). Zoo- and phytobenthic studies reveal advancing eutrophication around Öland and Gotland (CEDERWALL & ELMGREN 1980) and in the Åland Sea (KAUTSKY et al. 1986). The phytoplankton species composition has been found to be changing at the entrance to the Gulf of Finland (KONONEN and NIEMI 1984) and the zooplankton biomass has increased in the Baltic proper, as a result of eutrophication (WULFF et al. 1987). In our study area, the Archipelago Sea, JUMPPANEN (1987), compiled data from benthic and primary production capacity studies, and reports gradual eutrophication during the last 20 years.

Taking eutrophication as given, what is happening to the mesozooplankton? Pulses of saline water entering the Baltic Sea through the Straits of Denmark and penetrating into the Gotland Deep lift up saline and nutrient rich waters into the coastal areas of the northern Baltic and the Archipelago Sea. This increases the amount of neritic copepods, which form the main component in the total biomass of mesozooplankton (VUORINEN and RANTA 1987). On the other hand, eutrophication should increase total biomass and production, and also the numbers of short-lived, rapidly reproducing species (e.g. rotifers and cladocerans). There should be an overall increase in productivity (RAPPORT et al. 1985) and an increase in the total biomass (ODUM 1985) as a result of the increasing numbers of small, short-lived, r-selected species (RAPPORT et al. 1985). Simultaneously, a decrease in large, long-lived, K-selected species can be expected. In the zooplankton, rotifers and cladocerans are classified as r-selected, while copepods are K-selected species (ALLAN 1976). It is also possible that life-history parameters are affected within a species. Greater productivity may be caused by the higher numbers of r-selected species, as well as by the greater productivity of existing K-selected species (SARVALA et al. 1984). Population variability can be expected to increase in consequence of the increase in r-selected species. Furthermore, a decline in species diversity can be expected (ODUM 1985, RAPPORT et al. 1985).

In this paper, we shall discuss the mesozooplankton changes taking place at Seili (Northern Baltic Proper) in 1966–1975, as already documented by VUORINEN and RANTA (1987), against expectations based on eutrophication. Other factors simultaneously affecting the mesozooplankton are discussed.

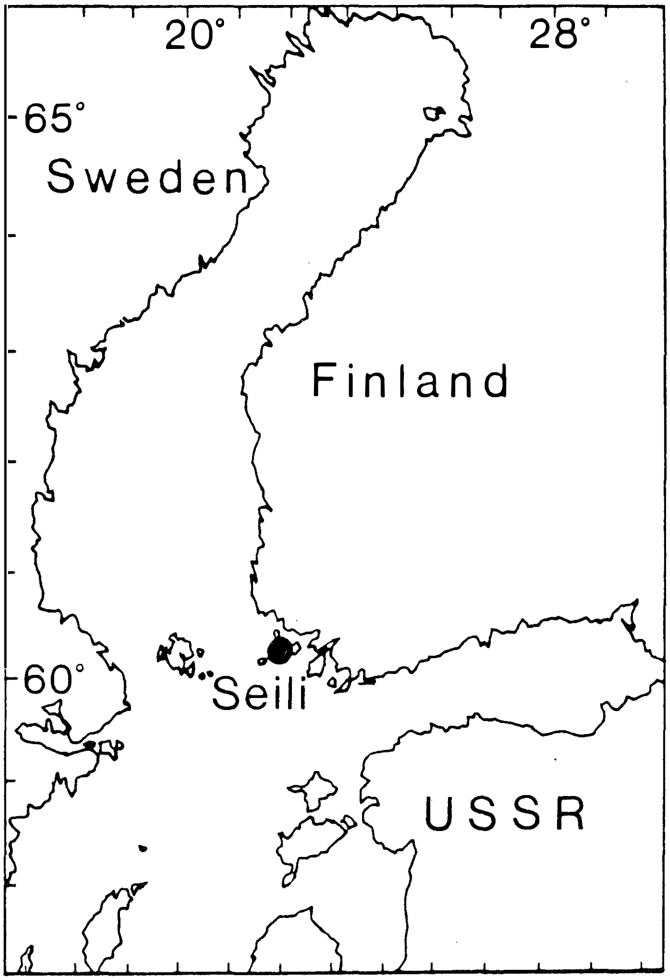


Figure 1

The mesozooplankton sampling site in a long-term monitoring of mesozooplankton in 1967–1975.

