

## Changes of the bottom macrofauna in the eastern Gulf of Finland in 1985–2002

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**Abstract.** Long-term changes of macrozoobenthos in the eastern Gulf of Finland are described on the basis of field observations during 1985–2002. Deep-water bottom communities were radically changed by the oxygen deficit in 1996. Deterioration of oxygen conditions was responsible for the strong impoverishment (biomass less than 1 g/m<sup>2</sup>) and complete disappearance of macrofauna in large bottom areas. Outside the confines of these areas no distinct difference was observed between the 2000s and the beginning of the study period; however, macrozoobenthos showed considerable interannual variations because of population fluctuations of dominant species.

**Key words:** Baltic Sea, Gulf of Finland, macrozoobenthos, population dynamics, long-term changes.

### INTRODUCTION

The Gulf of Finland is one of the largest gulfs of the Baltic Sea. It extends 420 km from west to east. By eastern Gulf of Finland the water area between the islands of Kotlin and Hogland is usually meant. From east this brackish water area is now separated from freshwater Neva Bay by a dam protecting St. Petersburg from floods. The bottom relief of the eastern Gulf of Finland is uneven. A characteristic feature is a large number of reefs, coastal and island banks. In general, the depth increases from east to west. Based on bottom morphometry this water body is subdivided into two natural regions. In the eastern shallow area from Kotlin Island to the Shepelevo–Ozerki transect the depth is less than 30 m. In a deep-water zone to the west of this transect the depth in open sites exceeds as rule 30 m and at the western border of the area near Hogland reaches 60–70 m.

This small part of the Baltic (about 3% of the total area of the sea) receives (mainly with the Neva River runoff) almost a quarter of the river waters entering the Baltic Sea. The salinity increases from east to west. In Neva Bay the water is fresh. Near Hogland Island the salinity averages 3–4 PSU on the surface and 6–7 PSU at the bottom in summer. The large extent of the water area, uneven bottom relief, and great continental runoff are responsible for a significant spatial and temporal variability of environmental conditions.

The eastern Gulf of Finland is among the most polluted parts of the Baltic Sea (HELCOM, 1996; Leppänen et al., 1997; Pitkänen et al., 1997; Savchuk & Skakalsky, 1997). On its catchment there are numerous densely populated areas with advanced industry and agriculture. The gulf receives from Neva Bay the waste waters of St. Petersburg – the largest city on the coast of the Baltic Sea.

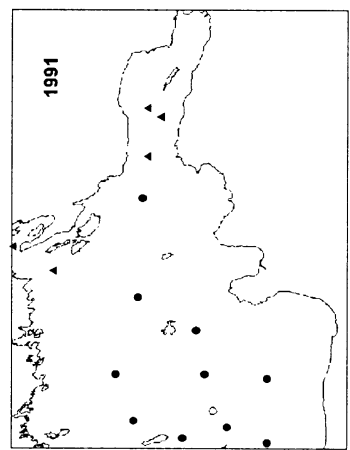
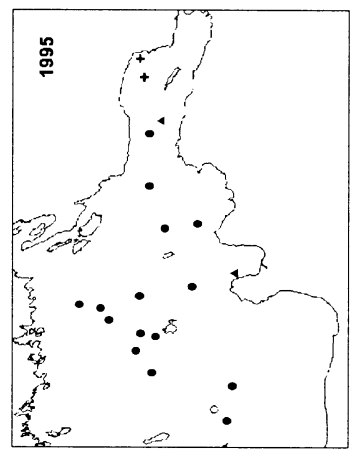
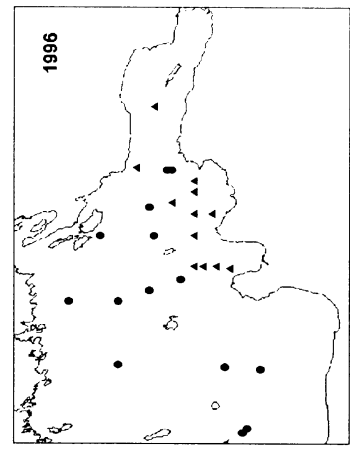
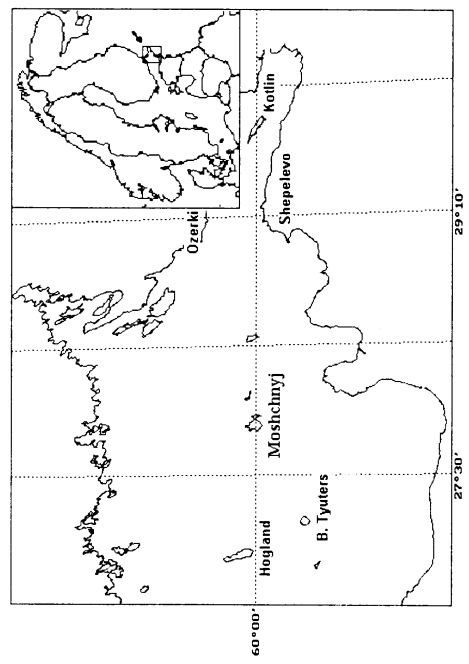
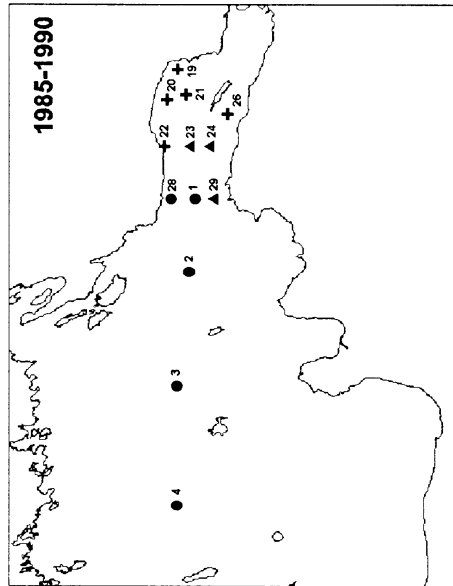
The importance of long-term studies in the interpretation of monitoring data is well known (e.g. Gray & Christie, 1983). The Baltic Sea is one of the most thoroughly studied marine areas of the world. Long-term changes in the bottom communities of the Gulf of Finland are described in many publications (Andersin et al., 1978, 1984; Karjala & Lassig, 1985; Sarvala, 1985; Aschan, 1988; Andersin & Sandler, 1991; Laine et al., 1997; Kangas et al., 2001). However, the information from the inner part of the gulf is insufficient. The aim of the present study is to describe the changes of macrozoobenthos in the eastern Gulf of Finland during the period from 1985 to 2002.

