Distribution of some nutrients in the southern Baltic in Aug/Sept 1983 in relation to conditions in two previous years*

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Nutrient distribution
Nitrates
Nitrites
Phosphates
Silicates
Southern Baltic
1981 – 1983

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Abstract

This paper presents the results of investigations carried out on board of r/v 'Profesor Siedlecki' in August/September 1983 in relation to hydrological conditions during this period. Changes in nutrient concentrations (phosphate, nitrate, nitrite, silicate) in 1981 – 1983, taking into account the effects of inflow from the North Sea which took place in October 1982, are discussed. The measurements were carried out in both the open sea and the coastal zone of the southern Baltic.

1. Introduction

Inorganically combined nitrogen, phosphorus and silicon belong to the major nutrient elements and are of great importance for the productivity of a marine ecosystem. Intensive primary production may lead to unbalance of nutrient concentrations and often to their complete utilization. The above process starts at the beginning of March in the Belt Sea, at the end of March in the Arkona Sea, in the April/May in the region of Bornholm Deep and Gulfs of Bothnia and Finland. This is determined by meteorological conditions and also by stratification of water column (Kaiser, Schultz, 1976). Strong seasonal decrease in nutrient concentrations in the euphotic zone of the southern Baltic is observed in March/April in the Gdańsk Basin and in April in inner part of the Gulf of Gdańsk (Trzosińska, 1977). Therefore, the content of nutrients in the euphotic layer depends on the intensity of the primary production and also on the possibility of transportation of nutrients from deeper layers, where organic matter is destructed. This vertical transport is hindered to a considerable extent by the halocline and, in warm season, additionally by the thermocline.

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Periodic inflows of water from the North Sea to the Baltic Proper, which generally occur in winter, lead to advective renewal of bottom water and, as a consequence, partial reactivation of accumulated there phosphate resources and their transport into the euphotic layer. Long-term studies of changes in oxygen and hydrogen sulphide concentrations in the main deep Baltic basins carried out by Fonselius (after *Assessment*..., 1981) have led to the conclusion that there were sixteen inflows of highly saline water to the Bornholm Basin in the period of 1958 – 1979 and 21 inflows to the Gotland Basin in the period of 1953 – 1979. In the years of 1979 – 1983 two inflows from the North Sea were observed: the first one in autumn of 1979 (Milewska, Andrulewicz, 1982), and the second one in October 1982 (Wojewódzki, Piechura, 1983).

Long-term studies of changes occurring in the Baltic Sea permitted to conclude that in the last twenty years the increase in phosphate concentration took place (Grasshoff, 1975; Trzosińska, Andrulewicz, 1977; Fonselius, 1980; Milewska, Andrulewicz, 1982). The increase in nitrate concentration in surface layer (Nehring, 1979), although less documented, has also been observed; the oxygen content in the deep waters of the Baltic Sea decreased from 3 ml/l to nearly zero in the last century (*Assessment*..., 1981) and the salinity in the surface layer increased annually by about $0.05.10^{-3}$ [kg/kg] (Nehring, 1979; Fonselius, 1980). According to the authors of the collective elaboration (*Assessment*..., 1981) the changes in the above-mentioned hydrological parameters may be brought about not only by large-scale changes of hydrological and meteorological conditions but also by a considerable increase of industrial and municipal discharges of easily oxidizable organic matter and nutrients, coming from increased use of fertilizers in agriculture, which in a consequence led to eutrophication of the Baltic Sea.

Growing interest in the Baltic Sea resulting from the increase in its contamination contributed to triple organization of comprehensive studies carried out in July 1981, May 1983 and in August/September 1983.

2. Materials and methods

Measurements were made on board of r/v 'Profesor Siedlecki' and were based on a grid of 106 oceanographic stations (Fig. 1). Water samples were collected using Nansen bottles at standard depths distributed every ten meters from the surface to the sea bottom. In addition to measurements of salinity, temperature and oxygen content, determinations of the following nutrients were carried out: phosphates, nitrates, nitrites, silicates and, in two cruises (May 1983 and July 1981) – of ammonia. Chemical analyses were conducted directly after collection of the samples. Phosphates were determined by Murphy and Riley method modified by Koroleff, nitrates – by Morris and Riley method, nitrites – by Bendschneider and Robinson method and silicon by the blue method of Mullin and Riley (The Baltic Year, 1968; Calberg, 1972; Grasshoff, 1976). Spectrophotometric measurements were made using a Beckman spectrophotometer (Model 26).

