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RECENT NUTRIENT TRENDS IN THE WESTERN AND CENTRAL BALTIC SEA, 1958–1989

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Trend studies on concentrations of phosphates and nitrates, covering the period of 1958–1989 show that a period of a strong increase in phosphates and nitrates accumulated in the winter surface layer of the Baltic proper was followed by a period of generally small changes, beginning in 1978. Since 1977, the positive trend coefficient of phosphates has been also decreasing in the oxic intermediate layer below the permanent halocline in the central Baltic Sea, whereas nitrate accumulation was continuing nearly unchanged in the whole period under investigation.

In connection with the absence of major inflows of highly saline water masses into the Baltic proper, the salinity and oxygen content have been decreasing in the stagnant deep layer of its central part since 1977, whereas phosphate contents increased mainly due to the release from sediments in the presence of hydrogen sulphide.

Very high peaks of nutrient concentrations were observed in shallow coastal waters (Pomeranian Bay) not only in the period of low biological activity, but also in late spring and summer.

Consequences of the recent nutrient conditions are discussed with respect to eutrophication of the Baltic Sea.

INTRODUCTION

In the recent years, eutrophication of water bodies has been mainly caused by anthropogenic factors, the importance of natural causes being minor. The Baltic Sea is a semi-enclosed basin with a restricted horizontal and vertical water exchange and is therefore very sensitive to inputs of organic matter and nutrients from land and air.

Regular hydrographic monitoring programmes have been performed in the Baltic Sea since the beginning of the century. Nutrients and biological parameters were

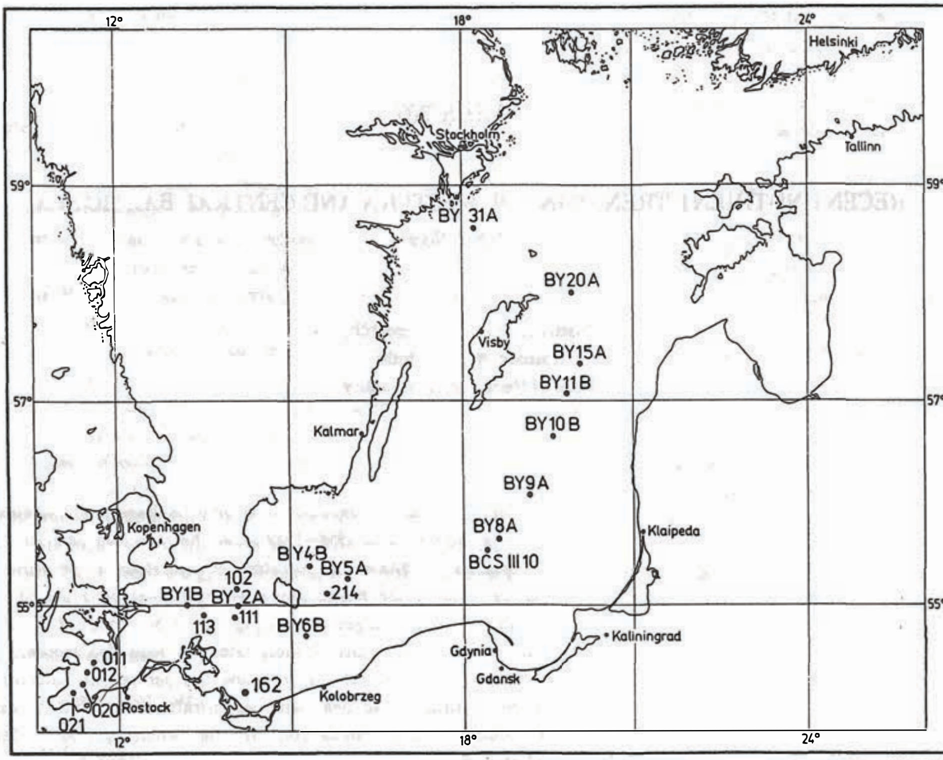


Fig. 1. Map of stations

included into these activitaties in the recent decades. Fig. 1 shows the distribution of stations monitored by the Institute of Marine Research, Rostock-Warnemünde.

The long time-series of nutrient data on hand, beginning in the late 1950's, makes trend studies, by means of linear regression analysis, possible. Data sources are given in the References.