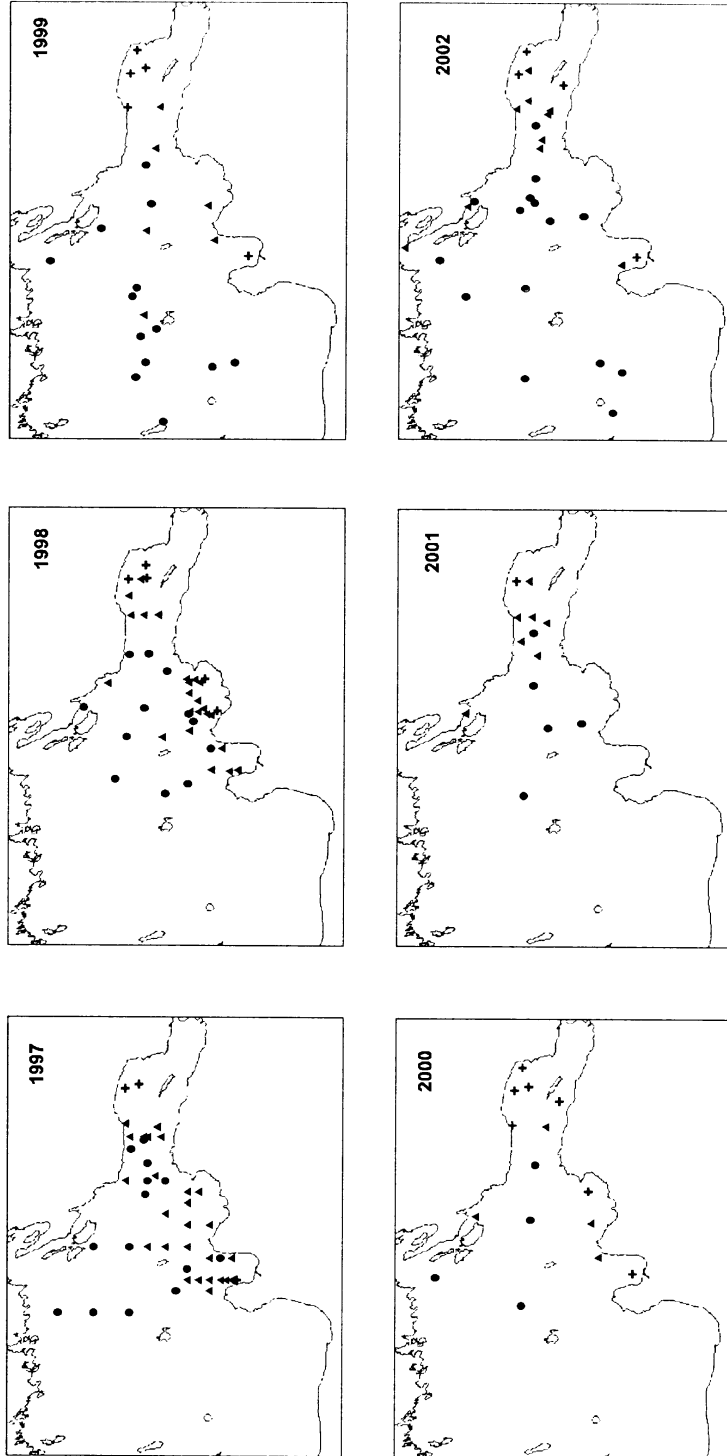
## MATERIAL AND METHODS

Maps of the study area with sampling stations in different years are presented in Fig. 1. At the beginning of the study period (1985–90) seasonal (May–November) series of samples (3–6 times a season) were obtained at 14 stations in the eastern shallow area and along the transect station 1–station 4. Some of these stations were occasionally visited also during the following years, when the investigation covered larger areas of the eastern Gulf of Finland (Fig. 1). In 1991–2002 samples were mostly taken only once a year. For the purposes of this study, I have used data from five comparatively regularly sampled stations at different depths (Table 1). The mean annual biomass and standard error were calculated by pooling replicate grab samples taken at a station, if seasonal series of samples were available. The description of large-scale changes in the macrozoobenthos was mainly based on the material collected in the 1990s (Table 2). Some of the data (up to 1996) included in the present study have been published earlier (Shishkin et al., 1989; Maximov, 1996, 1997).

Sampling was carried out from a depth of 7 m to a depth of 70 m. Macrozoobenthos were sampled mainly by Van-Veen (sampling area 0.1 m<sup>2</sup>) and Ekman-Birdge grabs (0.025 or 0.04 m<sup>2</sup>). Simultaneous samples taken by these grabs in 1990 showed that two methods give similar results (Maximov, 1996). At each

Sampling depth:  
 + 7 to 15 m  
 ▲ 15 to 30 m  
 ● 30 to 70 m





**Fig. 1.** Maps of the study area with the location of sampling stations in 1985–2002.

**Table 1.** Depth and geographical position of the regularly sampled stations

Station	Depth, m	Position	