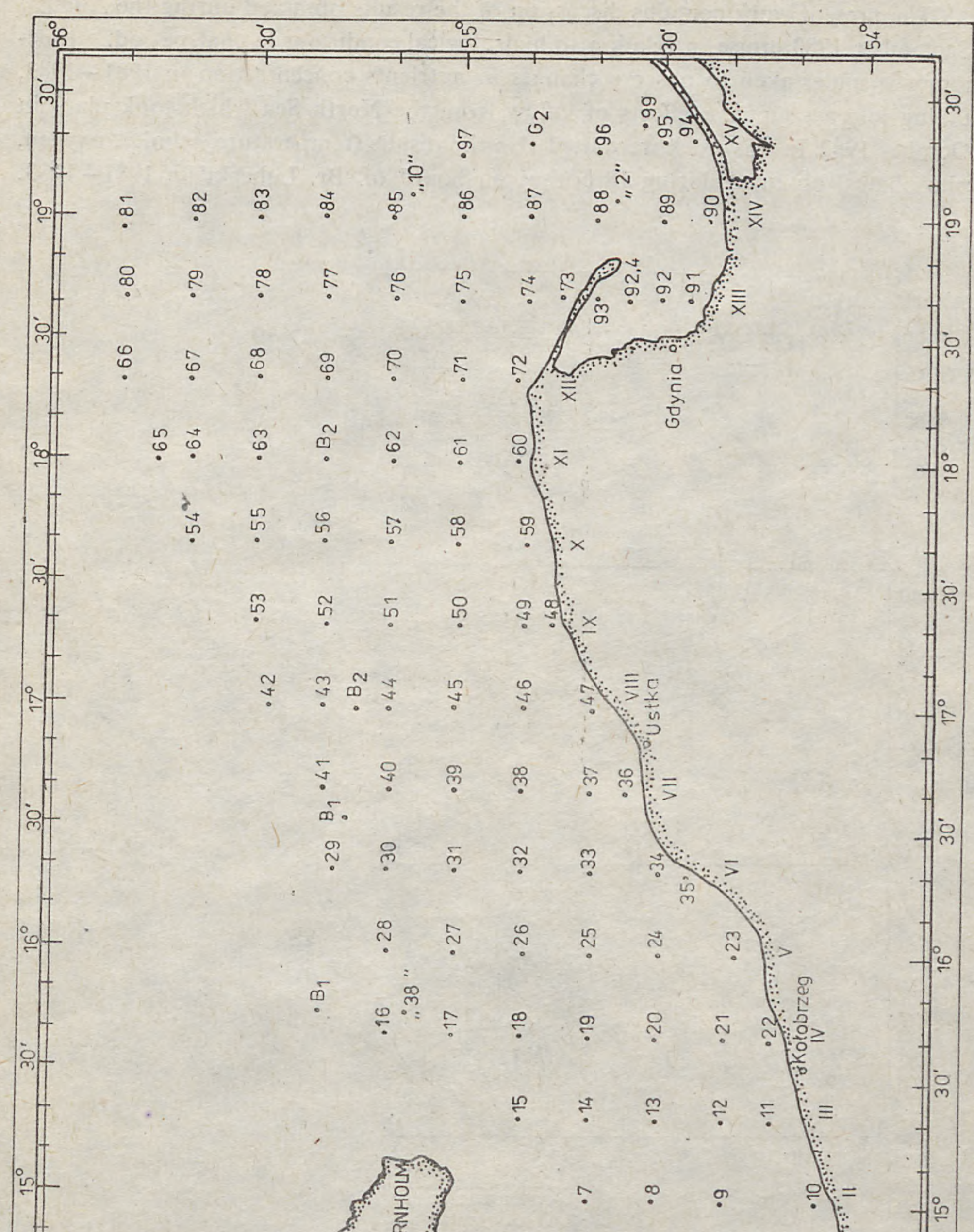

Fig. 1. Chart showing distribution of oceanographic stations (r/v 'Prof. Siedlecki' cruise – Aug/Sept 1983). Roman numerals indicate the consecutive numbers of cross-sections

The present work contains discussion of the results obtained during the August/September 1983 cruise in relation to hydrological conditions in that period. An attempt is undertaken to observe changes in nutrients concentration in 1981–1983, taking into account the effects of inflow from the North Sea which took place in October 1982. In this work were used also the results (temperature, salinity, oxygen, phosphates) obtained during 18 cruises on board of 'Br. Lubecki' in 1981–1983.

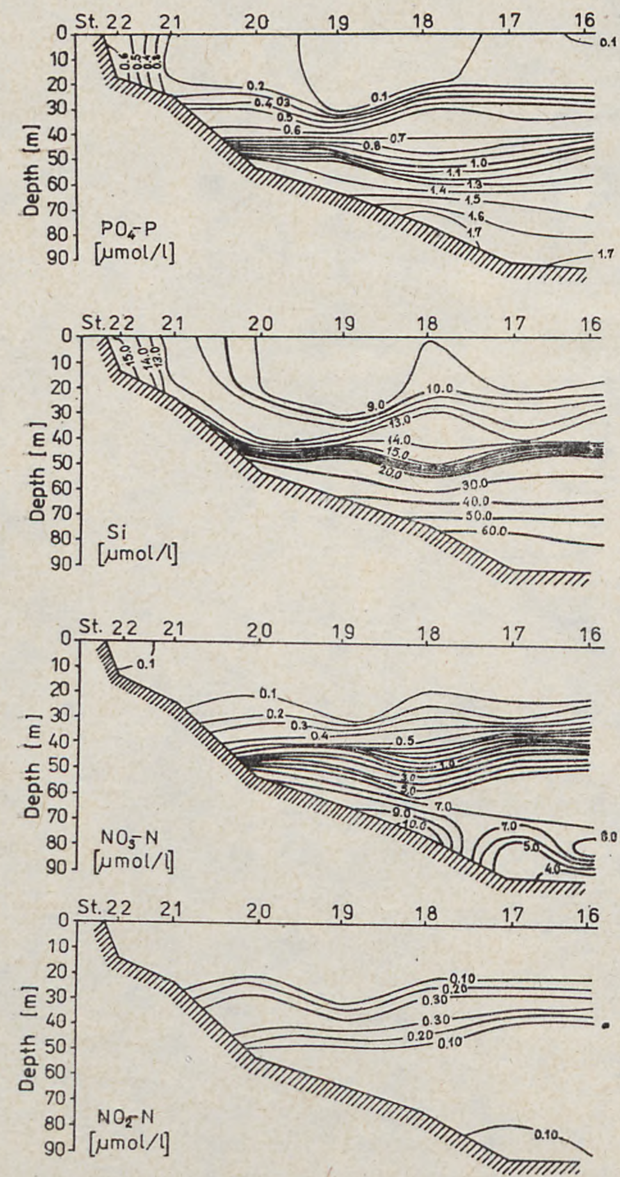

Fig. 2. Distribution of phosphate, silicate, nitrate, nitrite concentrations along the section IV (Aug/Sept 1983)