Nehring (1985) and Nehring and Francke (1985) studied longterm variations in phosphates and nitrates, the most important, algal growth limiting nutrients in the Baltic Sea. Concentrations of both nutrients showed a significant increase not only in the surface layer in winter, but also in the deep water below the permanent halocline in the period of 1958–1983. These findings, valid for the western and central parts, were also confirmed in other subregions of the Baltic Sea (Anonymus 1987b). The purpose of the present study was to bring the analysis of nutrient trends in the western and central Baltic Sea up to the present time.

RESULTS

Investigations into nutrient trends in the surface layer are restricted to the winter period when a low light intensity limits productivity of the phytoplankton, and nu-

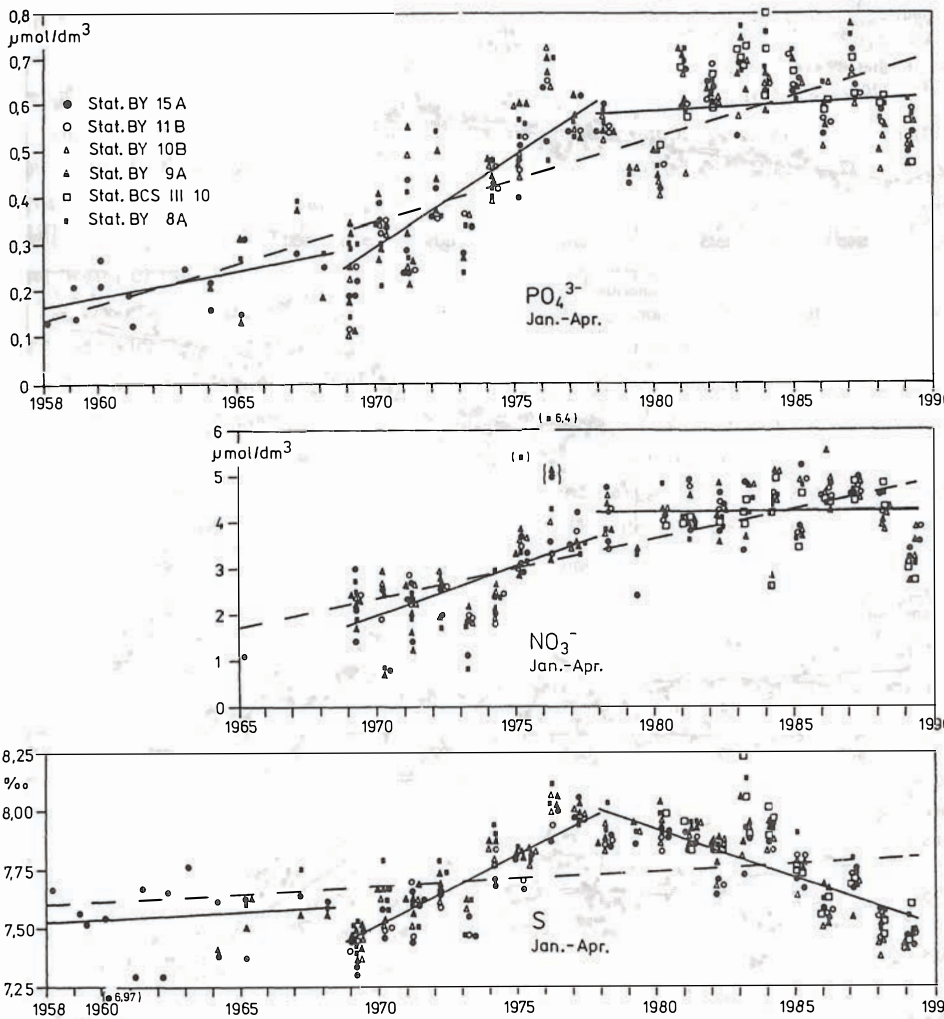


Fig. 2. Trends of nutrient concentrations and salinity under winter conditions in the surface layer of the southeastern Gotland Sea

trients are accumulated. Fig. 2. shows the behaviour of the phosphate and nitrate pools in the winter surface layer of the southeastern Gotland Sea. Both nutrients show a positive overall trend which is statistically significant (Student's t test). Separate trends covering shorter periods were also identified. The strong increase between 1969 and 1977 was followed by a period of generally insignificant changes. The last period is characterized by strong fluctuations in the nutrient accumulation.

Initially, salinity (Fig. 2) was strongly correlated with nutrient concentrations (cf. Nehring 1985). Since the 1980's, a significant decrease in salinity deviates from the behaviour of the nutrients in the winter surface layer.