Material and methods

A full description of the sampling and analysis is given by VUORINEN and RANTA (1987). Some results from this time-series have also been published by NIEMI (1984). The sampling site was in the Archipelago Sea off the southern coast of Finland (Fig. 1). The sampling was done around noon at intervals of about 10 days during the summer and once a month in wintertime in the years 1966 – 75. Each sample consisted of a single haul with a Hensen-type plankton net (mesh size 150 µm) from a depth of 25 metres up to the surface. The total depth at the sampling site was 50 metres. Simultaneously with the plankton sampling, water temperatures were measured and salinity samples were taken from depths of 0, 5, 10, 15, 20, 30 and 40 m. Zooplankton samples were preserved in formaldehyde and counted later using the Institute of Marine Research's standard methods. The total number of samples was 252. These were taken over 108 months, and included 42 mesozooplankton taxa (including the naupliar and copepodite stages of copepods). We excluded some rare groups from later analysis. The average seawater salinity figures were higher from the late 1970s on (Fig. 2). Almost all the zooplankton taxa occurring in decreasing or increasing amounts showed significant correlations with

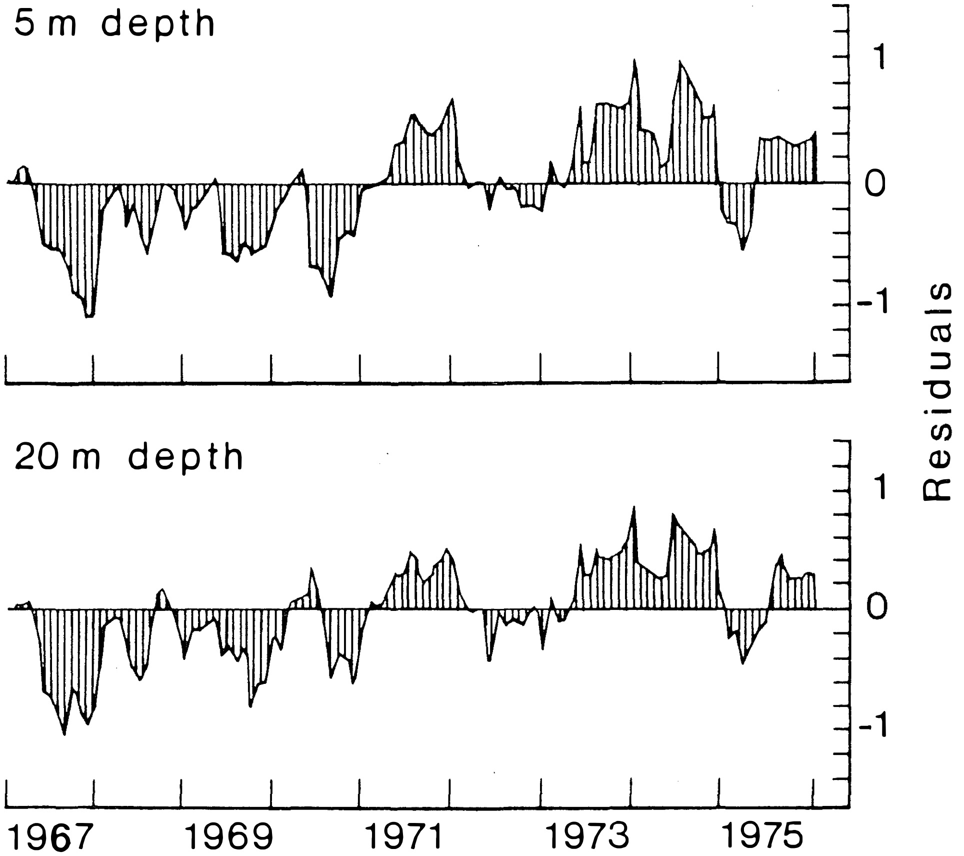


Figure 2

Deviations (in $^0\!/_{00}$ S) from the long-term monthly salinity averages off Seili, northern Baltic Proper in 1967–1975 (modified from VUORINEN and RANTA 1987).

salinity, either positive or negative (see Table 1), suggesting that salinity is among the most important factors affecting the amount of zooplankton in the Archipelago Sea. The changes in salinity are due to the pulses of relatively saline water entering through the Straits of Denmark (see e.g. FRANCKE et al. 1987).