3. Results

3.1. Open sea

3.1.1. Phosphates

The analysis of horizontal and vertical distributions of phosphates (Figs. 2,3,4,5, 11) shows that their concentration in the euphotic layer of the open sea ranged from zero to about 0.20 μmol/l in August/September 1983 and was lower than in May 1983 (0–0.6 μmol/l) and in July 1981 (0.4–0.8 μmol/l). This results from substantial consumption of phosphates in the process of active biological production in an exceptionally warm period of spring and summer of 1983. Concentration gradient of

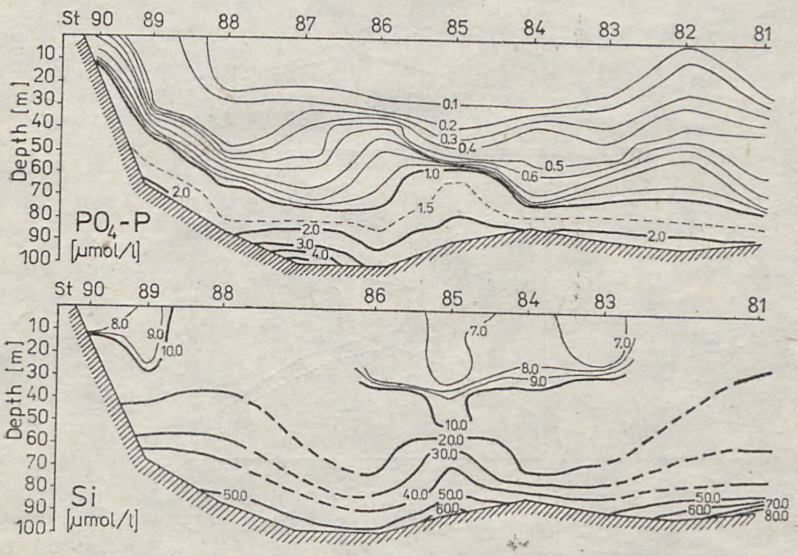

Fig. 3. Distribution of phosphate and silicate concentrations at the section XIV (Aug/Sept 1983)

phosphates was, as in previous cruises, the most distinct in the Gdańsk Basin and coincided approximately with the beginning of the halocline occurrence (60–80 m, Fig. 3). In the same layer an isoline corresponding to 1 μmol PO_4/1 usually occurred. Below this isoline the phosphate concentration increased steadily towards the bottom. Attention should be paid to the phosphate content in deep-water layer of the entire investigated region. Thus, with an exception of the region of the Gdańsk Deep, the phosphate contents observed in this layer were very similar to those found in May 1983. In the region of the Bornholm Deep the phosphate concentration ranged from 1.7 to 2.0 μmol/l and was lower by about 1 μmol/l than in July 1981.

The case of deep-water layer of the Gdańsk Deep should be described separately. In May 1983 the phosphate concentration (2 μmol/l) was much lower than in July 1981 (4–6 μmol/l), *ie* before the inflow from the North Sea. In August/Septem-

