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On eutrophication problems in the Baltic Sea - causes and effects

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1. Abstract

Eutrophication has developed to a global problem which increasingly affects coastal and semi-enclosed seas.

In recent decades oxygen concentrations, salinity, and temperature have decreased in the deepwater of Baltic Proper. The winter nutrient concentrations in the surface layer, which are characterized by strong fluctuations in recent times show an increase in the long run.

As expected from the long-term increase in the nutrient levels, also increasing tendencies could be observed for some pelagic biological variables. Changes have been detected even in other compartments of the ecosystem.

The results are discussed from the ecological point of view. The assessment of the present state of the Baltic Sea reflects the complicated combination of natural changes and man induced effects in a sensitive brackish environment.

2. Introduction

The Baltic Sea is a semi-enclosed basin with a restricted horizontal water exchange. Due to its positive water balance which is caused by the large drainage area, the Baltic belongs to the greatest brackish seas in the world. One of its most important features is the permanent halocline restricting the vertical water exchange and dividing the water column in a surface layer with the lower salinity and the more saline deepwater. Below this discontinuity layer, stagnant conditions prevail in central Baltic deep waters causing oxygen consumption and the formation of hydrogen sulphide. Episodic influxes of highly saline water from the North Sea renew the stagnant deep water and improve the oxygen conditions. These major inflows are connected with certain meteorological and hydrographic conditions, e.g. longer periods of strong westerly winds or gales generating a sea level difference between the Skagerrak and the western Baltic Sea.

Since the Baltic Sea lies in the humid climatic zone, its surface layer is characterized by seasonal variations in the hydrographic conditions, the nutrient distribution, and the development of the biota. Due to the heating in spring and summer a thermocline devèlops dividing the water column into the warm surface layer and the cold intermediate water. This discontinuity layer disappears in the cold season.

The Baltic Sea represents a unique brackish water environment with a long residence time of water calculated with about 30 years. It is a geological young sea and exists in the present state only about 5000 years. Therefore, SEGERSTRALE (1957) has called it not yet "matured" what might partly explain the high variability in the system . The fauna and flora is composed by euryhaline organismens with a high ecological capacity. Nevertheless they live under physiological stress conditions which result e.g. in lower diversity and generally in smaller size of the organismns compared with oceanic areas. All this features make the system very sensitive against natural changes and pollution.

On the basis of data obtained by the Institute of Marine Research, Rostock-Warnemünde, changes in the pelagic system which are related to the eutrophication process are discussed in the present paper. Effects on the other compartments of the ecosystem are compiled from the literature. In Fig. 1 the different areas of the Baltic Sea are shown.

3. Long-term nutrient variations

Monitoring data are available for phosphate covering a thirty year's period and for nitrate covering a twenty year's period in the Baltic Sea. With respect to eutrophication, nutrient trends in the surface layer are of high priority. Trend studies in this layer are restricted to the period of low biological activity, that means in winter and early spring, as long as light limits the phytoplankton development.

Fig. 2 shows that the winter concentrations of phosphate and nitrate are increasing on average in the whole period under investigation. The sub-trends indicate, however, that the positive overall-trends mainly result from the increase in the period 1969 - 1977. In recent times, nutrient concentrations show strong variations, but do no longer increase on average. The results explained for stations in the eastern Gotland Sea are also valid for other sub-regions of the Baltic Sea Area (NEHRING, MATTHÄUS, 1990, HELCOM, 1990).

Long-term trends for both phosphate and nitrate were also identified in central Baltic deep waters below the permanent halocline, as long as conditions are oxic. Whereas the nitrate sub-trends do not differ very much from the positive overall-trend shown in Fig. 3, the phosphate accumulation rate is decreasing in recent times.

The situation is more complicated in the near-bottom water layer characterized by alternating oxic and anoxic conditions. Due to denitrification nitrate concentrations decrease to zero during the transition from oxic to anoxic conditions. On the other hand phosphate is remobilized from the sediments in the presence of hydrogen sulphide.

The recent stagnation period beginning in 1977 is the most serious one that has been observed in the Gotland Deep up to now. As in Fig. 4 shown, this period is characterized by the strong increase of phosphate and hydrogen sulphide concentrations. The increase of the last one is reflected in the high negative oxygen equivalents. The recent salinity in central Baltic deep water is the lowest one that has been measured since the beginning of regular hydrographic observations about 100 years ago.

4. Long term changes in pelagic biological variables

Although the available biological data cover a shorter time span than the chemical data, even remarkable tendencies might be discerned. For this assessment only the summer data from four different areas in the Baltic Sea have been used. In this season the system approaches a state of balance and shows therefore the lowest variabilty compared to other seasons (SCHULZ, 1985). In Fig. 5 the chlorophyll content is depicted as an equivalent for the phytoplankton biomass. Although the median values show a high degree of variabilty, in all areas an increasing tendency is visible. Without the last three years, which exhibit a clear decline, the increase would be statistically significant for all areas. Fig. 6 contains the data on in situ primary production.

In this case the interannual variability is also very high, but the rising tendency is even present. Calculating the linear regression, the increase was significant for all areas. The zooplankton biomass (Fig. 7) shows only for the last years a pronounced increase, whereas in the years before only minor changes could be discerned.

5. Discussion

The above mentioned changes in the pelagic system are obviously closely related. As could be expected, an increase of nutrients should improve the growth of at least phytoplankton (SCHULZ, et al., 1985). But in most cases the nutrional conditions improved also for the following biological communities in the food chain. Phosphorus and nitrogen compounds originating from natural and anthropogenic sources are the basis for this process and the reason for an increasing biological production, which regard to higher fish production, a positive effect. The deterioration of the oxygen conditions in stagnant deep waters connecting also with eutrophication is however a serious and negative effect of this process.