Results

Biomass and productivity

The total mesozooplankton biomass showed a decreasing trend during the study period (Fig. 3, Table 1), due to the falling numbers of copepod adults and juveniles (Fig. 4). On the whole, copepod nauplii increased. The naupliar stages of neritic copepods – *Acartia* (three species are found in the study area), *Centropages hamatus* and *Temora longicornis* – showed an increase, while in the estuarine and limnic copepod species *Eurytemora affinis hirundides* and *Limnocalanus macrurus* there was a decrease in the numbers of naupliar stages (Fig. 4, Table 1).

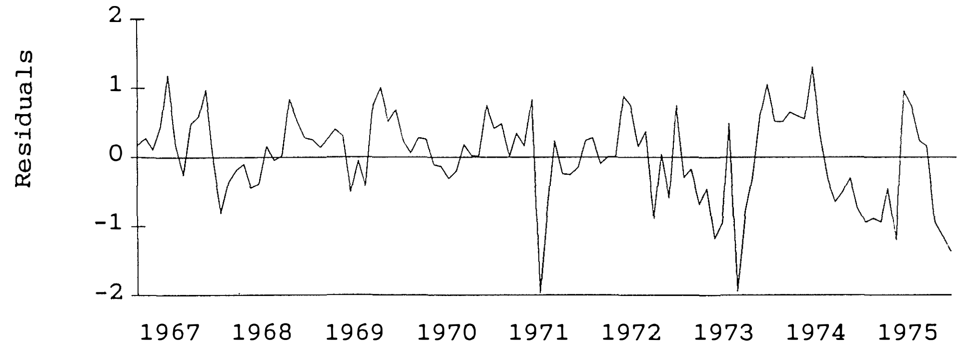


Figure 3

Deviations from the long-term monthly averages in the total meso-zooplankton biomass in Seili (modified after VUORINEN and RANTA (1987).

The increase in the naupliar stages of all neritic copepods, in spite of decreasing numbers of adults, suggests an enhanced production of nauplii. Being very small, they have no impact on the total biomass, however.

r- versus K-selected species

The overall-biomass of rotifers did not increase during the study period (VUORINEN and RANTA 1987, Table 1); rather, there was a slight decline in the abundance of rotifers. This was due to the decrease in *Synchaeta* species, which are the most common rotifers (Table 3, Fig. 4). The *Synchaeta* species found in the Seili area (*S. baltica* and *S. monopus*) are typical of brackisch water. The other r-selected group – cladocerans – did not increase in total biomass, either (VUORINEN and RANTA 1987). Two of the most important cladocerans – *Eubosmina longispina maritima* and *Podon polyphemoides* – showed a fall in numbers during the study period (Fig. 4, Table 1). *Eubosmina longispina maritima* is a brackish-water species, whereas *Podon* species are neritic.

Table 1

Summary of the time series analysis by VUORINEN and RANTA (1987). The list includes mesozooplankton taxa with A) an increasing trend, B) a decreasing trend, and taxa with C) no trend in numbers during the 1967–1975 study period. The correlation coefficient with salinity change (see Fig. 1) is also indicated (+ = significant positive, – = significant negative correlation 0 = no correlation).

	Correlation with salinity
A) Increasing trend	
Keratella quadrata	+
Acartia spp.	+
Centropages hamatus nauplii	+
Temora longicornis nauplii	+
Biomass of Copepod nauplii	+
B) Decreasing trend	
Eubosmina longispina	–
Podon intermedius	–
Gastropoda larvae	–
Eurytemora affinis juveniles	–
Eurytemora affinis adults	–
Biomass of adult copepods	–
Eurytemora affinis nauplii	0
Limnocalanus macrurus nauplii	0
Total biomass	0
Total biomass of copepods	0
Biomass of juvenile copepods	0
C) No trend	
Harpacticoida spp.	+
Polychaeta larvae	–
Balanus improvisus nauplii	0
Lamellibranchiata larvae	0
Electra crustulenta larvae	0
Polychaeta juveniles	0
Biomass of rotifers	0
Biomass of cladocerans	0
Biomass of meroplankton	0