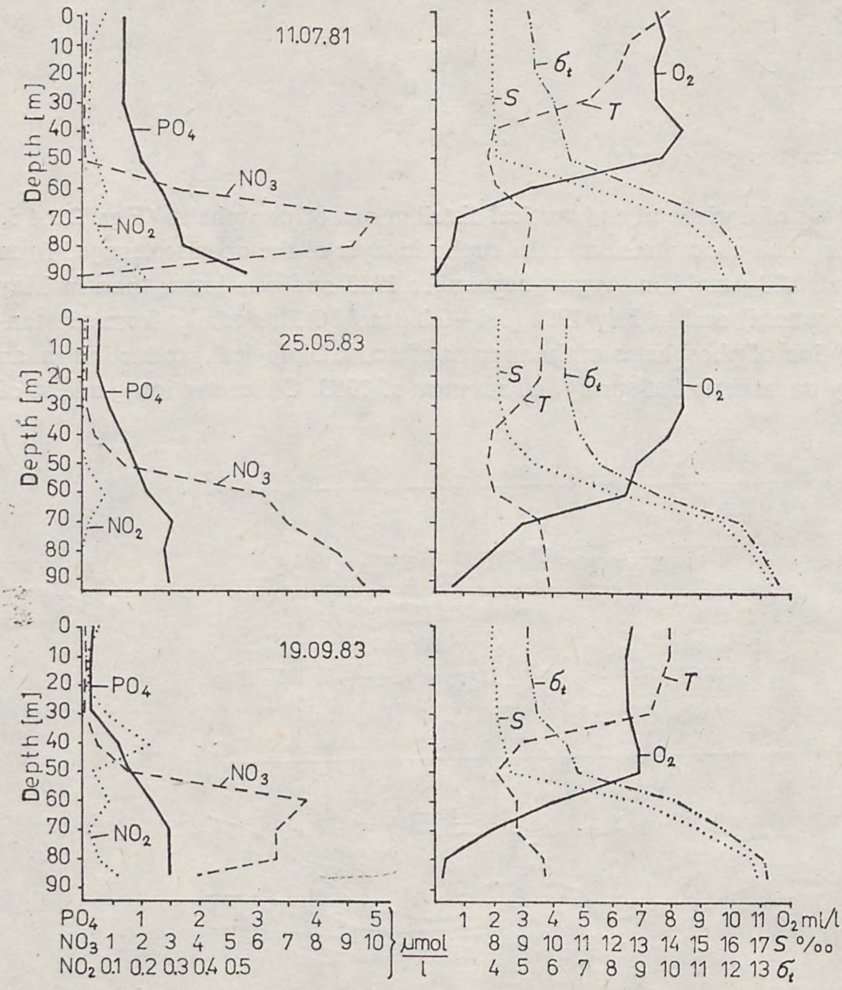

Fig. 4. Vertical distribution of nutrients, salinity (*S*), temperature (*T*), oxygen (O_2), density (σ_t) at the station 38 in the Bornholm Deep in years 1981–1983

ber 1983 the phosphate concentration increased again, this being particularly noticeable in central part of the basin (stations G_2, 87, 97), where the concentration approached that of July 1981 (before the inflow) or even exceeded it by more than 1 µmol/l (station G_2). This fact was associated with the decrease in oxygen content from May to August/September 1983.

3.1.2. Nitrates

Nitrate content in the euphotic layer (Figs. 2,4,5,6) varied from values close to zero to about 0.20 µmol/l; concentrations lower than 0.10 µmol/l being observed in most cases. This range of concentrations was similar to that of July 1981 and May

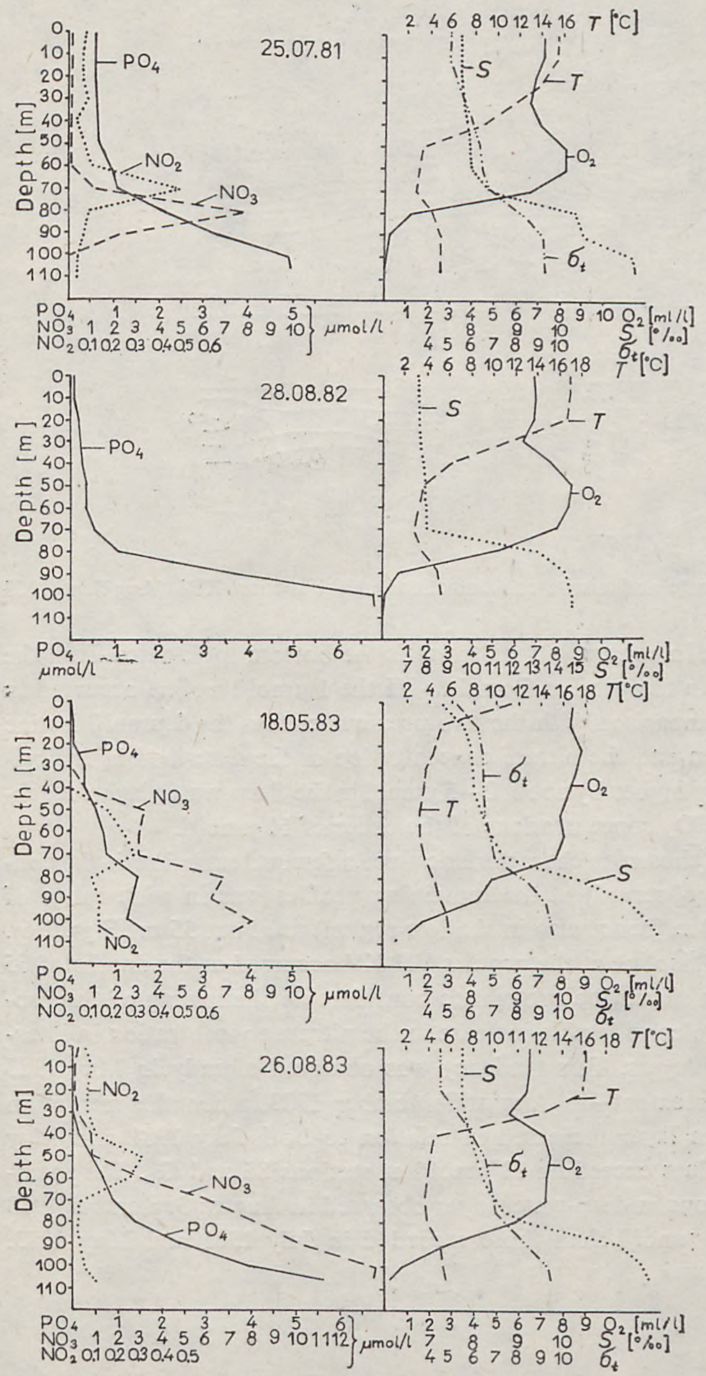

Fig. 5. Vertical distribution of nutrients, salinity (S), temperature (T), oxygen (O_2), density (σ_t) at the station G_2 in the Gdańsk Deep

