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ON THE ENVIRONMENT AND ZOOPLANKTON DYNAMICS IN THE GULF OF FINLAND IN 1961—1990

Abstract. The zooplankton composition, abundance, and biomass in the Gulf of Finland vary by areas, water layers, and seasons in accordance with variations in environmental conditions. The seasonal changes are the biggest in the upper 25 m layer, particularly in the eastern part of the Gulf. Considerable decline in salinity in the early 1980s and, possibly, an increase in man-made pollution induced drastic changes in zooplankton. The species of marine origin decreased in numbers and retreated to the west. The importance of copepods and rotifers diminished, but that of cladocerans increased. Essential changes in feeding conditions resulted in a sudden drop of the young herring weight.

Key words: zooplankton, copepods, cladocerans, rotifers, abundance, biomass, temperature, salinity, Baltic herring.

Introduction

Regarding environmental conditions, the Gulf of Finland is one of the most variable parts of the Baltic Sea. In its eastern part the winter temperature is much lower and the ice period substantially longer than in the western part. After Ostov (Остов, 1971) the ice period lasts at Stirsudden on the average 131 days against 69 days at Osmussaar.

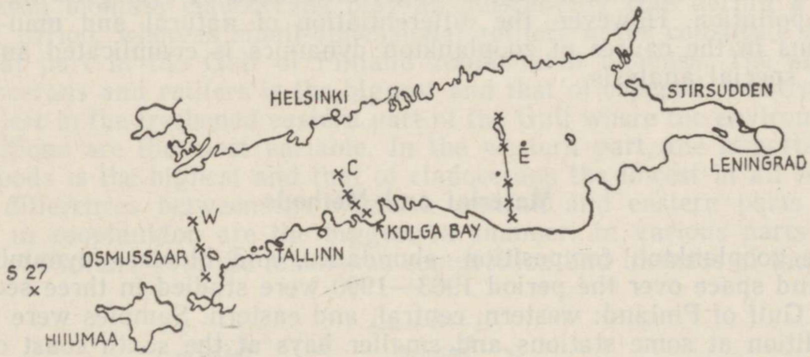

Fig. 1. Regular zooplankton sampling sites in the Gulf of Finland. Sections: W — western, C — central, E — eastern; S27 — sampling station in the Baltic proper.

In the cold season, the surface water temperature is generally less variable and somewhat higher in the western part of the Gulf of Finland than in the eastern part. The average temperature of the 0—20 m layer for May 1961—1990 was 4.2 °C in Station 27 and Section W and 3.8 °C in Section E (Fig. 1). In August the temperature of the 0—20 m layer was lower in the western part (13.7 °C) than in the eastern (14.6 °C) part. As to the average temperatures of the cold intermediate layer (40—60 m), the western and eastern parts of the Gulf differed insignificantly (respectively 2.0 °C and 2.2 °C in May, and 3.0 °C and 2.6° in August). There is

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no threshold in the bottom between the Baltic proper and the Gulf of Finland. The bottom waters penetrate from the northeastern Baltic freely into the Gulf of Finland. Therefore the difference in the salinity between the corresponding layers in the northeastern Baltic proper and the western part of the Gulf of Finland is rather small. In 1961—1990 the average salinity in the 0—20 and 80—120 m (bottom) layers was respectively 7.1‰ and 10.2‰ in the northeastern Baltic (Station 27, Fig. 1), whereas in the 0—20 and 80—90 m layers in Section W it was 6.7‰ and 9.7‰, respectively. Eastward the salinity decreases considerably. In the reference period the average salinity of the 0—20 and 50—60 m layers in Section E constituted correspondingly 5.1‰ and 7.3 ‰. Consequently, in the eastern Gulf of Finland the salinity of the bottom layer was roughly equal to the surface salinity at the mouth of the Gulf. The high gradient and variability of salinity in the Gulf of Finland are due to large fresh water masses brought into the Gulf by the Neva, Kemijoki, Narva, Luuga, and other rivers and intense mixing processes of more saline bottom waters with the freshened surface water.