		Latitude	Longitude
19	10–11	60°06.9'	29°52.4'
24	19–22	60°01.7'	29°26.0'
1	29–31	60°04.0'	29°08.0'
2	35–38	60°05.0'	28°43.0'
3	48–52	60°07.0'	28°04.0'

**Table 2.** Number of stations sampled in 1991–2002

Study area and depth	Year								
	1991	1995	1996	1997	1998	1999	2000	2001	2002
Eastern shallow area									
< 15 m	0	2	0	2	3	4	5	1	3
15–31 m	2	2	1	8	5	2	1	6	7
Deep-water zone									
< 15 m	0	0	0	1	2	1	2	0	1
15–30 m	3	1	11	20	18	4	3	2	4
30–70 m	11	16	13	12	12	13	5	4	14

sampling occasion from 1 to 5 (usually 3) samples were taken. The samples were sieved using screens with mesh sizes of 0.4 mm. The residues were fixed in 4% formalin solution. In laboratory the species composition, abundance, and biomass (formalin wet weight) were determined.

## RESULTS

The bottom macrofauna of the study area is very poor. Altogether about 50 species and forms were found; however, most of them are distributed only in shallow areas. The extensive areas of the deep-water zone (depth below 30 m) are inhabited only by the glacial relict crustaceans *Saduria entomon*, *Monoporeia affinis*, and *Pontoporeia femorata* and several species of oligochaetes. In shallow areas the bivalve *Macoma baltica*, Oligochaeta, and Chironomidae dominate. The eastern shallowest area (depth about 10 m) near Kotlin Island is inhabited mainly by freshwater chironomids and oligochaetes. The most important species are *Chironomus gr. plumosus* and *Potamothrix hammoniensis* (near 90% of the total abundance and biomass). In western areas *M. baltica* dominates.