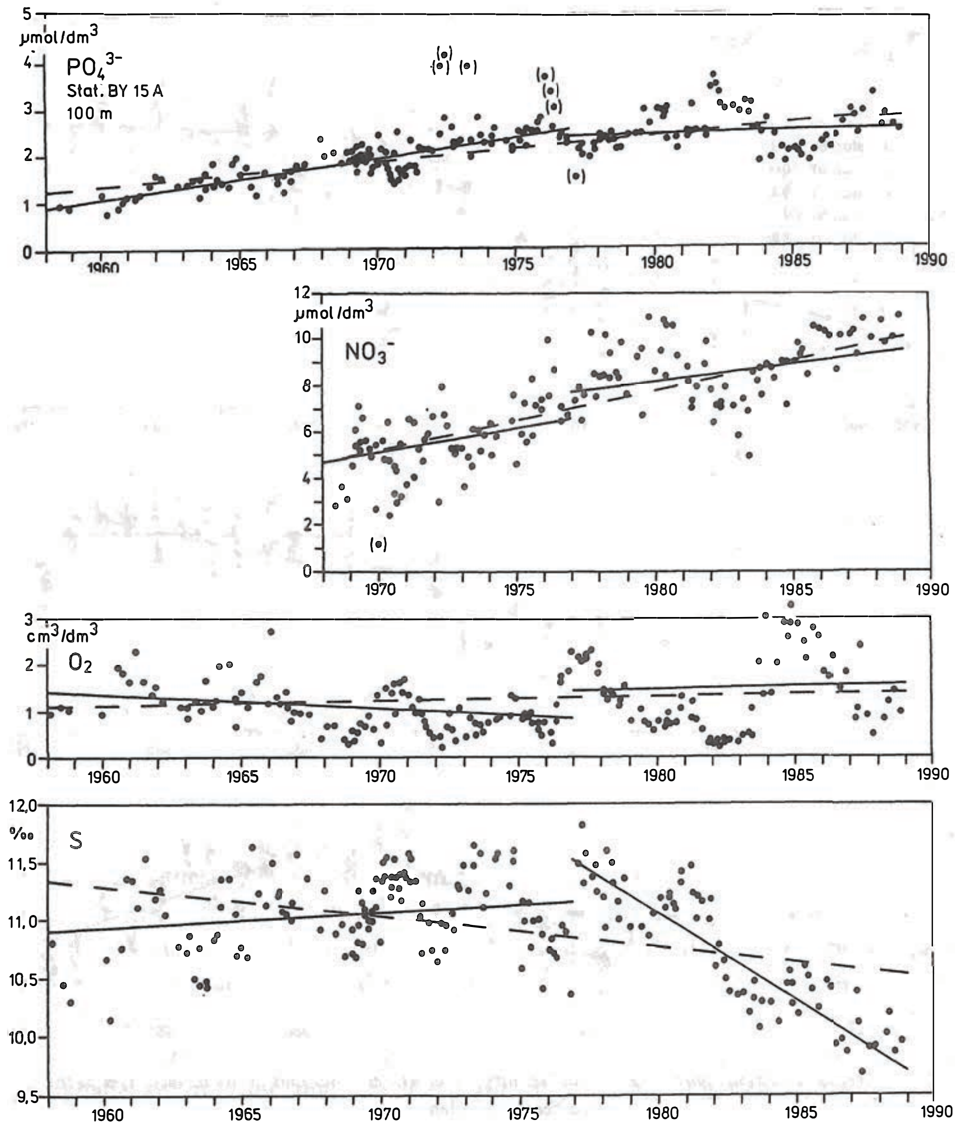


Fig. 3. Trends of oceanological parameters in the intermediate layer of the Gotland Deep

Findings shown for the winter surface layer in the southeastern Gotland Sea are also relevant for the Bornholm Sea and the Arkona Sea (Nehring and Matthäus in press). In the Mecklenburg Bight, the incerase in nutrient concentrations continues generally without characteristic trends in separate periods.

Long-term variations in the phosphate and nitrate concentrations were also studied below the permanent halocline in the central Baltic Sea. The results obtained show a difference to exist between the intermediate layer with permanent oxic conditions and the deep water with alternating oxic and anoxic conditions. In the latter case, denitrification during the anoxic transition and phosphate release from sediments in the presence of hydrogen sulphide influence the nutrient trends (cf. Nehring 1987).

The trends below the halocline are discussed on an example rendered by the situation in the Gotland Deep (Station BY15). The periods studied terminate with the last strong salt influx into the Baltic proper which brought about a renewal of water in the Gotland Deep in 1977. Since then, stagnant conditions have been prevailing in the deep water of the area.