In the eastern Gulf of Finland, the oxygen concentration probably did not hinder the distribution of organisms in the water column (in the 50—60 m bottom layer the average oxygen content was 4.7 ml/l) during the period studied. In the western part with a stronger halocline, the average for the period in the 80—90 m bottom layer was 1.6 ml/l. Low oxygen concentrations ($<$1.5 ml/l) in the 80—90 m layer were found there at least once a year during this period except in 1987, 1989, and 1990. In other years the oxygen content presumably hindered periodically free distribution of organisms in the deep layers.

The Gulf of Finland is very strongly influenced by ever growing man-made pollution. However, the differentiation of natural and man-made fractions in the causes of zooplankton dynamics is complicated and deserves special analysis.

Material and Methods

The zooplankton composition, abundance, and biomass dynamics in time and space over the period 1963—1990 were studied in three sections of the Gulf of Finland: western, central, and eastern. Samples were taken in addition at some stations and smaller bays at the south coast of the Gulf (Fig. 1). Sampling was done with a Juday net (mesh 170 μ) at the depth intervals 0—10 m, 10—25 m, 25—50 m, and 50 m—the bottom in May, August, and October-November. In connection with a certain change in the sampling nets during the investigation period (since 1983 kapron nets were applied instead of silk nets used before), data on smaller plankters — copepod *Nauplii* and *Keratella* sp. — can be biased to some extent (Lekholm et al., 1981). Therefore, below the copepod abundance and biomass are presented excluding *Nauplii*. Also, the number of rotifers in the samples collected before and beginning with 1983, cannot correctly be compared.

The samples were treated by the routine counting method (Лумберг, 1976).

Because of considerable variation of the physical fine structure of water masses and, correspondingly, environmental conditions (Raid, 1989), the single samples collected at a certain station may not be representative for a larger area. Therefore, below mainly data averaged both in time (long-term means) and space (means for the sections), have been applied.

The Composition of Zooplankton

In the investigated area a total of 43 zooplankton taxa was found (Table); 20 of them belong to freshwater, 15 brackish-water, and 8 to marine fauna. Some species are distributed in the whole studied area, whereas others are met with mainly in certain regions.

Bityukov et al. (Битюков et al., 1971) indicate that in the Gulf of Finland 293 zooplankton taxa are represented, 79 of them belonging to *Protozoa*, 2 to *Coelenterata*, 106 to *Rotatoria*, 73 to *Cladocera*, 26 to *Copepoda*, 1 to *Appendicularia*, 6 to *Mysidecea* and the larvae of bottom invertebrates. The freshwater complex is dominating — 87% of the total number of species, 8% of the species belong to the brackish-water, and 5% to the marine complex. Freshwater species occur mainly in the eastern part of the Gulf and in small coastal bights,

Seasonal Variations in Zooplankton Abundance and Biomass

In spring, after the winter with its unfavourable conditions for the majority of plankton species, the diversity and abundance of zooplankton are low (Fig. 2). It consists mainly of copepods that are the most stable components of zooplankton in the Gulf of Finland. Incidentally, the abundance of the glacial relict *Limnocalanus grimaldii* is the highest in spring. Rotifers and cladocerans overwinter mainly as resting eggs (Hernroth, Ackefors, 1979). In spring and summer with increasing temperature favouring reproduction of the warm-water species, the zooplankton abundance and biomass increase manifold. The burst is the largest in cladocerans and rotifers. Therefore, in summer their numbers are high. In the zooplankton biomass cladocerans play an outstanding role during a rather short period, whereas small-dimensional rotifers never constitute a substantial part in the Gulf of Finland zooplankton biomass. The share of cladocerans and rotifers is the biggest and that of copepods relatively the smallest in the freshened eastern part of the Gulf where the environmental conditions are the most variable. In the western part, the importance of copepods is the highest and that of cladocerans the lowest in all seasons. The differences between the western, central, and eastern parts of the Gulf in zooplankton are the biggest in summer. In various parts of the Gulf of Finland both the taxonomic composition and biomass of the higher