The nutrients originate mainly from municipal, agricultural, and industrial sources. They reach the sea by direct waste water input, by river discharge and by air-borne transport. Mass balances for the Baltic Sea also including the wet and dry deposition from the atmosphere yield a gross input of 60 000-80 000 t phosphorus and 800 000 - 1 200 000 t nitrogen compounds per year (MAXIMOVA, 1982, NEHRING, 1982, LARSON et al., 1985). These balances are very rough because the quantitative statements are uncertain for some sources and sinks.

The air-borne deposition is roughly calculated to be 500 000 t inorganic nitrogen compounds, whereas the atmospheric phosphate deposition is insignificant. Generally the air-borne input of nitrogen compounds seems to become more important in recent decades. Time series have shown a steady increase of nitrate and ammonium concentrations in atmospheric wet depositions over central Sweden (SEPA, 1990).

After the period with the strong increase between 1969 and 1977, the winter concentrations of phosphate and nitrate remain, on average, at their high levels in the surface layer of the Baltic Proper, but are characterized by stronger fluctuations in recent times. One reason for the sometimes lower winter concentrations might be that, due to the earlier start of the spring bloom, the nutrient reserves were already consumed to a certain extent by the phytoplankton before the measurements have been performed. Especially in the Bornholm Basin and the southern Gotland Sea, the bloom started very early after the last mild winters.

If the increase at least for the phytoplankton variables is still ongoing, several reasons should be responsible for this. At first the nutrient input acts along the whole year and cannot only be considered from the winter values alone. The winter pool should mainly influence the spring production, which for problems in timing of the observations and variability in the commencement of the bloom could not be included in this assessment. In this paper the summer values are used. It is well known that the rivers not in winter but in early summer transport the largest fright of water and subsequently nutrients to the sea. These nutrients should then enhance the summer production. During this time the utilization of the nutrients is much more intensive than in spring because the pelagic ecosystem approaches the summerly stage with higher turnover rates of the nutrients compared with the other seasons of the year (LEPPÄNEN, 1988). Also the air-borne input of nitrogen compounds should cumulate in the warm season.

In the discussion on eutrophication in the Baltic Sea, the summerly blooms of the bluegreens and their contribution to the nutrient cycle by fixing molecular nitrogen play an important part. Although their functioning especially with respect to the nutrient remineralization is not yet fully understood, one can expect that they are decayed under summer conditions in the surface layer (HORSTMANN, 1975, SCHULZ, 1985). In every case the amount of phosphate left in the pelagic system after the spring bloom is decisive.

Other environmental signals might cause effects on the biological productivity and the nutrient distribution as well. It is well known that an increase in temperature activates metabolic processes and can thus enhance the productivity and the nutrient cycles.

Additionally, periodic cycles of 3, 6 - 7 and 9 - 12 years and even longer are reported by KALEIS and OJAVEER (1990) and TRZOSINSKA (1990) for the Baltic Sea. These cycles are attributed to changes in the atmospheric circulation creating variations in the temperature regime as well as in the freshwater discharge. These variations are also reflected in nutrient cycles producing periods of decreasing and increasing winter concentrations.

One of the natural responses of the ecosystem to get rid of increasing nitrate concentrations is denitrifikation. This process counteracts eutrophication in the Baltic Sea. Budget studies account for a nitrogen loss of 470 000 t/a (RÖNNER, 1985). This is roughly 90 % of the total input from the catchment area and 50 %, when the atmospheric deposition is also included.

The present analysis for the three biological variables in the period 1976 - 1990 reveal beside the high degree of variability also some tendencies in relation to the progressing time. The course of the variables confirms in principle the increasing tendency of previous analysis for the years 1975-1983 (SCHULZ et al., 1985, SCHULZ, KAISER, 1986). This increase is for the three parameters differently pronounced and not over the whole time apparent. In the case of chlorphyll the increase reversed after 1987, wheras in case of primary production the tendency was clearly supported by the steaper rise after the low values of the years 1986/1987. The zooplankton biomass curve with the high values in the last years compensated the deep just before.

In a previous paper (SCHULZ, KAISER, 1986) and the subsequent assessment (HELCOM, 1987), primarily the increase in the nutrient supply and possibly oceanological pecularities of the Baltic ecosystem as e.g. the natural leaning towards stagnation, the nitrogen input by bluegreens etc. were considered as possible causes for the rising trends of the biological variables. The positive effect of nutrients to the phytoplankton productivity could be proofed experimentally in mesocosms also for the Baltic (SCHULZ et al., 1985). In the experiments it could be documented that after a nutrient input not only the productivity of the algae but also the duration of the bloom could be prolonged. This has, however, an important ecological implication, because it diminished the lap in the time scales between phyto- and zooplankton development in spring. This means that more energy is stored in the surface layer and can improve the production conditions also in summer.

Beside our results from the pelagic system , which are confirmed by other authors for different areas of the Baltic (HELCOM, 1990), signs for the eutrophication process are also reported for other compartments of the Baltic ecosystem. Above the permanent halocline an increase of benthos biomass was reported and related to the elevated pelagic productivity (HELCOM, 1985, 1990). Below the halocline a clear decrease was documented because of the oxygen decline. Another consequence of eutrophication is the disappearance of some benthic red and brown algae in shallow coastal areas and a shift to floating filamenteous plants. Partly the nutrient load but also the increasing turbidity due to the higher phytoplankton production is responsible for this development. In this way, spawning substrate and nursery areas for fish larvae and young fish are lost.