Fig. 3 shows the trends at the 100 m depth. The oxygen concentrations are sometimes very low there, but anoxic conditions had never been observed until now. The separate nutrient trends do not differ very much from the positive overall trends. However, the trend coefficient for phosphates shows a significant decrease in the second period, whereas nitrate accumulation continues nearly unchanged in the whole period under investigation. Oxygen conditions have the tendency to improve in this layer, although no significant trend could be identified. The salinity trend was

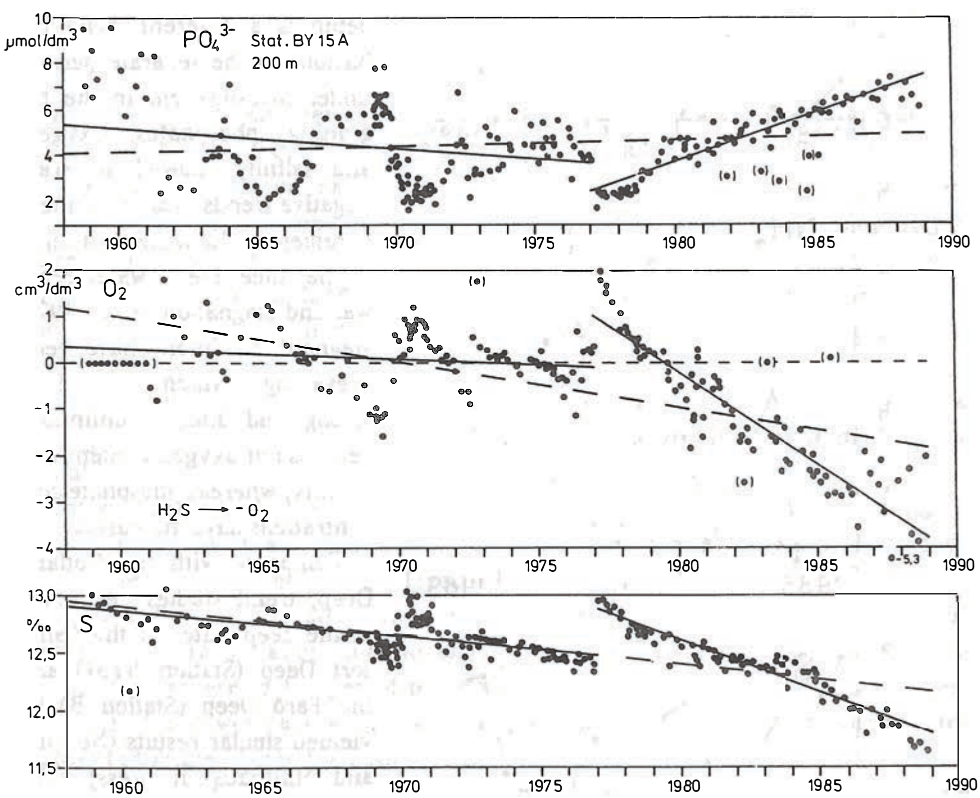
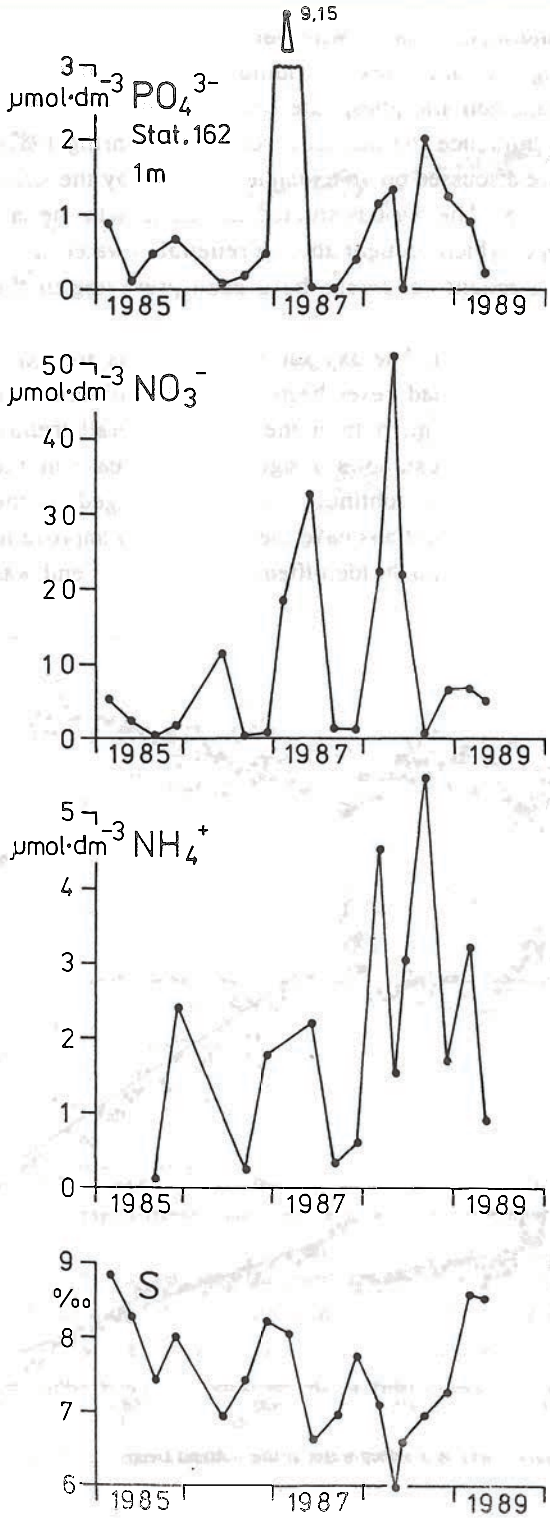