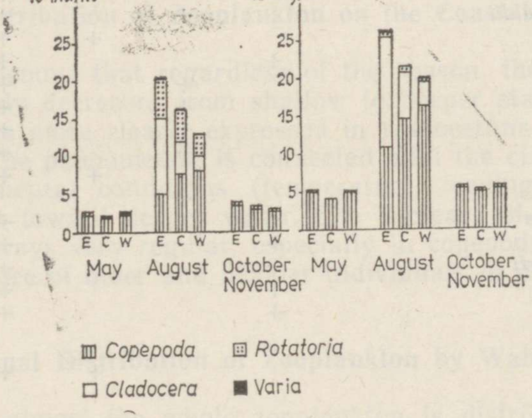

Fig. 2. Zooplankton average abundance and biomass by sections and seasons in 1963—1990.

systematic groups of organisms diverge clearly. For instance, differences between the eastern and western parts in the most stable and important link of the pelagic food chain — copepods — are obvious (Fig. 3). In

Composition of zooplankton in the investigated area

Zooplankton	Pertinence to complexes			Occurrence in the sections		
	freshwater	brackish water	marine	eastern	central	western
Rotatoria						
*Synchaeta baltica**		+		+	+	+
S. fennica		+		+	+	+
S. littoralis		+			+	+
S. monopus		+		+	+	+
Synchaeta sp. sp.				+	+	+
Polyarthra trigla	+			+	+	+
Asplanchna priodonta	+			+		
Asplanchna sp.	+			+	+	
Keratella cochlearis	+			+	+	+
K. c. recurvispina		+			+	
K. quadrata	+			+*	+*	+
K. q. platei		+		+	+	+
K. c. eichwaldi		+		+	+	+
Euchlanis diladata	+			+	+	
Euchlanis sp.	+			+		
Notholca striata	+			+		
N. acuminata	+			+	+	+
Lecane sp.						
Cladocera						
Daphnia cucullata	+			+*	+	
Ceriodaphnia quadrangula	+			+*	+	
Chydorus sphaericus	+			+*	+	
Alona affinis	+			+		
A. rectangula	+			+		
Alona sp.				+		
*Bosmina c. maritima**		+		+	+	+
Podon intermedius			+	+	+	+
P. polyphemoides		+		+	+	+
Evadne nordmanni			+	+	+	+
Leptodora kindtii	+			+		
Copepoda						
Pseudocalanus elongatus			+	+	+	+*
Centropages hamatus			+	+	+	+
Limnocalanus grimaldii		+		+*	+	+
Temora longicornis			+	+	+*	+*
Eurytemora velox	+			+		
E. affinis		+		+	+	
*E. hirundoides**		+		+	+	+
E. hirundo		+		+	+	+
*Acartia bifilosa**		+		+	+	+
A. longiremis			+	+	+	+
A. tonsa		+			+	
Eucyclops serrulatus	+			+		
var. proximus	+			+		
Mesocyclops leuckarti	+			+*	+	+
M. oithonoides	+			+	+	
Cyclopidae	+			+	+	
Cirripedia						
Balanus improvisus			+	+	+	+
Appendicularia						
Fritillaria borealis			+	+	+	+*

* denotes mass occurrence of the species throughout the whole area or in its certain part.

the east the percentage of *L. grimaldii* with the upper range of the salinity adaptation about 6‰ (Hernroth, Ackefors, 1979) and that of *Eurytemora hirundoides* are high in all seasons, especially in spring. Westward the importance of the marine *Pseudocalanus elongatus* and *Temora longicornis* adapted to the salinities down to 6‰ (Hernroth, Ackefors, 1979) as well as that of the most abundant copepod species in the Gulf of Finland — *Acartia bifilosa* — increase while those of *L. grimaldii* and *E. hirundoides* decrease notably. However, with the decrease of salinity since 1983 the area of the main stock of *E. hirundoides* in the Gulf of Finland has shifted westward.