Eutrophication might also be one reason for the appearance of "exceptional phytoplankton blooms". An example is the Chrysochromulina polylepis bloom observed in the Kattegat, Skagerrak, and northern North Sea in May 1988 (NIELSEN, RICHARDSON, 1990, HORSTMANN, JOCHEM, 1990) causing among others fish losses in mari cultures (BOKN et al., 1990). Because of the different oceanographic conditions (double layering in summer, thermocline is not nutricline) in the Baltic, the probability of such bloom events can be excluded for the open Baltic waters. A feature of the Baltic, however, is the mass occurance of bluegreens. They might also form toxic events under certain circumstances (HELCOM, 1990).

Remarkable changes have also taken place in the fish stocks of the ecosystem. Total catches of the most important commercial fish species herring, sprat, and cod increased in the Baltic Sea from 450 000 t in 1965 to 900 000 t in 1980 according to ICES statistics. This is partly due to the increasing fishing effort but also induced by improved nutritional conditions for young and adult fish and subsequently higher growth rates. This could be proved for young herring (RECHLIN, 1984). The mentioned fish stocks are ,however,in nutrional relation e.g. the clupeids are food for cod. Variations in one stocks change automatically the balance. The decrease in cod, as observed in recent times, influences the clupeid stocks generally positively. On the other hand, the environmental conditions do not only influence the stock size but also the recruitment success. The decrease in this respect especially for cod is not only caused by the unfavourable oxygen condition but also by the extremely low salinity in Baltic deep waters injuring the fertilization of the cod eggs (WESTIN, NISSLING, 1991).

The recent nutrient pool in the Baltic Sea and the resulting organic production and sedimentation of organic matter burden the oxygen conditions near the bottom. In late summer and autumn, this process is sometimes strenghened by the low oxygen concentrations of the inflowing deep water. Hydrogen sulphide concentrations are increasing in central Baltic deep waters. Fig. 8 shows the areas which are very often affected by low oxygen concentrations and anoxic conditions in the near- bottom water layer.

Occasionally, anoxic conditions are also observed in the relatively shallow Mecklenburg, Lübeck, and Kiel Bays as well as in the southern Kattegat. Even when the deep water contains oxygen, the transition zone between water and sediment is often anoxic in late summer and early autumn. The deterioration of the oxygen conditions restricts the living space of benthic organisms including demersal fish.

5. Conclusions

The present status of the Baltic Sea indicates that eutrophication and its consequences are proofable for all compartments of the ecosystem. The reaction of the biota to this process is an increase in the productivity of the organisms living in the well aereted surface water. No clear changes have been identified in the species composition up to now. The opposite development must be stated for the communities living in the deeper parts of the Baltic Sea. Below the halocline serious impoverishment at the species level and decrease in biomass has taken place due to the deterioration of the oxygen conditions. This is valid expecially for the benthic community.

The causes for the eutrophication are primarily the continuation of nutrient inputs into the system. However, the special oceanological conditions in the Baltic characterized by the restricted horizontal and vertical water exchange should not be disregarded in this respect. Furtheron the climatological changes taking place, especially the global heating, must be considered.

Thus, the changes observed in the Baltic Sea are the combination of different causes. This makes the decisions finding very difficult and uncertain. It is, however, a well proofed fact that the man induced nutrient input into the sea creates at least a considerable part of the problems. The decision of the Baltic States to reduce the input of pollutants to 50 % until 1995 is therefore a good message for the Baltic ecosystem.

6. Literature

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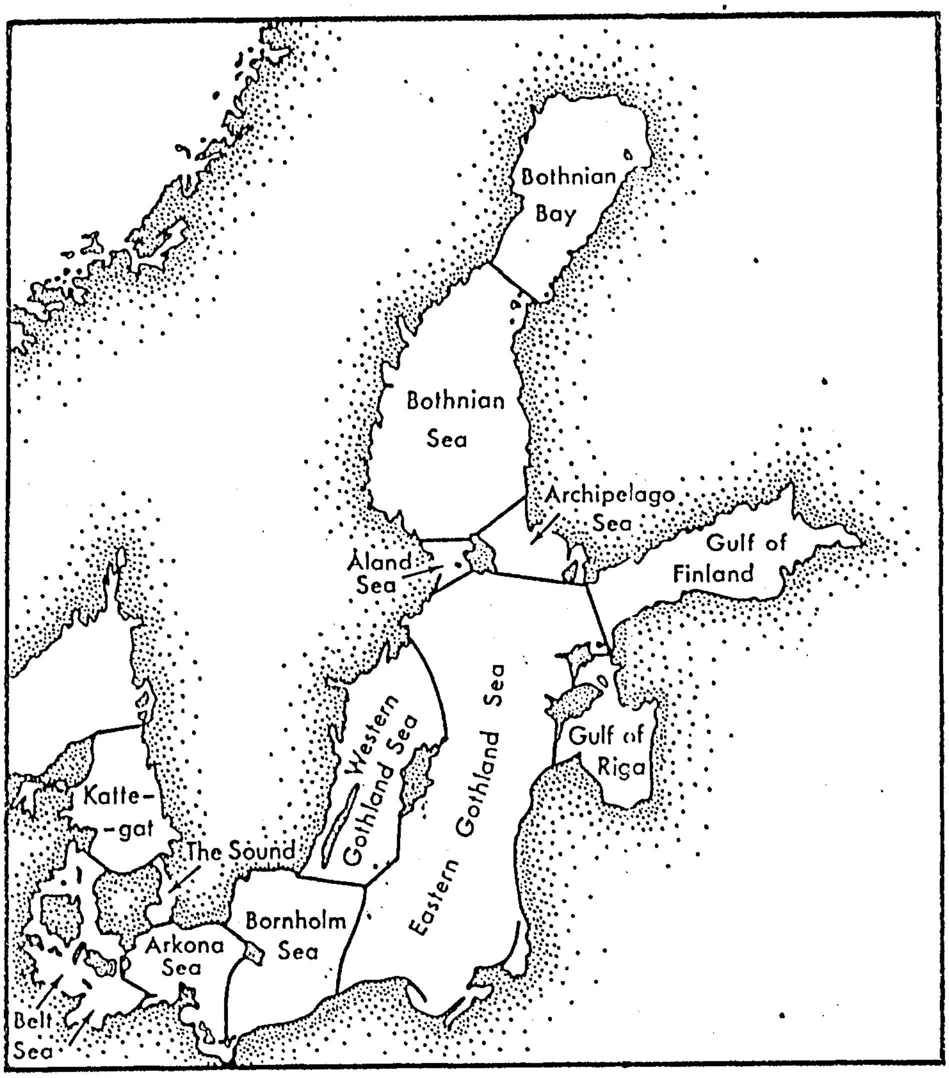