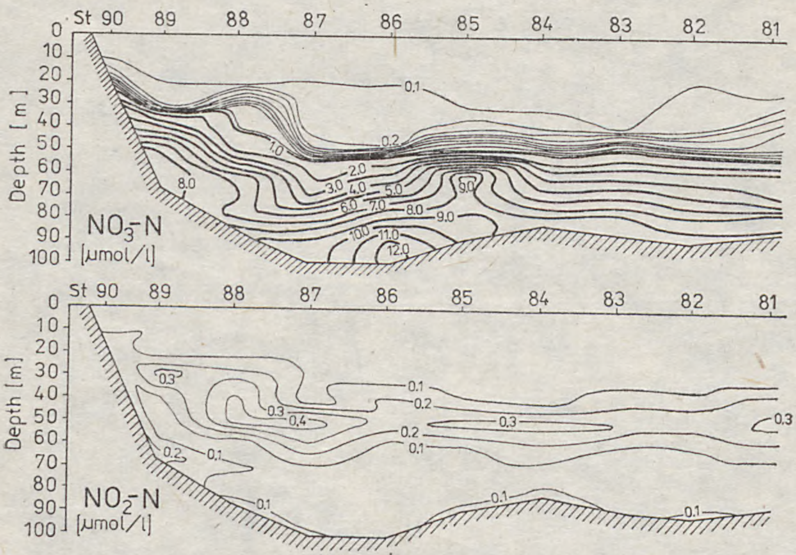

Fig. 6. Distribution of nitrate and nitrite concentrations at the section XIV (Aug/Sept 1983

1983. A distinct increase in concentrations towards the bottom took place from the depth of 30–40 m and in the profiles from I to VI the 1 µmol/l isoline occurred in this layer (Fig. 2). In comparison with the two previous cruises the 1 µmol/l isoline moved up by about 10 m and the nitrate concentration at the described hydrological profiles was generally higher by about 2–5 µmol/l in the deep-water layer, reaching maximum value of NO_3 concentrations of the order of 11 µmol/l.

The 1 µmol/l isoline (chosen as characteristic since a few meters below it the concentration gradient was observed) at the remaining profiles was in wide range of depths, *ie* from about 30 m (hence also in shallow region) to about 55 m (Figs. 2,6). In July 1981 the 1 µmol/l isoline at the profiles VII-XV occurred at the depths of 65 to 75 m. Thus, attention should be brought to considerable shallowing of this isoline or, in other words, to considerable increase in the nitrate concentration in intermediate and deep-water layers. This tendency was observed already in May 1983 and–to an even greater extent–in August/September 1983, when the maximum concentrations in bottom layer increased in relation to both July 1981 and May 1983, and rached the values exceeding 13 µmol/l at stations 86 and G_2. The maximum nitrate concentrations in deep-water layer observed in August/September 1983 were higher by about 5 µmol/l than those recorded in July 1981 and May 1983.

3.1.3. Nitrites

Concentrations of nitrite in the euphotic layer (Figs. 2, 4, 5, 6) ranged from 0.02 to 0.10 µmol/l, the most frequent concentration being observed in the range of 0.04–0.07 µmol/l. These values were slightly higher in comparison with those observed in July 1981 and May 1983, when at many stations nitrites were exhausted as a result of biological activity. As in previous years, the presence of maximum of the nitrites concentration in an intermediate layer was observed (Figs. 2, 6). This maximum, owing to season and the depth at individual stations, and hence higher NO_3 concentrations, was observed in August/September 1983 in the northern part of the investigated region, from profile IV up to profile XV. In the case of profiles XIV and XV, the maximum appeared along the entire length of these profiles. The depth of occurrence of this maximum ranged from 30 to 50 m or more for the profiles XI–XV (Figs. 3, 6), and concentrations in the layer of maximum varied from 0.30 to 0.60 μmol/l. In May 1983 the maximum occurred only in the Gdańsk Basin and at considerably larger depths (60–70 m) and the NO_2 concentrations were lower, ranging from 0.10 to 0.40 μmol/l. In July 1981 the maximum of nitrite concentration (0.40 μmol/l) was observed at the depth of 70 m as a discontinuous layer and only in the region of the Gdańsk Basin.

3.1.4. Silicates

Silicate distribution (Figs. 2, 3) clearly indicates well-ordered vertical stratification, similarly to findings in previous investigations. It is noteworthy that the silicate concentration increased in August/September 1983 in the entire investigated region to the level in July 1981. In May 1983 the silicate concentrations nearly halved due to the bloom of dinoflagellates and diatoms during that period. The silicate concentrations in the euphotic layer in August/September 1983 varied from over 6 to about 11 μmol/l (Figs. 2, 3). The concentrations increased steadily with depth and reached the maximum at the lowest investigated levels. The highest silicate content (82.5 μmol/l) was observed at the profile XIV near the bottom.

The silicate concentrations in a bottom layer is closely associated with depth. In shallow waters the silicate concentration at the bottom was of the order of several μmol/l, while in deeper waters it was of the order of tens of μmol/l up to the maximum value given above.

3.2. Coastal zone

The results described above referred to the content of individual components in the open sea. Coastal zone must be treated separately owing to continuous input of nutrients from inland waters. The input was most clearly visible in the Gulf of Gdańsk and the Pomerania Bay. This is due to the fact that these regions are supplied by the largest Polish rivers and water exchange between these bays and the open sea is smaller than in the case of the central coast.

In case of phosphates, considerably higher concentrations were observed in the coastal zone at the profiles I, II, III and IV that is in zone larger than the extent of the Pomerania Bay and at the profiles XIII, XIV, XV – in the Gulf of Gdańsk. The concentrations were often higher than 1 μmol/l and not only in the surface layer but down to the depth of 15 m. These values were substantially higher than the phosphate concentrations in the open sea (0–0.20 μmol/l) in the same period.