Fig. 4. Trends of oceanological parameters in the deep water of the Gotland Deep



significantly positive initially and turned negative since the late 1970's. Because of this inversion, the overall trend strongly differs from the separate trends.

The situation under alternating oxic and anoxic conditions is illustrated for the 200 m depth level in Fig. 4. Nitrates were excluded from the analysis because of denitrification. Hydrogen sulphide was converted to negative oxygen equivalents ($S^{--} + 2O_2 = SO_4^{--}$) in order to get comparable values.

The most important feature of the parameters studied at that depth is a different trend behaviour in the separate periods under investigation. In the beginning, phosphates, oxygen, and salinity showed moderate negative trends. Values of these parameters fluctuated strongly at that time due to water renewal and stagnation. Since 1977, stagnant conditions have been prevailing, which caused a strong and almost continuous decrease in oxygen content and salinity, whereas phosphate concentrations have increased.

Compared with the Gotland Deep, trend studies performed in the deep water of the Landsort Deep (Station BY31) and the Farö Deep (Station BY20) yielded similar results (Nehring and Matthäus in press). The

Fig. 5. Variations of nutrients and salinity in the surface water of the Oder Bank

Bornholm Deep (Station BY5) differs in this respect. In contrast to the eastern Gotland Basin, the deep water in this area has occasionally been renewed in the recent times. Therefore, variations caused by water renewals and stagnation periods influence the trends for the whole period under investigation. The overall nutrient trends are positive in the deep water of the Bornholm Deep and negative for oxygen and salinity. Due to seasonal water renewals, it was not possible to identify trends of hydrochemical parameters in the deep water of the Arkona Basin and the Mecklenburg Bight.

Eutrophication-caused problems are intensifying in coastal areas. Fig. 5 shows the behaviour of nutrients and salinity in the shallow Pomeranian Bay (Station 162). Too few data points have prevented trend calculations.

The peak nutrient concentrations measured near the sea surface in the Pomeranian Bay are increasing. Occasionally, concentrations of phosphates and nitrates by far exceeded the concentrations found in oceanic deep waters. High nutrient values were not restricted to the period of low biological activity, but were also observed in May and August. They are roughly correlated with a lower salinity indicating the influence of river water.

DISCUSSION

Phosphorus and nitrogen compounds are the driving forces in eutrophication. Changes in trends of these parameters, which have occurred since the late 1970's, concern not only the surface layer, but also the deep water in the Baltic proper. Generally, the winter concentrations of phosphates and nitrates have no longer been increasing significantly in the surface layer since 1978. As there is no indication of a considerable decrease in land-based and airborne inputs, the changes in the nutrient trends recently observed in most parts of the Baltic Sea Area can be summarized as follows:

- Steady state has been approached between inputs, biogeochemical sinks, and recycling of nutrients, including also nutrient exchange through the inlets to the Baltic.
- Interannual 3– to 4– and 6– to 7-year cycles attributed to changes in the atmospheric circulation create variations in the river run-off and are also reflected by changes in the nutrient trends (Trzosińska in press).