Fig. 1

The subareas of the Baltic Sea

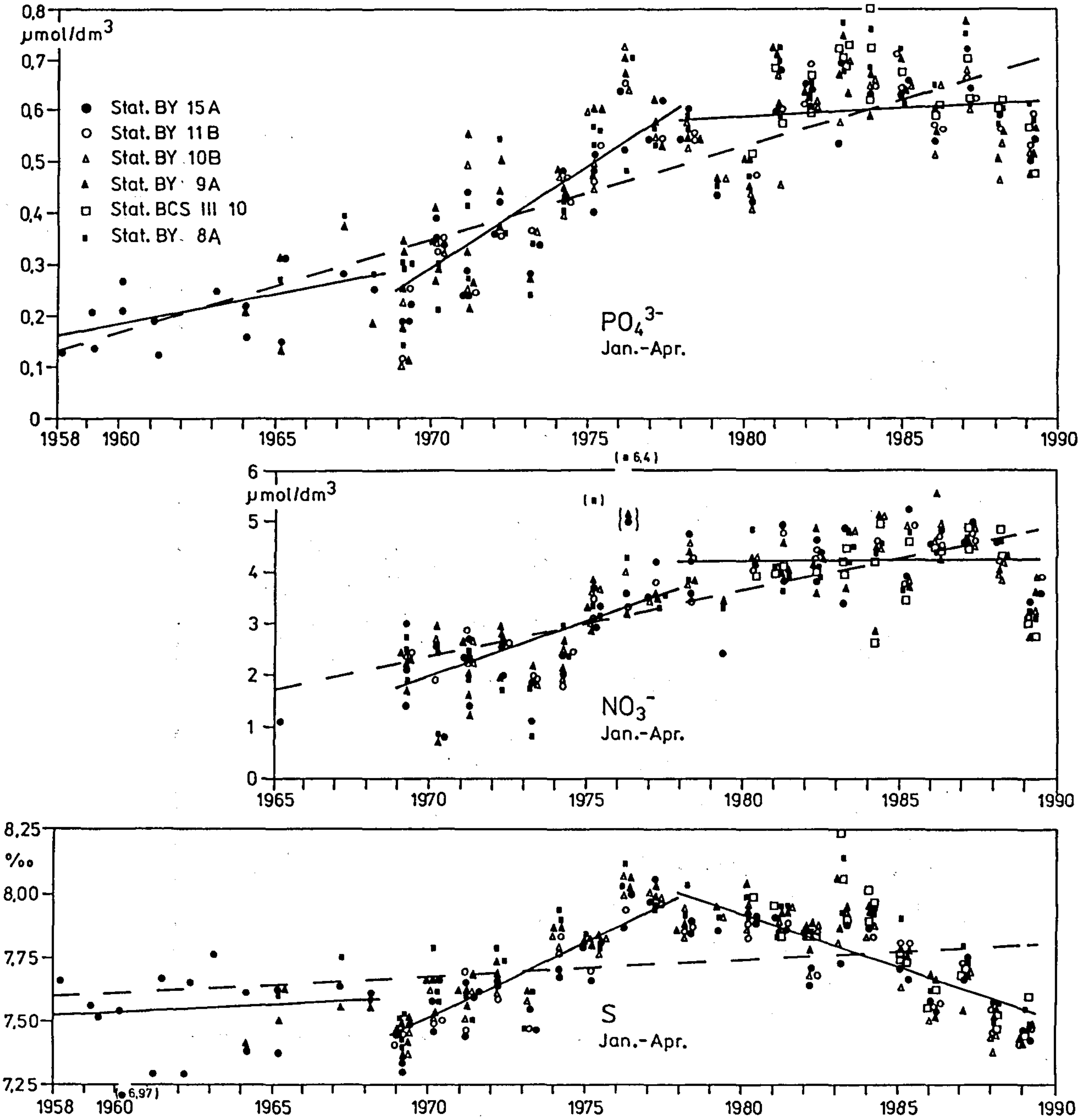

Fig. 2

Trends in the winter surface layer of the south eastern Gotland Sea

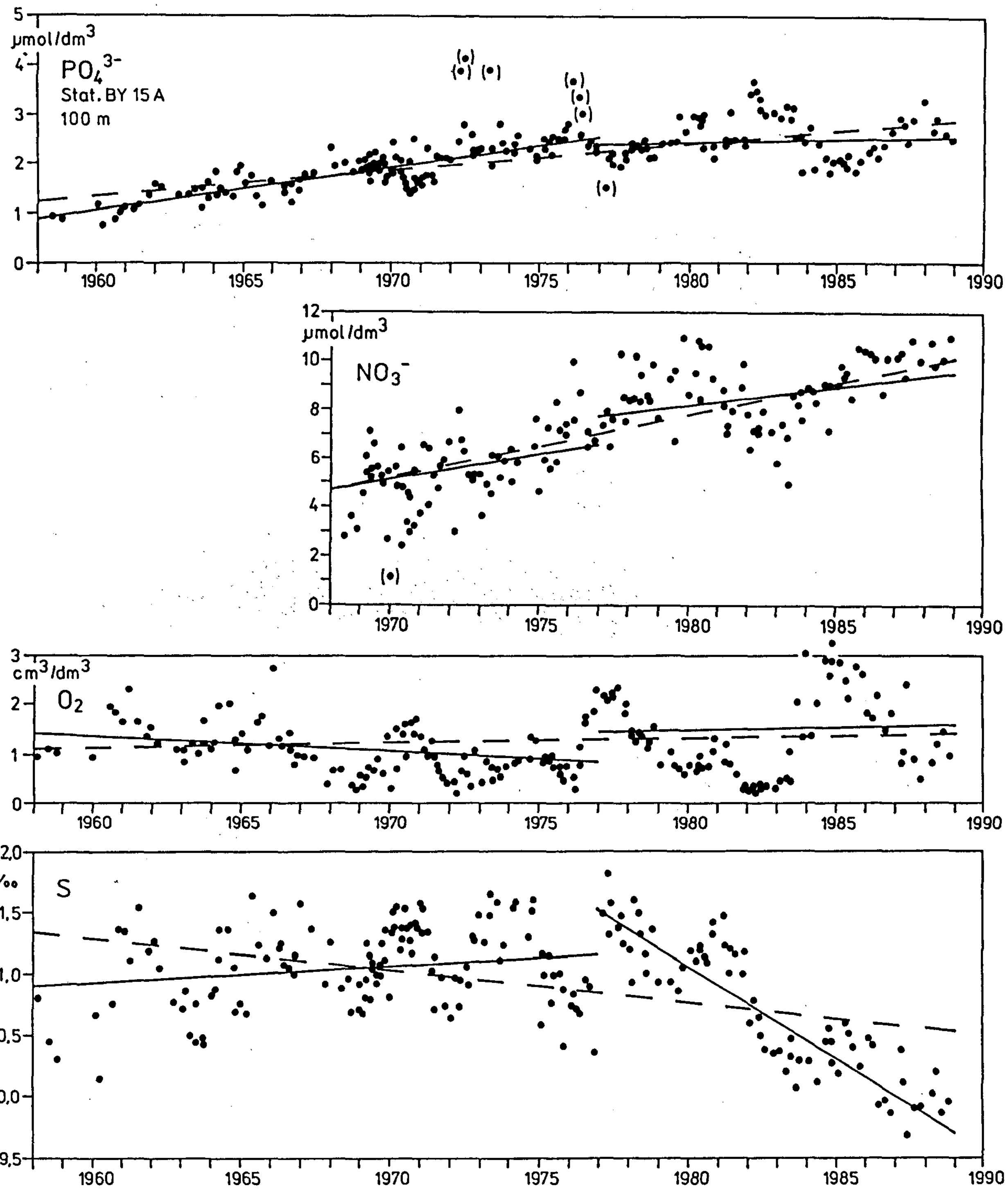

Fig. 3

Trends in the deep water (100 m) of the Gotland Deep