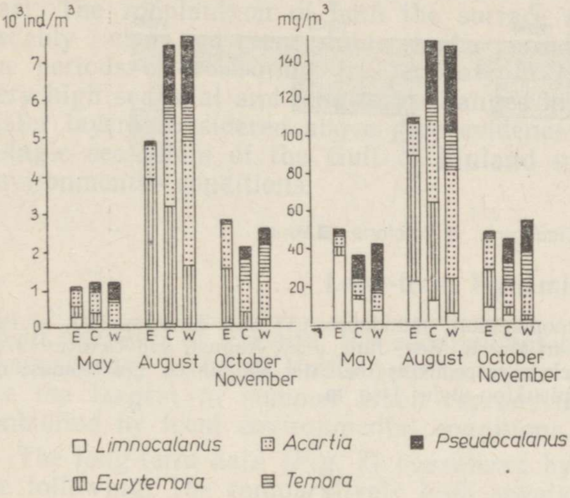

Fig. 3. Average abundance and biomass of some copepod species by sections and seasons in 1963—1985.

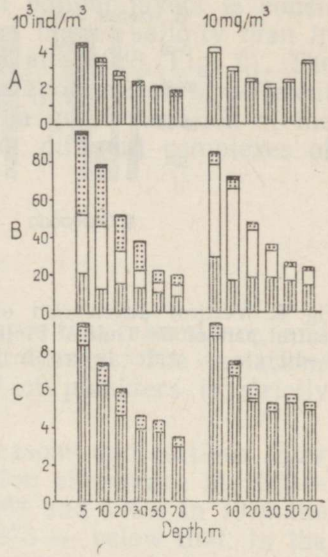

Fig. 4. Zooplankton average abundance and biomass at various depths on the coastal slope in Kolga Bay in May (A), August (B), and October (C) in 1975—1989. For designation see Fig. 2.

Distribution of Zooplankton on the Coastal Slope

It is conspicuous that regardless of the season, the density or organisms commonly decreases from shallow to deeper stations (Fig. 4). In summer, this is more clearly expressed in cladocerans and rotifers than in copepods. The phenomenon is connected with the clinal change of the main environmental conditions (temperature, feeding conditions, etc.) from the coast toward deeper water. The decrease of biomass does not seem to be always very regular, especially in copepods. The main cause is a higher share of older and heavier individuals in deeper areas.

Seasonal Distribution of Zooplankton by Water Layers

In winter, almost the whole zooplankton is distributed deeper than 25 m, virtually in the bottom layers (Fig. 5). In spring, with the warming of the surface layers, part of plankters rise nearer to the surface.

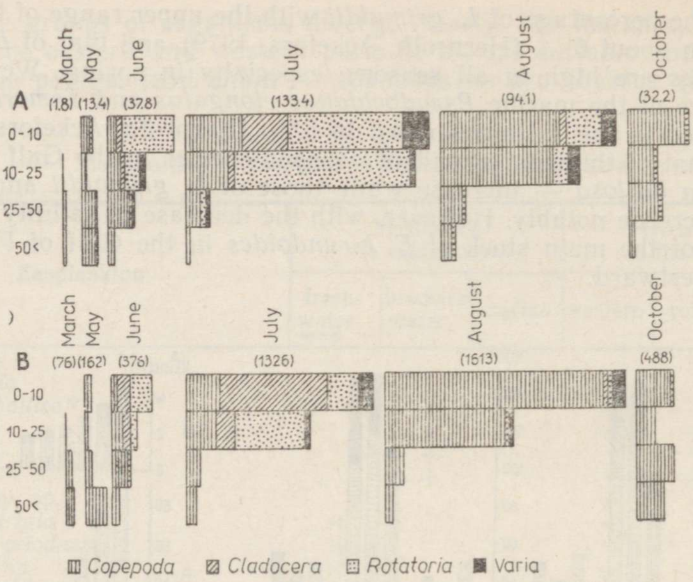

Fig. 5. Vertical distribution of zooplankton abundance (A) and biomass (B) in the central part of the Gulf of Finland in March, May, June, July, August, and October 1974. 0—10, etc. — water layers. In brackets respectively the total abundance and biomass of zooplankton under 1 sq. m.