### Changes in the deep-water zone

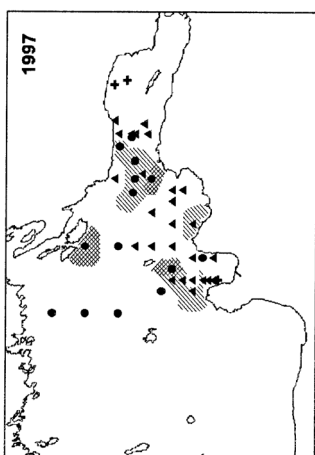
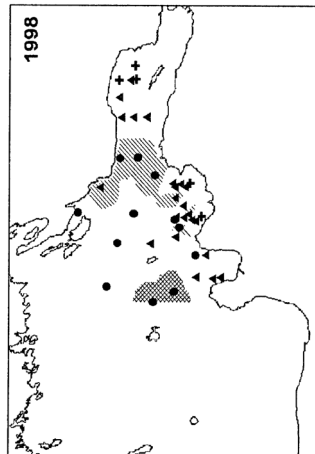
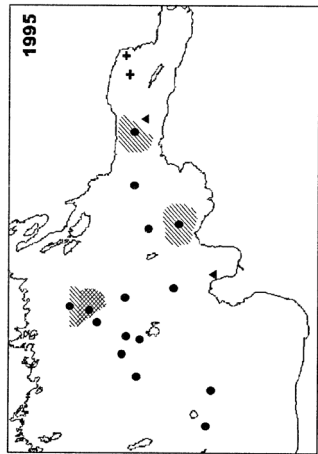
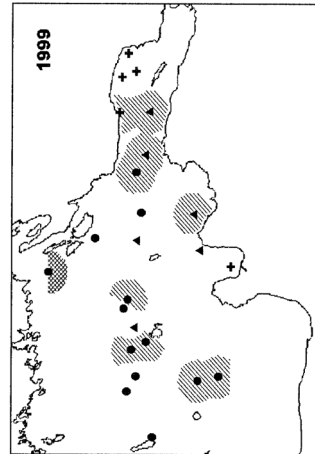
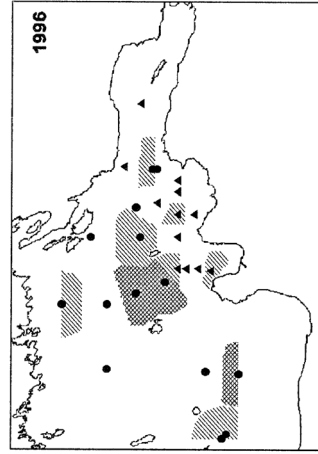
The major changes in the macrozoobenthos of the deep-water area are depicted in Fig. 2. At the beginning of the study period the bottom of the open area was inhabited by dense populations of the glacial relict crustaceans *M. affinis* and *S. entomon*. The abundance and biomass of these animals varied significantly among years and among stations. In the 1980s the biomass of crustaceans reached 50–100 g/m<sup>2</sup> at some sites in the centre of the deep-water zone, the abundance exceeded 10 thousand ind./m<sup>2</sup>. In 1991 bottom animals were most abundant near Narva Bay (about 50 g/m<sup>2</sup>), but a comparatively high biomass (more than 1 g/m<sup>2</sup>) was observed at all stations in the open area. Only one station with a very poor macrofauna was found in the northern part of the Gulf of Finland (Fig. 2). The first observation of an impoverishment of the macrozoobenthos in the open area of the eastern Gulf of Finland was made in June 1995, when a very low biomass (less than 0.01 g/m<sup>2</sup>) was recorded at one station (depth 45 m) in the central part of the study area.

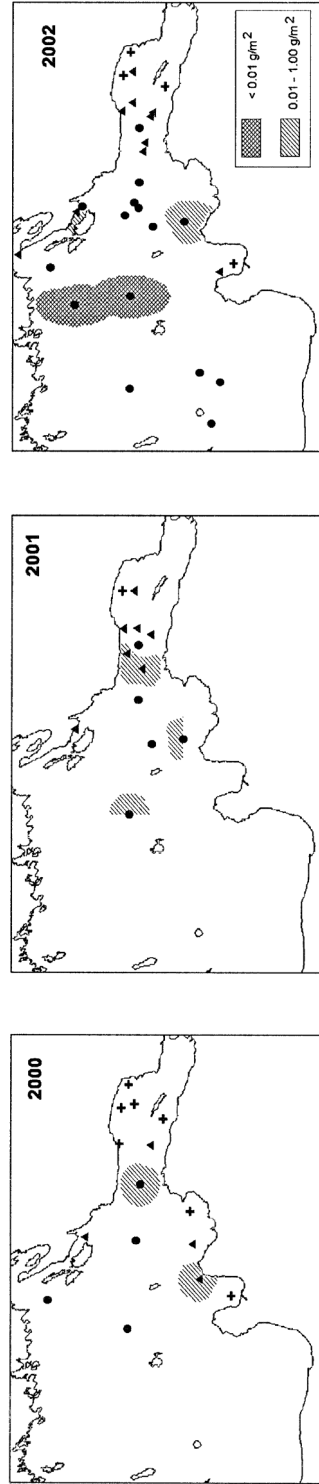
Especially drastic changes took place in 1996, when macrozoobenthos disappeared at several stations (Fig. 2). After that a gradual recovery of bottom communities was observed, but up to 1998 large areas in the eastern Gulf of Finland were totally devoid of macrofauna. In 1999–2001 lifeless bottoms were not recorded; however, macrofauna in previously azoic areas was still poor (biomass was less than 1 g/m<sup>2</sup>), consisting mostly of oligochaetes. In 2001 juveniles of the invasive polychaete *Marenzelleria viridis* settled in high abundance (up to 600 ind./m<sup>2</sup>) over the whole deep-water area, but the biomass of this species was negligible (less than 0.2 g/m<sup>2</sup>). In 2002 bottoms devoid of macrofauna occurred again (Fig. 2).