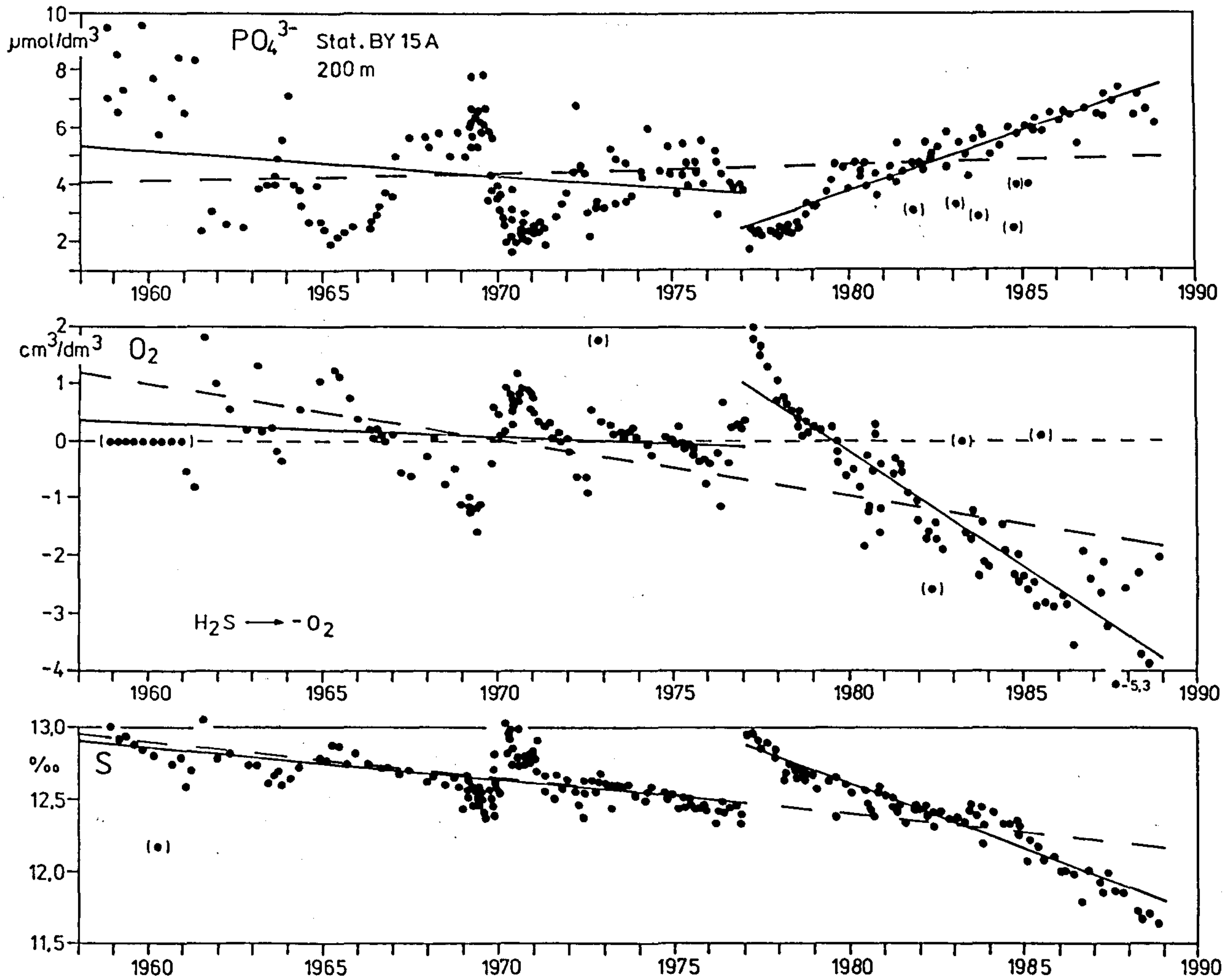

Fig. 4

Trends in the near-bottom water layer (200 m) of the Gotland Deep

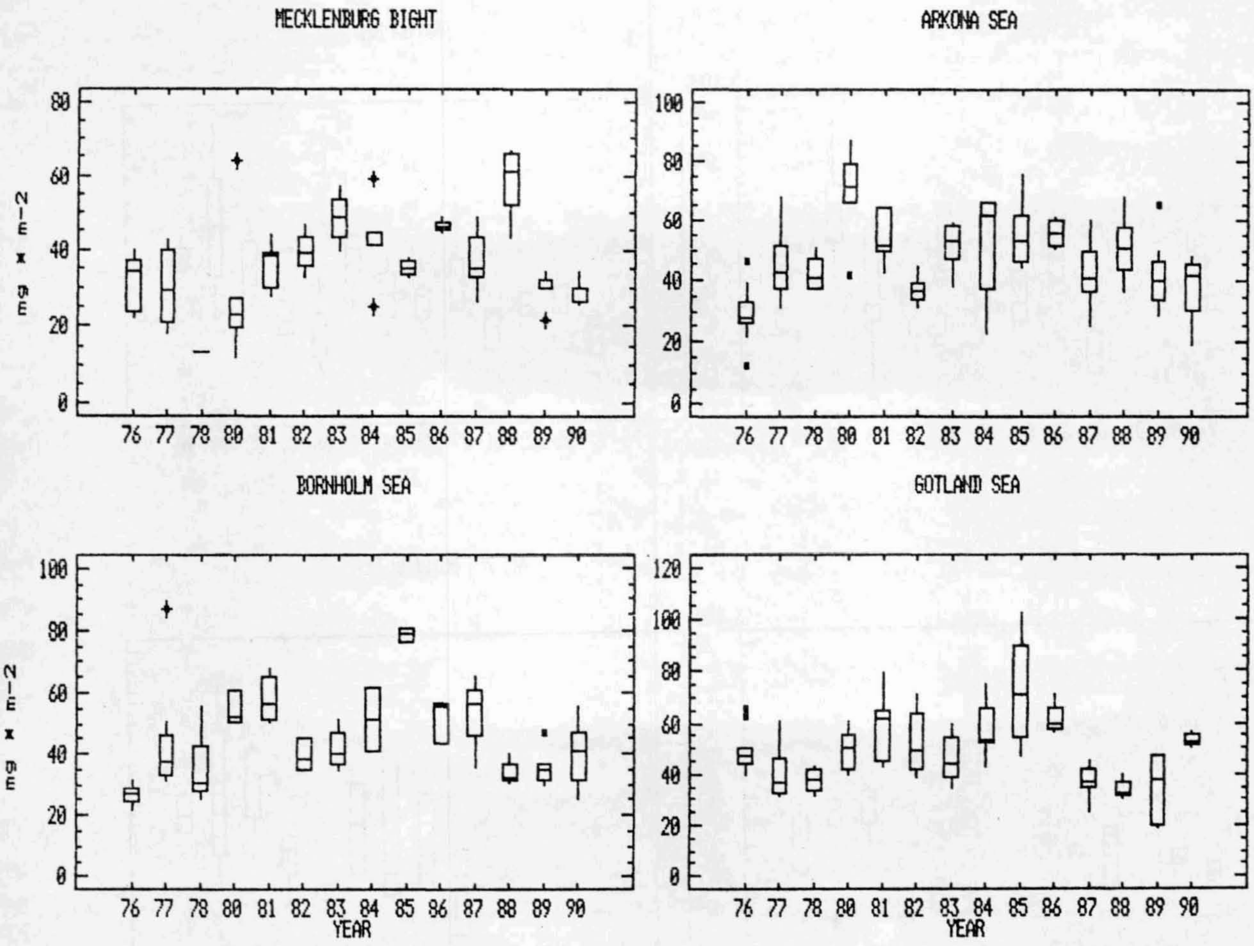

Fig. 5

The variability of chlorophyll concentrations ($mg.m^{-2}$) in the uppermost 0 - 30 m layer of the different areas of the Baltic Sea in summer. The central box covers the middle 50 % of the data values, between the upper and lower quartiles. The central horizontal line represents the median. The "whiskers" extend to the maximum and minimum values. Extrema are plotted as separate points.