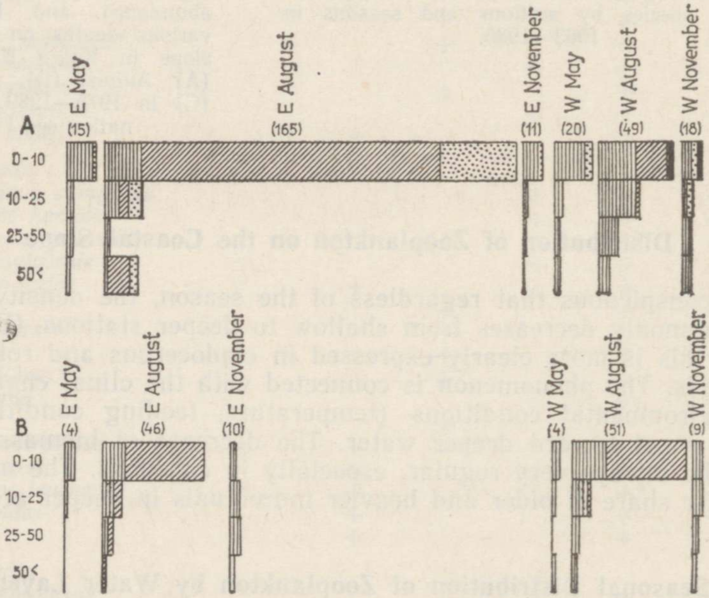

Fig. 6. Vertical distribution of zooplankton abundance in Sections E and W in May, August, and November 1979 (A) and 1988 (B). For designation see Fig. 5.

As a result of intense reproduction in spring and summer, the abundance and biomass of rotifers and cladocerans living mainly in the upper layers, to a lesser extent also those of copepods, increase. In autumn copepods dominate clearly. Drastic changes take place in the upper 25 m water layers — from rare occurrence of larger plankters in winter to their high density in summer.

The differences in the seasonal distribution of zooplankton in water layers in different parts of the Gulf of Finland and between the climatic periods are very substantial (Fig. 6). In the eastern part with a lower salinity and a higher amplitude of temperature changes, the seasonal variation of zooplankton by water layers is bigger than in the western part. The zooplankton of both the surface and bottom layers is considerably richer and more stable in the periods of higher salinity than in the periods of freshening (respectively in 1979 and 1988, Fig. 6). The very high seasonal and long-term changes in the zooplankton of different water layers considered above give evidence of a great variation of the pelagic ecosystem of the Gulf of Finland under different complexes of environmental conditions.

Long-term Dynamics

In the Gulf of Finland, the zooplankton composition, abundance, and biomass vary in broad limits both by areas and seasons. The variations are the largest in summer when reproduction of plankters is strictly controlled by local environmental conditions.

The long-term data (Fig. 7) considered by seasons and sections show the following. The comparatively high zooplankton abundance in 1963—1967 was followed by clearly lower values in 1968 and 1969. In 1970 the level was about the average, but in 1972 and 1973 — below that. In the period 1974—1982 zooplankton was generally numerous (only in 1978 and 1980 it was moderate) and its composition diverse. A sudden decrease in zooplankton abundance occurred in 1982—1984. Rotifers, notably in the eastern and central parts where their numbers had been relatively the highest, declined strikingly. As has been shown above, some decline in the number of rotifers in the samples can be due to the use of kapron nets since 1983 instead of silk nets used before. Also the copepod abundance reduced. The importance of cladocerans increased, particularly in the central and western Gulf of Finland.