Species diversity and population variability

Diversity is regarded here as having two components: the number of species (species diversity) and the dominance (equitability) (PIELOU 1969). There are no changes in the number of species. The constancy of species is high during the whole study period (Table 2). There are no species which are present or absent only in one half of the study period, if it is divided in two. There are no directional changes in dominance among the different mesozooplankton groups; rather, there are rapid irregular changes in the dominance of species (Table 3). *Keratella quadrata* became very abundant in 1973, increasing from 4 to

78 % over two years. Among the cladocerans, two common species also show rapid changes. In the years when salinity was rising (1970–1971), there was an increase in the percentage of *Evadne nordmanni* from 9 to 31 %, and *Podon polyphemoides* also increased its percentage from 8 to 44 % in 1969–1970 and from 7 to 54 % during 1973–1974. Thus, there are large changes in the dominance component of diversity, but these do not increase towards the end of the study period.

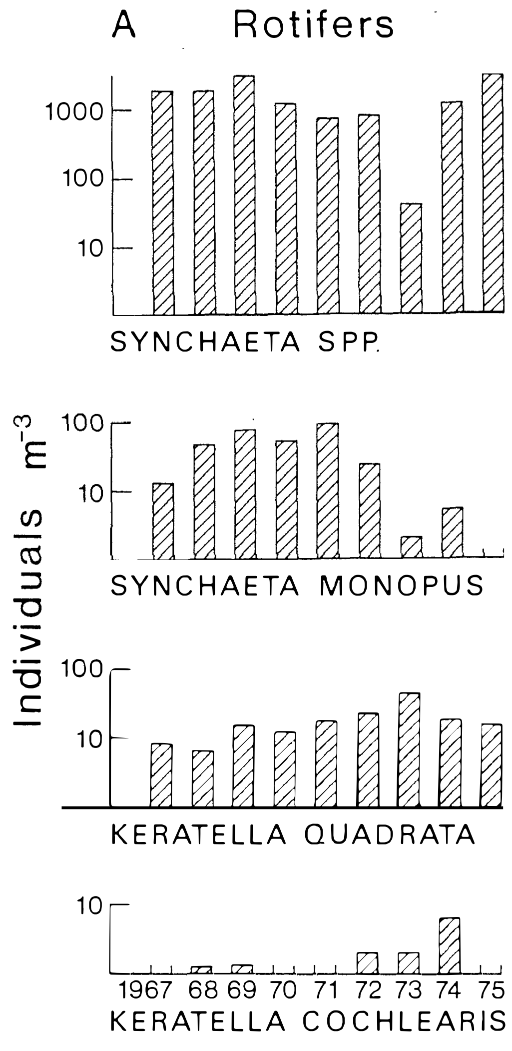
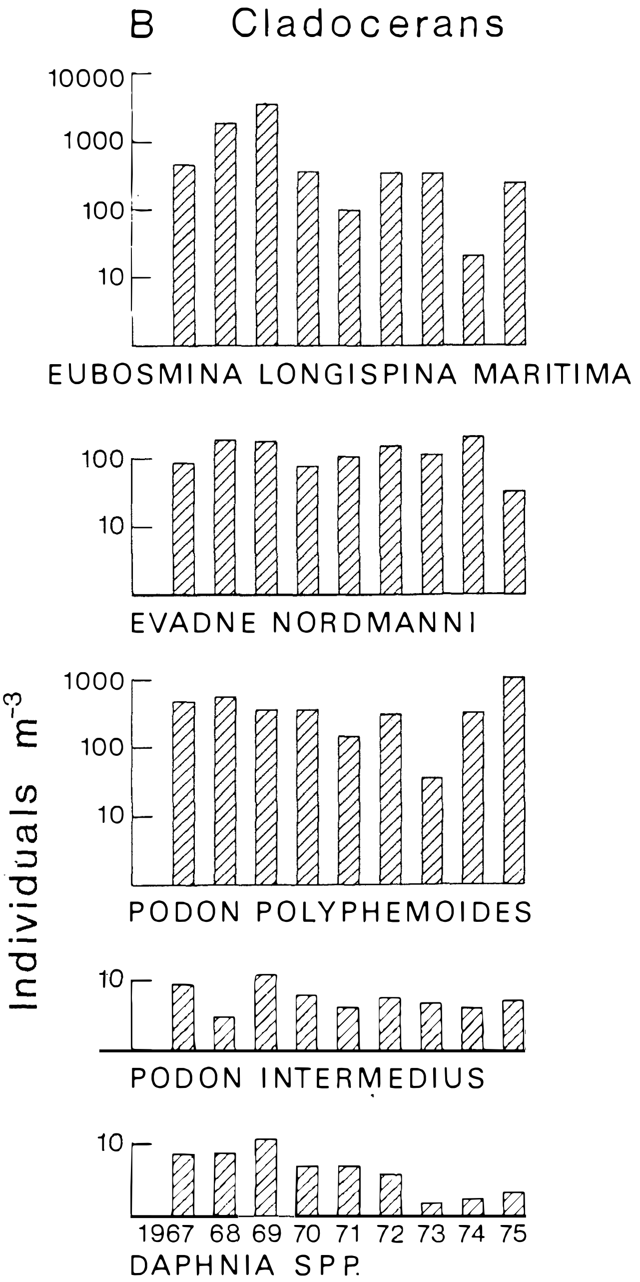
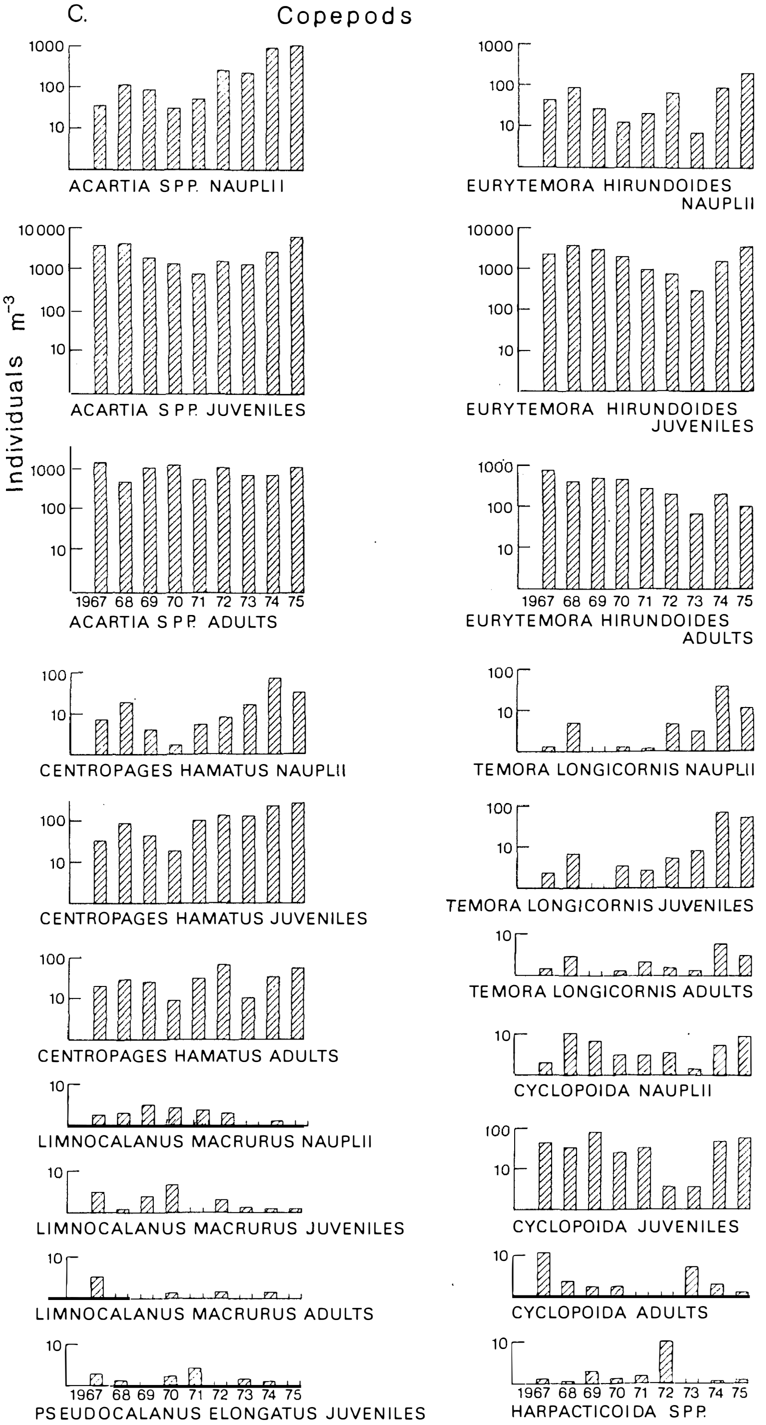