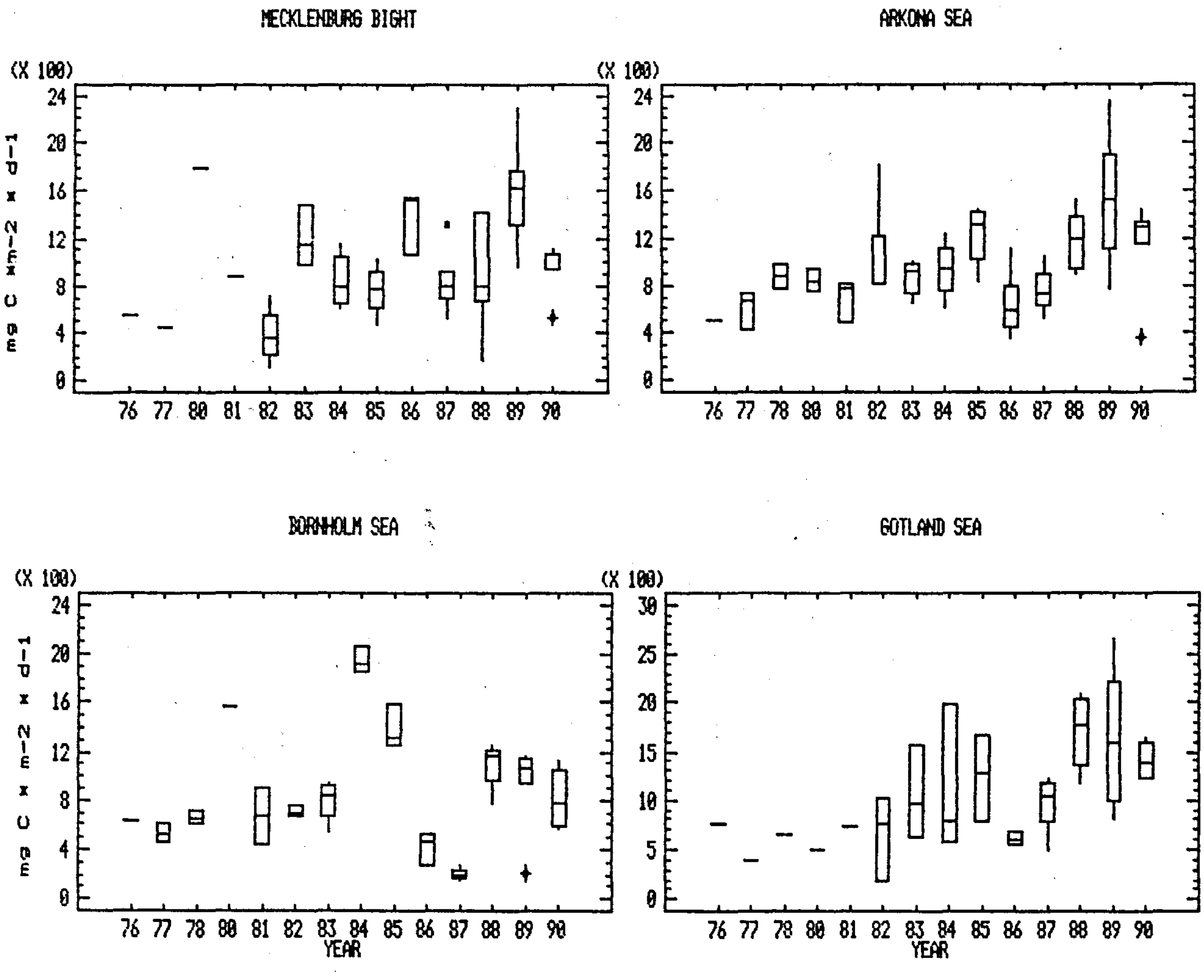

Fig. 6

The long-term variability of summer primary production values (mg $C.m^{-2}.d^{-1}$) in different areas of the Baltic Sea