Changes in different depth zones are presented by data from three almost continuously sampled stations. Station 3 (depth 50 m) near Moshchnyj Island provided a good example of long-term changes described above (Fig. 3). At station 1 (depth 30 m) in the eastern part of the deep-water zone macrozoobenthos showed similar development, with very low biomass in the late 1990s (excluding the seldom occurring large individuals of *S. entomon*) (Fig. 3). At station 2 (depth 36 m) a comparatively abundant but strongly fluctuating macrofauna was observed during the study period (Fig. 3). Both dominant macrofauna species at station 2 exhibited similar trends in interannual abundance and biomass fluctuations: the changes of *S. entomon* populations followed the changes in *M. affinis* abundance.

### The eastern shallow area

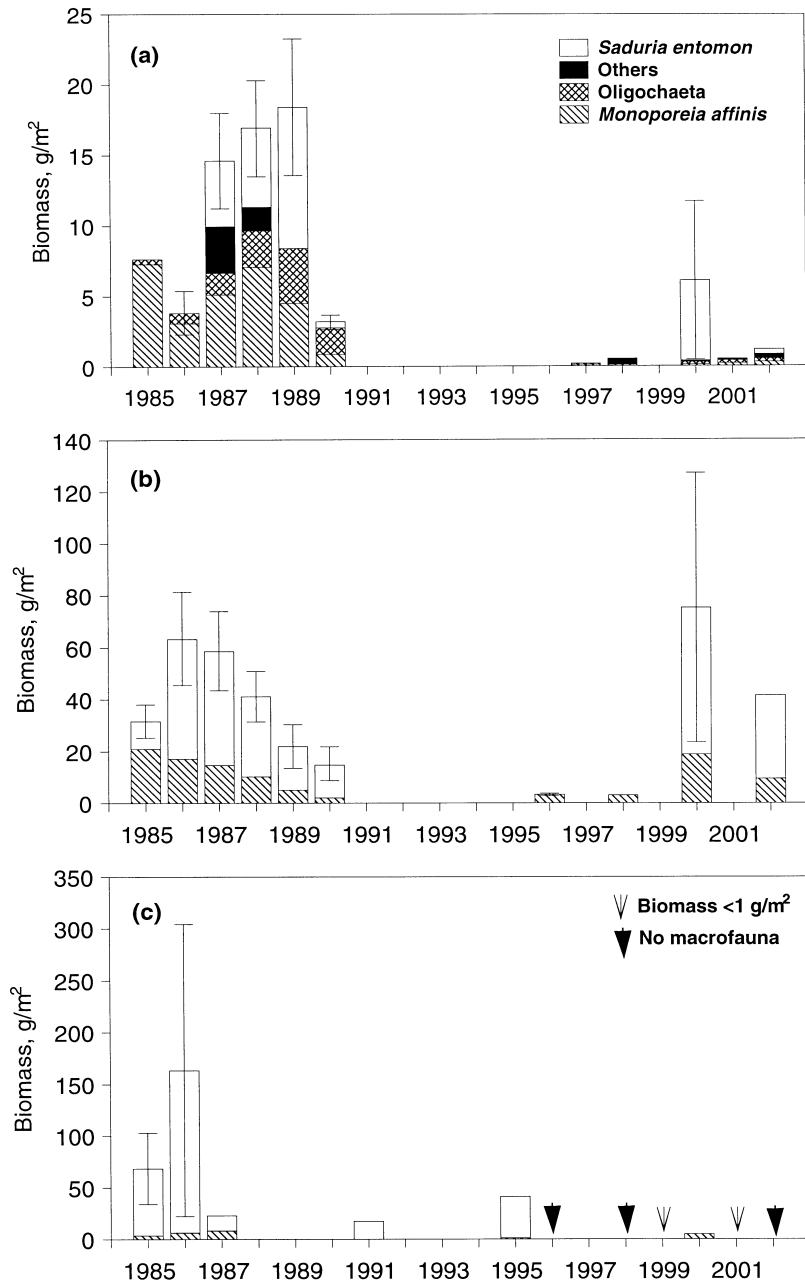
In the eastern shallow area no distinct difference was observed between the 2000s and the beginning of the study period. However, the abundance and biomass of bottom macrofauna fluctuated significantly.