Figure 4

Population densities (individuals · m^{-3}) of different mesozooplankton taxa at Seili in 1967–1975. A = rotifers, B = cladocerans, C = copepods, D = meroplankton. The data displayed refer to annual summer month (June–September) averages (see VUORINEN and RANTA 1987 for a more detailed presentation).



Continuation of Fig. 4



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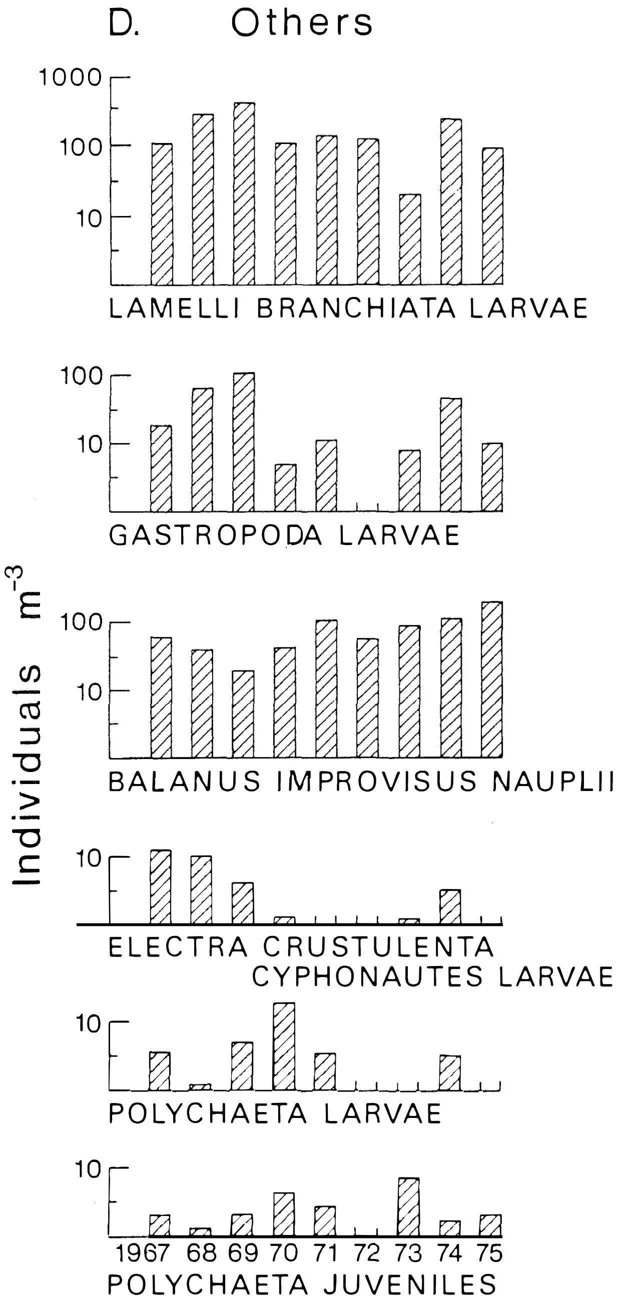

Continuation of Fig. 4

Table 2

Occurrence (1 = present, 0 = absent) of the different mesozooplankton taxa in samples from different years. The only taxa included are those with more than 250 counted individuals during the study period. Years with low (–) and high (+) salinity are indicated (modified from RANTA and VUORINEN, in prep.).