The driving force for the dynamics in biota is variation in the basic environmental conditions (salinity, heat, and oxygen content of water layers, horizontal and vertical movements, etc.), which depend on changes of climatic periods. In the Gulf of Finland the most important of them is variation of salinity and, probably, man-made pollution. The sequent period of high river discharge began in 1977—1978 (Kalejs, Ojaveer, 1989). The water exchange between the Baltic and Kattegat decreased, stagnant conditions established in the Baltic Sea, and the salinity declined. The phenomena manifested themselves clearly also in the Gulf of Finland (Fig. 8). In the period of high salinity, in the second half of the 1970s and in the beginning of the 1980s, the zooplankton abundance and diversity were comparatively high. The importance of marine species, including copepods, was considerable. As the salinity decreased, their number diminished drastically and they retreated from the eastern and central parts of the Gulf. The abundance of the *Pseudocalanus elongatus* that is remarkably restricted by the salinity in the Gulf of Finland, closely follows the salinity graph of the main water mass (0—60 m). Vice versa, with decreasing salinity the species of freshwater origin gained higher

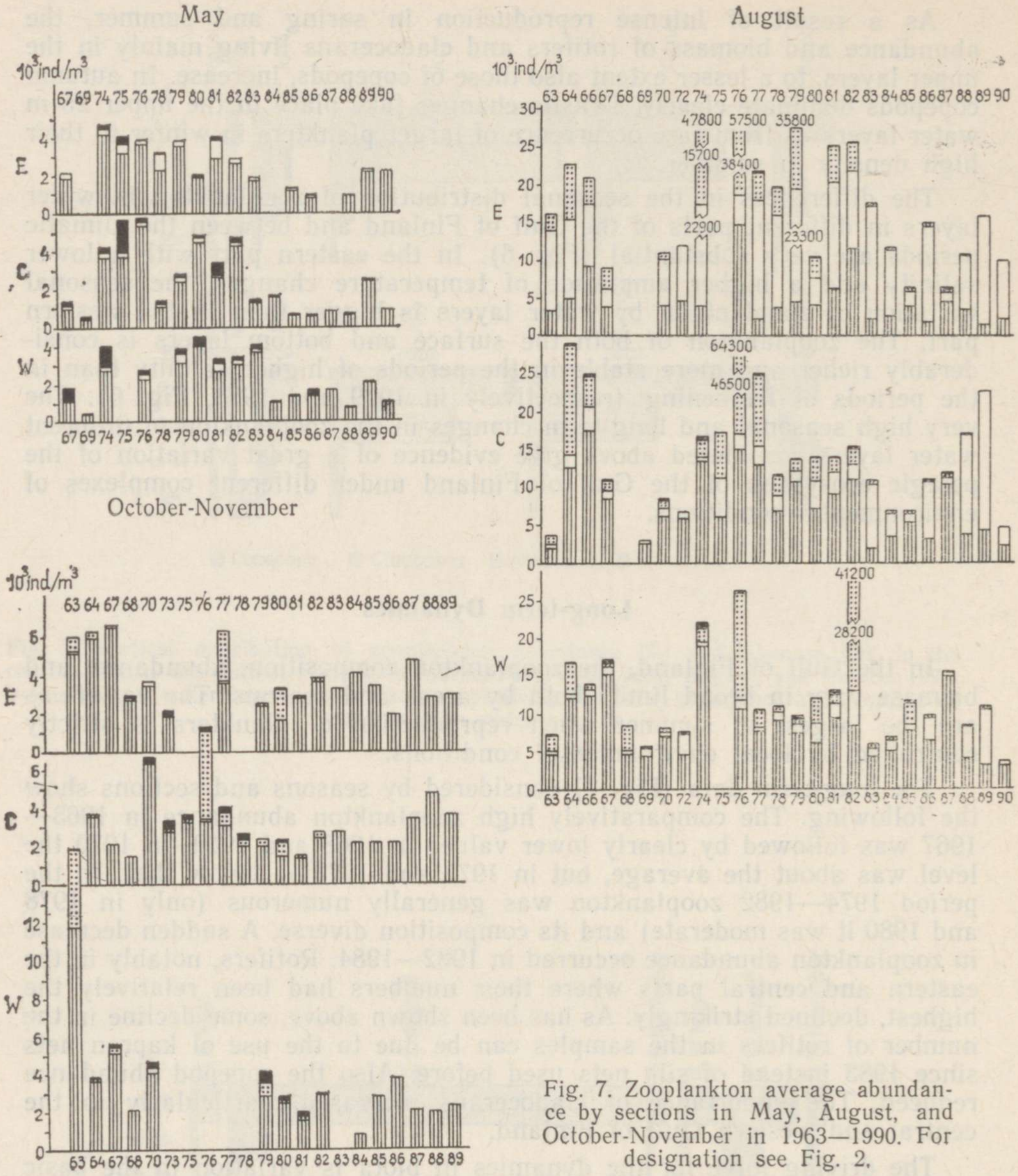

Fig. 7. Zooplankton average abundance by sections in May, August, and October-November in 1963—1990. For designation see Fig. 2.