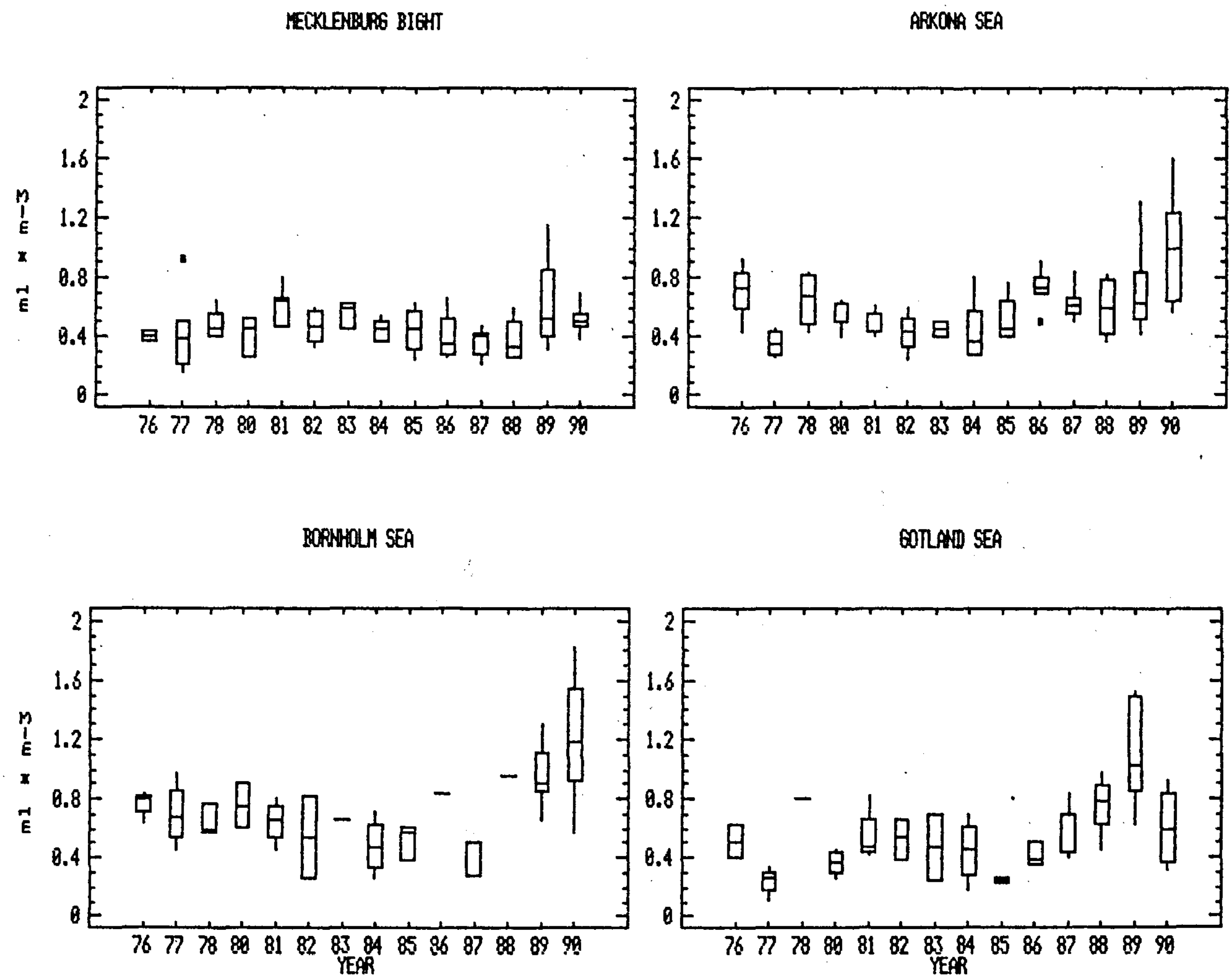

Fig. 7

The variability of mesozooplankton biomass ($ml.m^{-3}$) for the surface layer (0 - 25 m) in the different areas of the Baltic Sea

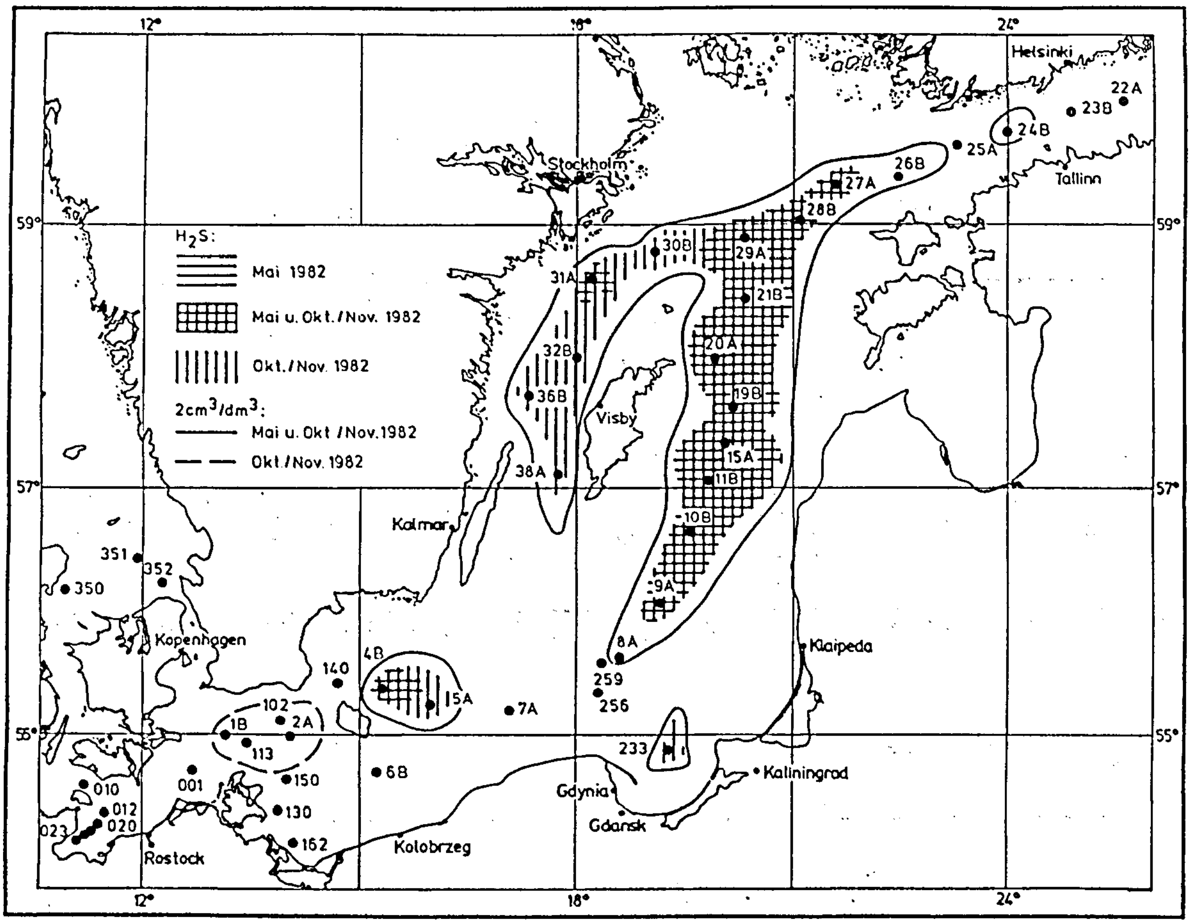

Fig. 8

Areas with low oxygen concentrations and hydrogen sulphide in the near-bottom water layer