	–		–	–	+		+	+	
	1967	68	69	70	71	72	73	74	75
Keratella quadrata	1	1	1	1	1	1	1	1	1
Synchaeta spp.	1	1	1	1	1	1	1	1	1
Synchaeta monopus	1	1	1	1	1	1	1	1	0
Eubosmina longispina	1	1	1	1	1	1	1	1	1
Daphnia spp.	1	1	1	1	1	1	1	1	1
Evadne nordmanni	1	1	1	1	1	1	1	1	1
Podon intermedius	1	1	1	1	1	1	1	1	1
Podon polyphemoides	1	1	1	1	1	1	1	1	1
Acartia spp. nauplii	1	1	1	1	1	1	1	1	1
Arcartia spp. juveniles	1	1	1	1	1	1	1	1	1
Acartia spp. adults	1	1	1	1	1	1	1	1	1
Centropages hamatus nauplii	1	1	1	1	1	1	1	1	1
Centropages hamatus juveniles	1	1	1	1	1	1	1	1	1
Centropages hamatus adults	1	1	1	1	1	1	1	1	1
Eurytemora affinis nauplii	1	1	1	1	1	1	1	1	1
Eurytemora affinis juveniles	1	1	1	1	1	1	1	1	1
Eurytemora affinis adults	1	1	1	1	1	1	1	1	1
Limnocalanus macrurus nauplii	1	1	1	1	1	1	0	1	0
Limnocalanus macrurus juveniles	1	1	1	1	0	1	1	1	1
Pseudocalanus elongatus juveniles	1	1	0	1	1	0	1	1	0
Temora longicornis nauplii	1	1	0	1	1	1	1	1	1
Temora longicornis juveniles	1	1	0	1	1	1	1	1	1
Temora longicornis adults	1	1	0	1	1	1	1	1	1
Cyclopoida spp.	1	1	1	1	1	1	1	1	1
Harpacticoida spp.	1	1	1	1	1	1	0	1	1
Balanus improvisus nauplii	1	1	1	1	1	1	1	1	1
Gastropoda larvae	1	1	1	1	1	0	1	1	1
Lamellibranchiata larvae	1	1	1	1	1	1	1	1	1
Fritillaria borealis	1	0	0	0	0	0	1	0	0
Polychaeta juveniles	1	1	1	1	1	0	1	1	1
Number of taxa	30	29	25	29	28	26	28	29	26

Table 3

Percentage composition of the mesozooplankton community at the Seili sampling site in low and high salinity years (c.f. Fig. 1). The data are based on pooled summer month samples (June–September) for each year (modified from RANTA and VUORINEN, in prep.), and they are split up into the three main categories: rotifers, cladocerans and copepods (% of total number of individuals in each group). The less frequent taxa are excluded from the tabulation (percentages of less abundant taxa are indicated as * = 1–0.1 %, + = 0.1–0.01 %, – = not observed).

	Years with					
	low salinity			high salinity		
	1967	1969	1970	1971	1973	1974
Rotatoria						
Synchaeta spp.	97	96	89	84	21	84
Synchaeta monopus	*	2	4	11	*	*
Keratella quadrata	3	1	8	4	78	15
Keratella cochlearis	–	+	–	–	*	*
Cladocera						
Eubosmina longispina	44	83	46	31	71	5
Evadne nordmanni	8	9	9	31	21	40
Podon polyphemoides	47	8	44	36	7	54
Podon intermedius	1	+	*	*	*	*
Daphnia spp.	1	*	*	1	+	+
Copepoda						
Acartia spp.						
nauplii	*	1	*	1	10	14
juveniles	52	33	30	41	35	40
adults	11	14	24	19	35	9
Eurytemora affinis						
nauplii	*	*	*	*	*	2
juveniles	26	41	35	24	10	23
adults	8	8	9	7	3	4
Centropages hamatus						
nauplii	*	+	+	*	*	1
juveniles	*	*	*	4	6	4
adults	*	*	*	*	*	*