Concentrations of nitrates were only slightly higher in the coastal zone compared to the open sea in August/September 1983. Comparison of the results from the three cruises shows that the input of nitrates from inland waters varies with time to a considerable degree. The highest surface concentrations in the coastal zone were found in May 1983 in the region of Vistula estuary and ranged from several μmol/l to over 50 μmol/l.

The largest input of silicates was found in inner part of the Gulf of Gdańsk (from mainland to the Hel promontory) and varied from 28 to 35 μmol/l. The concentrations increased with depth and at the depth of 35 m approached 50 μmol/l. In the open sea, the euphotic layer contained 6–11 μmol/l and the concentration of 50 μmol/l was found at the depth of 80–90 m. Substantial input of silicates from inland waters was also observed in the Pomerania Bay and eastwards at the profiles I–IV, *ie* in the same region, where the phosphate concentration was high. In this region the surface concentration varied from about 14 to about 19 μmol/l. These concentrations were close to these found in July 1981.

4. Discussion

The low concentrations of nutrients in the euphotic layer observed in August/September 1983 (lower than in July 1981 and May 1983) resulted from high consumption of nutrients during summertime and from limitation of their transport from deeper layers by a natural barrier of the halocline and the thermocline, the latter being strongly developed in this period.

Several factors contributing to enrichment of the euphotic layer in nutrients are: thermocline dispersion and diminition of density gradient in the halocline, water inflows from the North Sea which occur in winter and result in upward movement of nutrient-rich deep water of the Baltic Proper, the processes of local upwelling and local eddies which can cause upward movement of nutrient-rich water (Hortsmann, 1983). The phenomenon of two counter current eddies with the same vertical axis was observed in August 1983 at the station 85 (Majewicz, Grelowski, in press). An anticyclonic eddy occurring from the surface down to the depth of about 60 m forced the upper water downwards and a cyclonic eddy occurring from the depth of about 60 m down to the bottom forced deep water upwards. This phenomenon was reflected in characteristic deflection of isolines of physical and chemical parameters (Figs. 3, 6) in the area of the station 85, where the cyclonic eddy moved upwards of about 20 m the deep water rich with phosphate, nitrate and silicate.

Long-term observations of changes taking place in the entire ecosystem of the Baltic Sea, including phosphate concentrations, led many authors to the conclusion that in the last twenty years the phosphate content increased both in surface and in deep-water layer. According to Fonselius (1980), the increase in phosphate concentration in the surface layer has been evident for the last twenty years and began in

1969 in the whole Central Basin. According to this author the phosphate concentration in winter is presently at least twice as high as it was at the end of sixties. Giving possible causes of that increase the author points out that the Baltic salinity increased by about $0.5 \cdot 10^{-3}$ in the last decade. This resulted in stronger stratification and, hence, prolonged stagnation periods in deep basins favorable to phosphate accumulation below the halocline.

Under conditions of good oxygenation the phosphate content in deep layer of the central basins of the Baltic Sea ranges from 2 to 3 μmol/l (*Assessment...*, 1981). Stagnation periods which are very distinct in the Basins of Bornholm, of Gdańsk and of Gotland and which may last for several years are characterized by depletion of oxygen and considerable phosphate accumulation (6-9 μmol/l or even more below the halocline) (Grasshoff, 1975; *Assessment...*, 1981; Grasshoff, Voipio, 1981). Lowered redox potential of the environment observed in these periods results in conversion of sparingly soluble ferric phosphate to readily soluble ferrous phosphate and, hence, liberation of phosphates precipitated in bottom sediments (Holm, 1978). According to this author, in the stagnation period in 1975 about 1.7 g P/m^2 was released in the Bornholm Basin. He also points out that in addition to oxygen deficit, the liberation process is influenced by sediment composition, pH, and the depth at which process takes place. Grasshoff and Voipio (1981) claim that the phosphate liberation from the sediments proceeds under anoxic conditions when pH drops to values close to 7.0.

The stagnation in the Bornholm and Gdańsk Basin was observed in July 1981 and it intensified until October 1982, when there was the inflow from the North Sea. In August/September 1982 the oxygen content dropped to nearly zero and the salinity in the Bornholm Deep to $14 \cdot 10^{-3}$ (Wojewódzki, in press). In the same period, the phosphate concentration in deep layer was at maximum: 8.2 μmol/l for the Bornholm Deep and about 6.8 μmol/l for the Gdańsk Deep. Observed in October 1982 in flow of saltier and well oxygenated water reached the Bornholm Deep in November 1982 and resulted successive exchange of the bottom layer in this region until the end of March 1983. In the Gdańsk Deep the inflow was noted at the beginning of March and was active until the end of March 1983. It improved oxygen conditions in the whole water column. After termination of the inflow and stabilization of hydrological conditions the minimum oxygen content was of about 2.5 and 1.5–3.7 ml/l for the Bornholm Deep and the Gdańsk Deep, respectively (Wojewódzki, Piechura, 1983).

Ocean inflows, *via* advection, renew bottom layers of the Baltic Proper and hence cause transfer of phosphates from deep basins to intermediate and surface layers (Figs. 4, 8). This was clearly visible in the case of the inflow discussed above. The phosphate content in intermediate and surface water layers increased 2–3 times and reached about 1 μmol/l.