**Fig. 2.** The distribution of the lifeless bottom areas and strongly impoverished macrozoobenthic communities in the eastern Gulf of Finland. See Fig. 1 for stations.





**Fig. 3.** Changes in the biomass and composition of bottom macrofauna at three sites in the deep-water zone of the eastern Gulf of Finland. (a) Station 1, depth 30 m; (b) station 2, depth 36 m; (c) station 3 (depth 50 m). The mean annual biomass ( $\pm$ SE) was calculated by pooling replicate grab samples taken at a station if seasonal series of samples were available.

In 1985 chironomid larvae (mainly *Ch. gr. plumosus*) dominated the biomass at the shallowest sites near Kotlin Island at depths 10–15 m, contributing 98% of the total biomass of macrozoobenthos (Tables 3 and 4). In 1986–87 the abundance and biomass of oligochaetes increased almost ten times in comparison with 1985. So in May 1987 oligochaetes contributed 98% of the total biomass of macrozoobenthos. Owing to almost complete disappearance of the large *Chironomus* larvae the total benthic biomass decreased approximately 6 times in comparison with the same period of the previous year, though the abundance increased (Tables 3 and 4). Considerable fluctuations in this area were observed during the following years. The highest total biomass (over 50 g/m<sup>2</sup>) was found in the years of maximal abundance of *Ch. gr. plumosus*. As an example, the changes of the macrofauna biomass at easternmost station 19 (depth 10 m) are presented in Fig. 4.

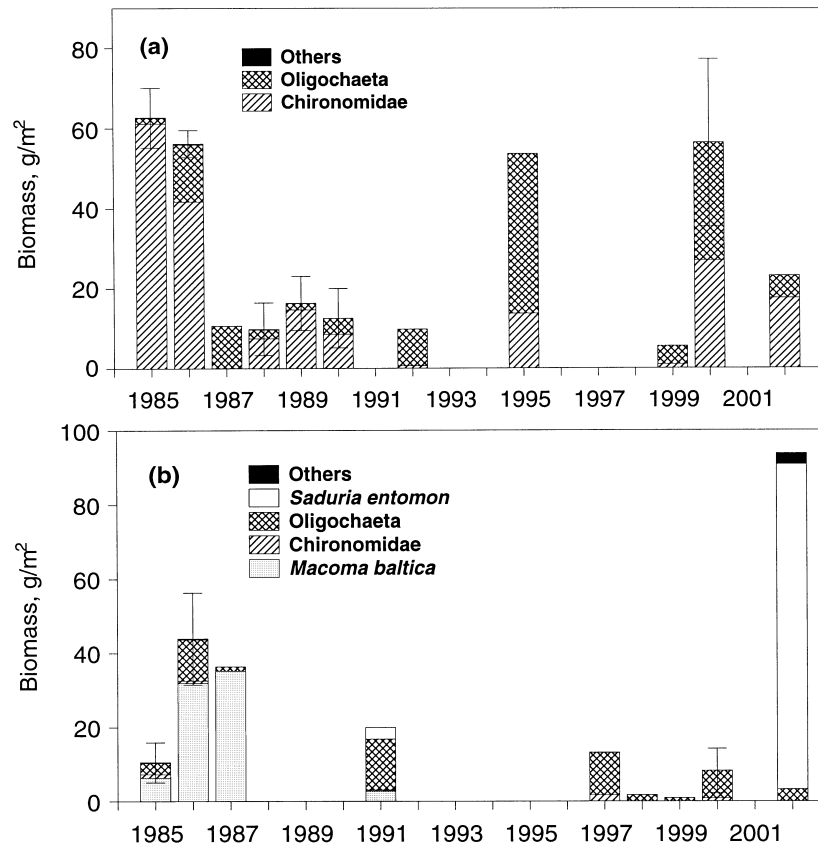
The most important change at depths around 20 m in the eastern shallow part of the study area was the disappearance of the marine bivalve *M. baltica*. In the first years of the study dense *M. baltica* populations (with biomass up to 50 g/m<sup>2</sup>) were observed in this region. In the succeeding years these populations gradually declined and in the early 1990s died out (Fig. 4). After that *M. baltica* was recorded only at stations situated to the west of the Shepelevo–Ozerki transect.