It seems that nutrient distribution in the winter surface layer is characterized by stronger temporal variations than assumed previously. This assumption also includes the strong increase in the period of 1969–1978. Although eutrophication at present proceeds at a slower pace with respect to phosphate and nitrate accumulation, the nutrient pools are high in the Baltic proper.

As opposed to the offshore areas in the Baltic Sea, eutrophication strongly increases in the shallow coastal waters due to river discharges and direct inputs of waste water and sewage. An example is rendered by the Pomeranian Bay in the southern Arkona Sea. The nutrient load discharged by the rivers Oder and Peene is the reason for the extremely high phosphate and nitrate concentrations recorded occasionally in the area. The high nutrient concentrations are not restricted to the winter conditions, but were also observed in late spring and summer when the surface layer in the western Baltic Sea is usually impoverished in inorganic phosphorus and nitrogen compounds owing to the phytoplankton growth. This means that light may become the limiting factor for the phytoplankton community in the Oder Bank area during the biologically productive seasons.

A consequence of the high nutrient pool in the euphotic layer of the Baltic Sea is the increasing biological productivity. This is indicated by the positive trends in the phytoplankton biomass (chlorophyll *a*) and primary productivity (Schulz and Kaiser 1986) and also by increasing biomass of the macrozoobenthos (Cederwall and Elmgren 1980; Gosselck 1985) wherever the gen content is not the limiting factor. According to ICES statistics, overall catches of the most important commercial fish species: herring, sprat, and cod, had also increased from 450,000 t in 1966 to 900,000 t in 1980, thereafter remaining at that level. It is not only the growing fishing effort, but also eutrophication resulting in better feeding conditions for fish larvae and fish that is responsible for the increasing catches in the 1970's.

The most important negative change caused by eutrophication is the deterioration of oxygen conditions in the Baltic Sea, indicated not only by the decreasing oxygen concentrations, but also by the increasing contents of hydrogen sulphide and spread of the anoxic zones in the deep water. This process, which restricts the living space for fish and other aerobic organisms, results from oxygen consumption during microbial decomposition of the increasing amount of biogenic organic material produced in the euphotic layer mainly during spring phytoplankton blooms.

Another reason for the current strong deterioration of oxygen conditions is the absence of major inflows of highly saline water masses into the Baltic Sea since 1977. The stagnant conditions reflected in the nearly continuous decrease in salinity contribute also to accumulation of hydrogen sulphide (negative oxygen equivalents) in the deep layer of the Gotland Sea. The decrease in the redox potential caused by increasing concentrations of hydrogen sulphide favours phosphate release from sediments (cf. Nehring 1987), which – taken together with microbial remineralization of organic matter – has been the main cause of phosphate accumulation in the anoxic deep water since 1977.

The increasing phytoplankton biomass in polluted coastal areas reduces the light penetration depth, thus deteriorating living conditions of phytobenthos in shallow waters, whereby much of the fish spawning substrate is lost, fish larvae and young fish losing their nursery areas.

Nutrient discharge in coastal areas favours also exceptional algal blooms. An example is the toxic *Chrysochromulina polylepis* bloom observed in the Kattegat and

North Sea in May 1988 (Dahl et al. in press; Horstmann and Jochem unpubl. manuscript; Lindahl 1988).

Major inflows of highly saline water into the Baltic Sea depend on the development of an anomalous atmospheric circulation pattern over the northern hemisphere (Dickson 1971). They are also connected with variations in the meridional circulation over the North Atlantic Ocean, the zonal circulation over the Baltic Sea, and the sea level (Börngen et al. in press). Both the strong deterioration of oxygen conditions and phosphate accumulation in the central Baltic deep waters prevailing since 1977 resulted predominantly from a prolonged absence of water renewal in the recent times and were therefore caused by climatic changes.

On the other hand, the high land-based (Anonymus 1987a) and atmospheric (Anonymus 1987b) inputs from antropogenic sources show effects of human activities on eutrophication in the Baltic. Domestic and agricultural sewage directly discharged or transported by rivers into the sea is the main cause of the increasing nutrient load in shallow coastal areas.

The countries bordering the Baltic have to make a great effort to protect the environment of this semi-enclosed sea against irreversible changes and to avoid having foul beaches. The efforts are coordinated by the Helsinki Commission. Within the framework of this cooperation, the ministers responsible for environmental protection in the Baltic countries agreed, in 1988, on a 50% reduction of pollutants discharged into the Baltic Sea (Anonymus 1988). The goal is to be achieved by 1995.

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