Improvement in oxygenation of the deep layer resulting from the inflow was short-term only and already in April 1983 the oxygen content in the Bornholm and Gdańsk Deep was as low as half of that in March and this tendency kept up till the end of 1983. In May 1983 the oxygen content at the bottom was of the order of 0.5

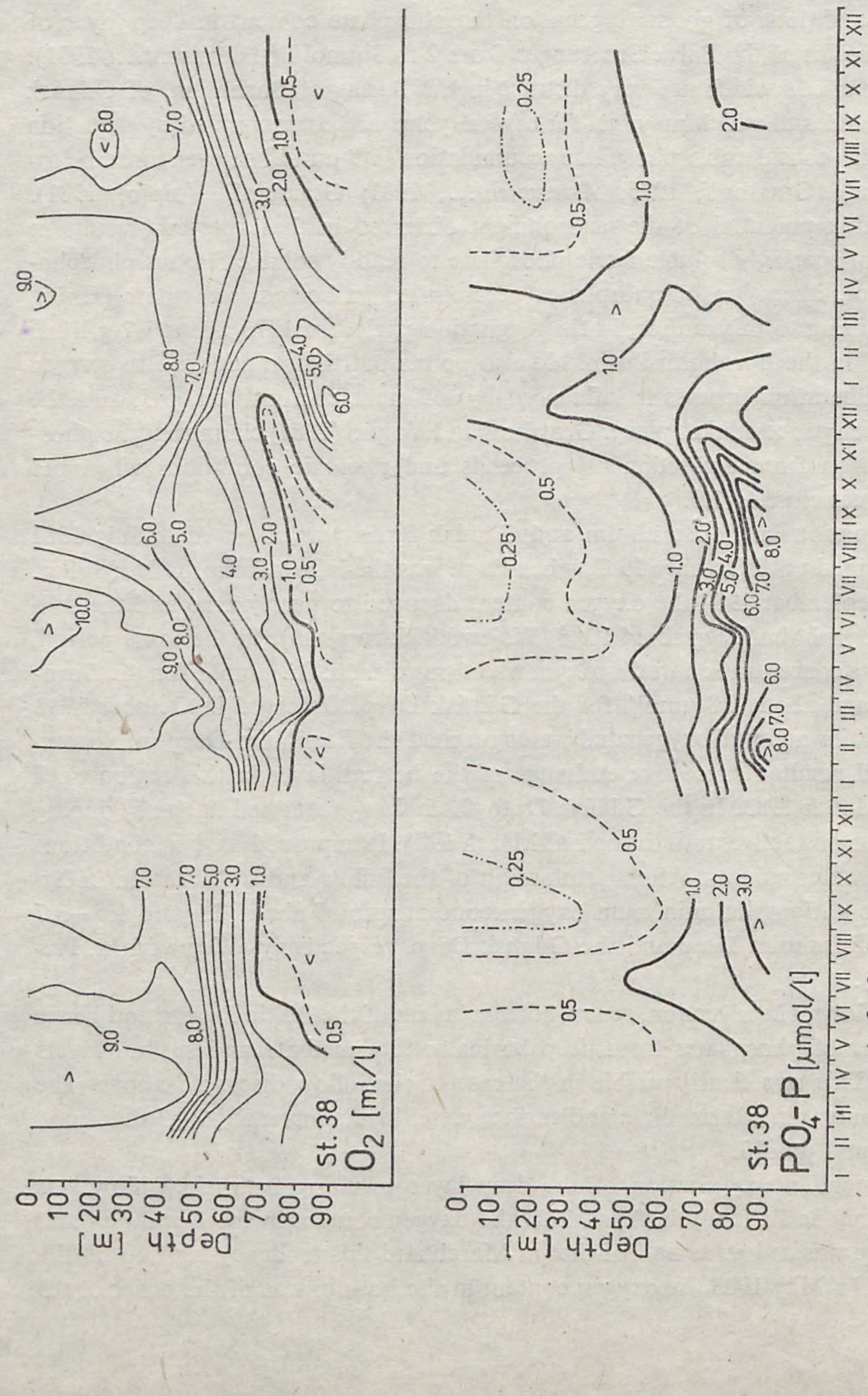

Fig. 7. Isopleth diagram of oxygen and phosphate concentrations in the Bornholm Deep (station 38) in years 1981 – 1983