**Table 3.** Interannual fluctuations of the macrofauna abundance (ind./m<sup>2</sup>) at the eastern shallowest sites. NS – no sampling

Station	1–2 June 1985			6–9 June 1986			21–23 May 1987		
	Chironomidae	Oligochaeta	Others	Chironomidae	Oligochaeta	Others	Chironomidae	Oligochaeta	Others
19	3600	800	0	4320	5760	0	220	10 240	0
20	NS	NS	NS	3210	930	0	720	16 300	0
21	1800	440	20	1120	3200	240	NS	NS	NS
22	1520	1760	0	7200	7760	420	180	1 580	160

**Table 4.** Interannual fluctuations of the macrofauna biomass (g/m<sup>2</sup>) at the eastern shallowest sites. NS – no sampling

Station	1–2 June 1985			6–9 June 1986			21–23 May 1987		
	Chironomidae	Oligochaeta	Others	Chironomidae	Oligochaeta	Others	Chironomidae	Oligochaeta	Others
19	69.44	0.64	0	45.20	5.60	0	0.08	10.60	0
20	NS	NS	NS	78.20	1.39	0	0.38	10.52	0
21	25.56	0.14	0.02	11.20	2.32	0.88	NS	NS	NS
22	17.88	1.92	0	105.20	8.80	4.24	1.04	1.56	0.24



**Fig. 4.** Changes in the biomass and composition of bottom macrofauna at two sites in the eastern shallow area. (a) Station 19 (depth 10 m); (b) station 24 (depth 20 m). The mean annual biomass ( $\pm$ SE) was calculated by pooling replicate grab samples taken at a station if seasonal series of samples were available.

## DISCUSSION

The deep areas of the Baltic Proper and the western Gulf of Finland have occasionally been devoid of bottom macrofauna for more than a hundred years because of unfavourable oxygen conditions (e.g. Andersin et al., 1978; Järvekülg, 1979; Seire, 1988; Andersin & Sandler, 1991; Laine et al., 1997). In the eastern Gulf of Finland the salinity stratification is weaker and oxygen concentrations in bottom waters are therefore much higher than in the western part of the gulf. Before 1996 no lifeless bottom was observed in the eastern gulf. However, there were few benthic studies before the 1980s.

In the late summer and autumn of the first year of the study period very low oxygen concentrations (near 2 mg/L) were recorded at some sites, but this short-term oxygen depletion had no effect on the benthos (Shishkin et al., 1989;

Maximov, 1994). During the late 1980s and early 1990s the lack of major salt water inflows into the Baltic Sea resulted in decreasing salinity, and the oxygen conditions in the eastern Gulf of Finland improved (HELCOM, 1996; Lyakhin et al., 1997; Mikhailov, 1997). The favourable hydrographic conditions continued until 1995–96, when oxygen-poor water reached the inner part of the gulf after a salt water inflow into the Baltic Sea (Lyakhin et al., 1997). In 1996 extensive areas of the open eastern Gulf of Finland had very low deep-water oxygen concentrations (less than 2 mg/L) and total anoxia at the surface of the bottom (Lyakhin et al., 1997; Pitkänen & Välipakka, 1997). The conceivable reasons of oxygen depletion in that year were discussed by Lyakhin et al. (1997) and Pitkänen & Välipakka (1997). It is beyond the scope of the present article to review this problem, but undoubtedly the unfavourable oxygen conditions were responsible for the disappearance of macrozoobenthos in the deep zone of the study area in 1996. In that year a large area depleted of macrofauna was found also in the easternmost Finnish waters of the Gulf of Finland (Pitkänen & Välipakka, 1997).

In the eastern Gulf of Finland hypoxia cannot persist over a prolonged period because intensive convective and wind-induced circulation in late autumn breaks stratification of the water column. Hence the oxygen content in the near-bottom water increases (Ostov, 1971; Mikhailov, 1997). This made possible the development of the macrofauna in the eastern Gulf in the late 1990s and early 2000s. The slow recovery of bottom communities after the collapse can likely be explained by the small number of species that can recolonize the lifeless bottom. The recovery of macrozoobenthos ceased in 2002. I have no oxygen data for that year, but the disappearance of the macrofauna indicates that oxygen conditions deteriorated probably in 2002.

Thus the major long-term changes in the macrozoobenthos of the deep-water zone were likely caused by large-scale variations of hydrographic conditions in the Baltic Sea. In sites where disappearance of zoobenthos was not observed in 1996, no clear differences were evident between the 1980s and 2000s. However, the macrozoobenthos biomass showed large interannual fluctuations during the study period.