Discussion

Although the number of different zooplankton taxa in the Seili area changed during the study period, few if any of the changes expected because of eutrophication were found in the mesozooplankton. An effect due to salinity changes was clearly found. This was expected, since both limnic and neritic species live in extreme conditions which cause a minimum in the species diversity (REMANE and SCHLIEPER 1971). This salinity-mediated effect has been documented earlier by e.g. SEGERSTRÅLE (1951, 1953, 1965). However, not all the documented changes in mesozooplankton (VUORINEN and RANTA 1987) can be explained by the change in salinity. For example, one might expect all the species which can be characterized as limnic and brackisch or neritic to show consistent changes. But this was not the case. For instance, there was a clear increase in the naupliar stages of neritic copepods, but at the same time *Podon polyphemoides* and the larvae of Gastropoda showed a decreasing trend, and both are also neritic. Furthermore, one might expect all the developmental stages of one species to show similar changes. However, the nauplii of neritic copepods increased, while their adults showed a decrease.

The decrease in total biomass (due to decreasing numbers of adult neritic copepods) cannot be explained by eutrophication or oceanization. There must be further factors causing simultaneous changes. One possibility is selective predation by planktivores, which is known to be very efficient in changing the composition of the plankton fauna (review by ZARET 1980). One example of general change is the size decrease due to the selective removal of larger species (e.g. copepods). This, in turn, is another change expected as a consequence of eutrophication. The effects of “consumer regulation” by selective planktivores have been found to resemble those of eutrophication in lake ecosystems (ANDERSSON et al. 1978, HENRIKSSON et al. 1980), but its role in larger ecosystems like the Baltic Sea is still in question. Trawling data from the Åland Sea, Gulf of Finland and the northern Baltic Proper indicate that herring stocks increased between the 1950s and 70s (SJÖBLOM and PARMANNE 1981). This would suggest major changes in selective planktivory. However, the accompanying changes in fishing effort and gears make it difficult to evaluate these changes (HANSSON 1985).

There were marked changes in productivity, seen as an increase in neritic copepod nauplii, despite the simultaneous decrease in the numbers of adult stages. If we suppose, for argument, that there was also an increase in adult neritic copepods, could this be a result of eutrophication? Another explanation, as VUORINEN and RANTA (1987) have shown, is oceanization, with the plankton fauna reflecting a change from a situation characterized by brackish water and limnic species to one dominated mainly by neritic species. Thus the numbers of neritic copepods are expected to rise, and the effects of oceanization are largely opposite to the effects of eutrophication. We suggest that the same increase in the abundance of neritic copepods might have occurred if salinity alone were rising. However, the rise in salinity may be accompanied by a rise in the nutrient content of the water (NEHRING 1981, KONONEN and NIEMI 1984, NEHRING et al. 1984, 1987), making it very difficult to claim that we are dealing with the effect of eutrophication only or oceanization only.

There were large and irregular fluctuations in the dominance of several species during the study period, but they were not more more common towards the end of the 9-year period, as might be expected if they were caused by eutrophication. Species diversity, on the other hand, was remarkably constant during the study period.

In conclusion, there is no reason to expect eutrophication in the mesozooplankton of the Baltic Sea to proceed similar ways as it does in purely limnic and/or marine environments. The changing characteristics of the Baltic Sea, i.e. oceanization and its planktivore stocks, create a situation in which eutrophication does not affect the mesozooplankton in the way expected from studies made in purely limnic or marine environments. For the effects of eutrophication to surpass the short-term fluctuations associated with oceanization, they must be larger than these. The answer to the question posed in the title is dubiously positive; the long-term data on zooplankton do not primarily reflect eutrophication, but if we are interested in what is happening in the planktonic ecosystem as a whole, we must include eutrophication among the hypothetical factors playing a role.

We feel that it will be possible to identify the effects of eutrophication among the mesozooplankton if certain condiditions are fulfilled: 1) Sampling must be frequent enough to cover even short bloom periods and the succession of different species with different life-cycle strategies. 2) Replicate sampling or time series (e.g. longer than 9 years) are essential. 3) Animals must be identified at least at species level and their ecological constraints as well as their position on the limnic – brackish – neritic continuum must be known. 4) Proper statistical methods must be used for the data processing. 5) The trends, state and/or cycles of important environmental factors must be known, including the chemical, physical and biological environment. 6) A broad taxonomic spectrum must be monitored. 7) A high level of general knowledge about the planctonik ecosystem and its function must be available for interpretation of the results.

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