abundance in the central and western sections. Temperature regime has also had substantial influence. Comparatively high temperatures of the upper 20 m layer prevailing in a number of summers in the 1980s (1981, 1983, 1984, 1986, 1989) resulted in large numbers of the warm-water *Bosmina coregoni* constituting the bulk of cladocerans. The increase in the abundance of cladocerans and the decrease in that of copepods in the 1980s resulted in considerable changes in the zooplankton structure, numbers, and biomass. As compared to the earlier period, the average numbers diminished substantially in 1982—1983, excluding the eastern part in autumn (Fig. 7). This was connected with the increase in the number of the cold-water *L. grimaldii* after some severe winters and a certain increase in the abundance of *E. hirundoides* resulting from the freshening of the Gulf.

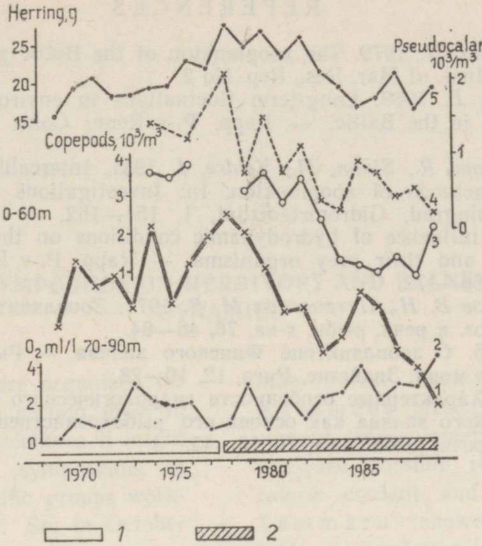

Fig. 8. Relationship between the average water salinity, oxygen content, copepod abundance, and the average weight of the 2-year-old herring in the Gulf of Finland in 1969—1989. 1 — salinity of the 0—60 m layer; 2 — oxygen content of the 70—90 m layer; 3 — average copepod abundance in May; 4 — average abundance of *Pseudocalanus elongatus* in August; 5 — average weight of the 2-year-old herrings; *1* — periods of low, and *2* — high river discharge.

The decrease in salinity and zooplankton abundance induced essential changes in the following link of the food chain. Young herring lives mainly on zooplankton and its average weight is in significant correlation with the copepod abundance in the growth period ($r=0.61$; $P<0.05$; Fig. 8). As the abundance of *P. elongatus*, *T. longicornis*, and *Centropages hamatus* decreased markedly since 1982, the average weight of young herring dropped drastically. It can be supposed that after 1982 herring had to utilize food organisms of generally poorer quality than during the 5-year-period before. Also, the direct impact of the salinity decrease on the herring physiology cannot be excluded. The distribution of zooplankton in the bottom layers depends on oxygen concentration. Under oxygen deficiency the density of zooplankton is considerable in a narrow layer just above the critical O_2 values for the organisms. This favours fishes in catching their prey. The changes in oxygen concentration in the Gulf of Finland bottom layer in 1964—1987 (i. e. in the years of periodic oxygen deficiency near the bottom) are generally opposite to the course of the graph showing the average weight of the two-year-old herring (Fig. 8). It can be supposed that the good growth of the Gulf of Finland herring at the end of the 1970s and in the beginning of the 1980s was due both to the high abundance and density of their food organisms in the Gulf of Finland.

The above shows that alteration of climatic periods is reflected, via changes in the basic environmental conditions, in the whole pelagic food chain and ecosystem of the Gulf of Finland.

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