In the 1980s fluctuations of the bottom animals abundance in the deep-water area of the eastern Gulf of Finland were specially studied at stations 1 and 2 (Maximov, 1996, 1997). It was found that these fluctuations can be explained relying on the hypothesis of Sarvala (1986) that the interannual variations of the *M. affinis* population in the Baltic Sea are connected with intraspecific competition for limited food resources and the action of the mechanism of density dependent regulation. This hypothesis has been supported by field and experimental studies (Hill, 1992; Maximov, 1996; Lehtonen & Andersin, 1998; Elmgren et al., 2001; Wenngren & Ólafsson, 2002). The production calculations showed that in the eastern Gulf of Finland in the years of the peak *Monoporeia* abundance the sedimented detritus can be consumed only by *M. affinis* (Maximov, 1997). Likely, the alternation of the periods of the affluence and the deficit of food

resulted in interannual fluctuations in populations of other detritus-feeding animals (oligochaetes) at station 1, whose abundance followed the changes of *Monoporeia* populations in the 1980s before the oxygen deficiency in 1996 (Fig. 3). The abundance of the predatory *S. entomon* also followed the changes in the populations of its prey – *M. affinis*. Thus, *M. affinis*, because of the auto-oscillatory properties inherent in the populations of this species, generates the fluctuations in the abundance of other bottom animals.

In the eastern shallow area changes of benthic biomass were mainly connected with abundance fluctuations of *M. baltica* and *Ch. gr. plumosus*. The population dynamics of these animals in the eastern Gulf of Finland was not studied in detail. However, considerable fluctuations in the abundance of these species are typical of the Gulf of Finland. They were observed already by Segerstråle (1960, 1969), one of the first researchers of this area of the Baltic Sea. Consequently, the high interannual variability of macrozoobenthos in the eastern shallow area is not surprising.

Significant *Chironomus* abundance fluctuations are known in many water bodies (e.g. Sokolova, 1983; Kangur, 1990). According to Segerstråle (1969), these are a usual phenomenon in the coastal waters of the Gulf of Finland. It is known that the abundance of chironomids can strongly be influenced by meteorological conditions (e.g. Sokolova, 1983; Kangur, 1990). Most likely the fluctuations of *Chironomus* populations in the eastern Gulf of Finland were not linked with any long-term environmental changes. The reasons of changes in the amount of oligochaetes are less clear. In various water bodies, including coastal areas of the Baltic Sea (e.g. Järvekülg, 1979), antagonism between chironomids and oligochaetes is observed. Usually this is explained by consumption of oligochaetes by predatory chironomids (Poptchenko, 1972; Loden, 1974; Soster & McCall, 1989). At a high density *Chironomus* larvae can consume young oligochaetes as an accidental food along with detritus. In the view of some authors (Jonasson & Thorhauge, 1976; Loden, 1974), such non-specific predation can control the abundance of oligochaetes. Explanation of a likely negative influence of oligochaetes on chironomids is possible in the context of the theory of amensalism of trophic groups, which is used widely for the explanation of the spatial distribution of infauna in marine biotopes (Rhoads & Yung, 1970; McCann & Levin, 1989). This theory states that the bioturbation activities of vagile deposit feeders (oligochaetes) will depress less mobile filter-feeding and detritivorous animals (*Chironomus*).

Abundance fluctuations of *M. baltica* in the Gulf of Finland were described by Segerstråle (1960, 1969), Andersin et al. (1978, 1984), Sarvala (1985), and Karjala & Lassig (1985). In the eastern shallow areas *M. baltica* totally disappeared in the early 1990s before the deterioration of oxygen conditions. This disappearance may be explained by decreasing salinity in the eastern Gulf of Finland because of the lack of salt water influxes to the Baltic Sea from the North Sea in 1985–93 (HELCOM, 1996; Lyakhin et al., 1997). However, from 1996, when salinity increased, to the present no recovery of *M. baltica* populations in the eastern area was observed.

Thus, the bottom communities in the eastern Gulf of Finland were radically changed by the extensive deep-water oxygen deficit in 1996. Deterioration of oxygen conditions was responsible for the strong impoverishment and complete disappearance of macrofauna in large bottom areas. Outside of these areas macrozoobenthos showed considerable interannual variations. These variations were likely connected with natural population fluctuations of dominant species. The unusual poverty of bottom macrofauna of the eastern Gulf of Finland leads to uniquely simple bottom communities consisting of only some species. As a result, the fluctuations of the abundance of the dominant species have a great impact on the total biomass of benthos.

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## **Põhjaloostiku muutused Soome lahe idaosas aastail 1985–2002**

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Soome lahe põhjaloostiku muutusi kirjeldatakse ajavahemikul 1985–2002 korraldatud välivaatluste põhjal. 1996. aastast valitseva hapnikudefitsiidi tõttu on süvikute loomastik oluliselt muutunud. Hapniku kontsentratsiooni langusest tingituna on põhjaloostik ulatuslikel aladel vaesustunud (biomass alla 1 g/m<sup>2</sup>) või kadunud. Ehkki madalate merepiirkondade põhjaloostiku kooslustes selgesuunalisi muutusi ei täheldatud, iseloomustab uurimisala loomastikku suur aastavaheline varieeruvus.