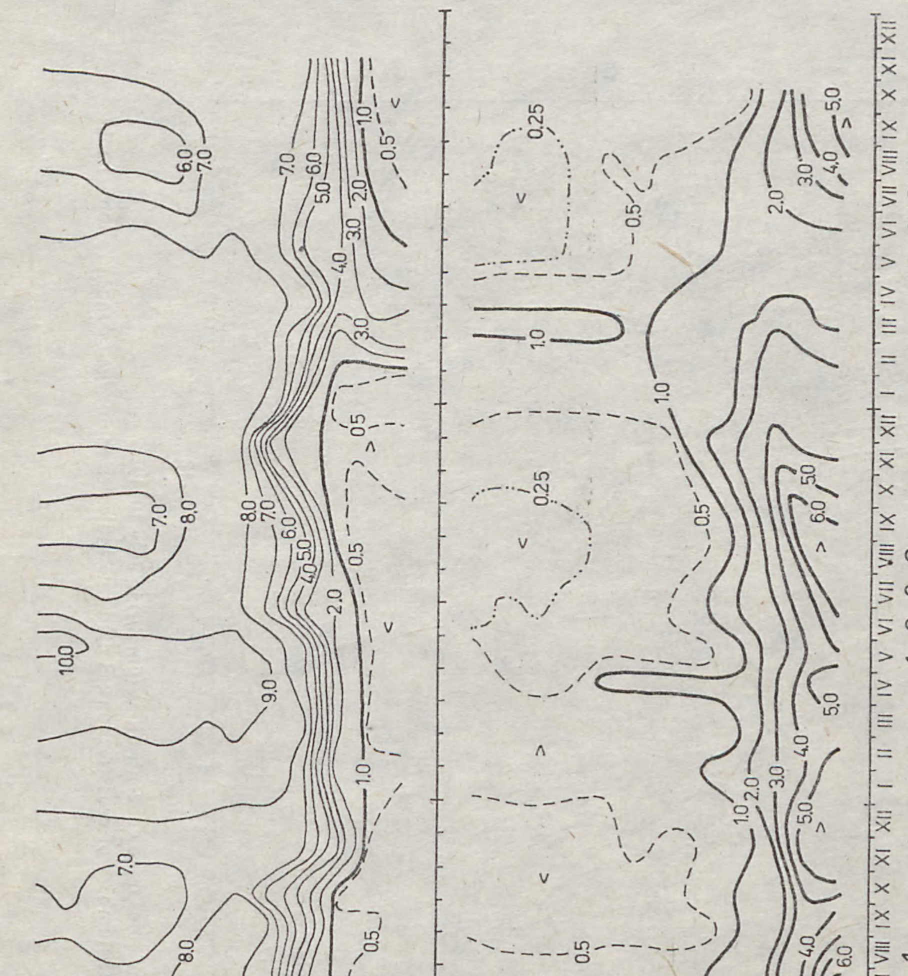

Fig. 8. Isopleth diagram of oxygen and phosphate concentrations in the Gdańsk Deep (station G_2) in years 1981 – 1983

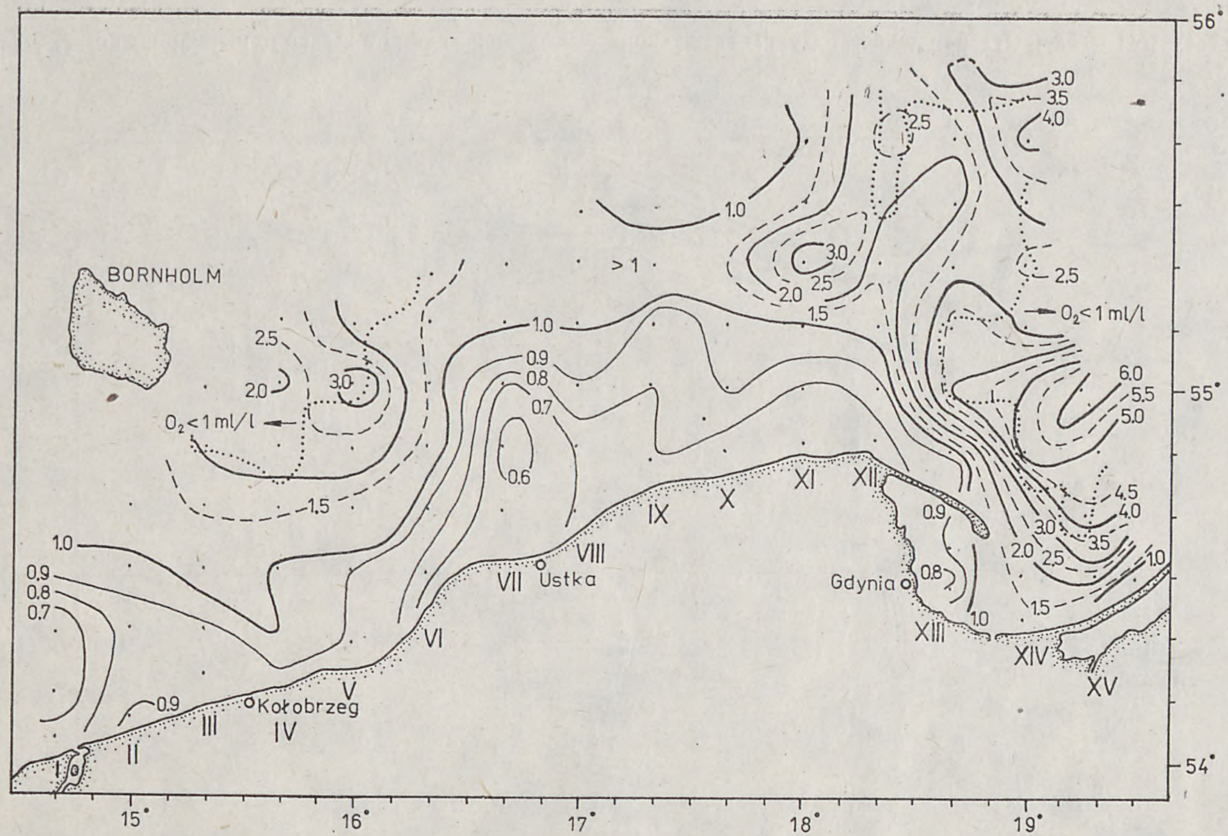

Fig. 9. Bottom distribution of phosphate concentrations (µmol/l) in July 1981.
Roman numerals indicate the numbers of cross-sections; dotted line indicates the oxygen concentration – 1 ml/l

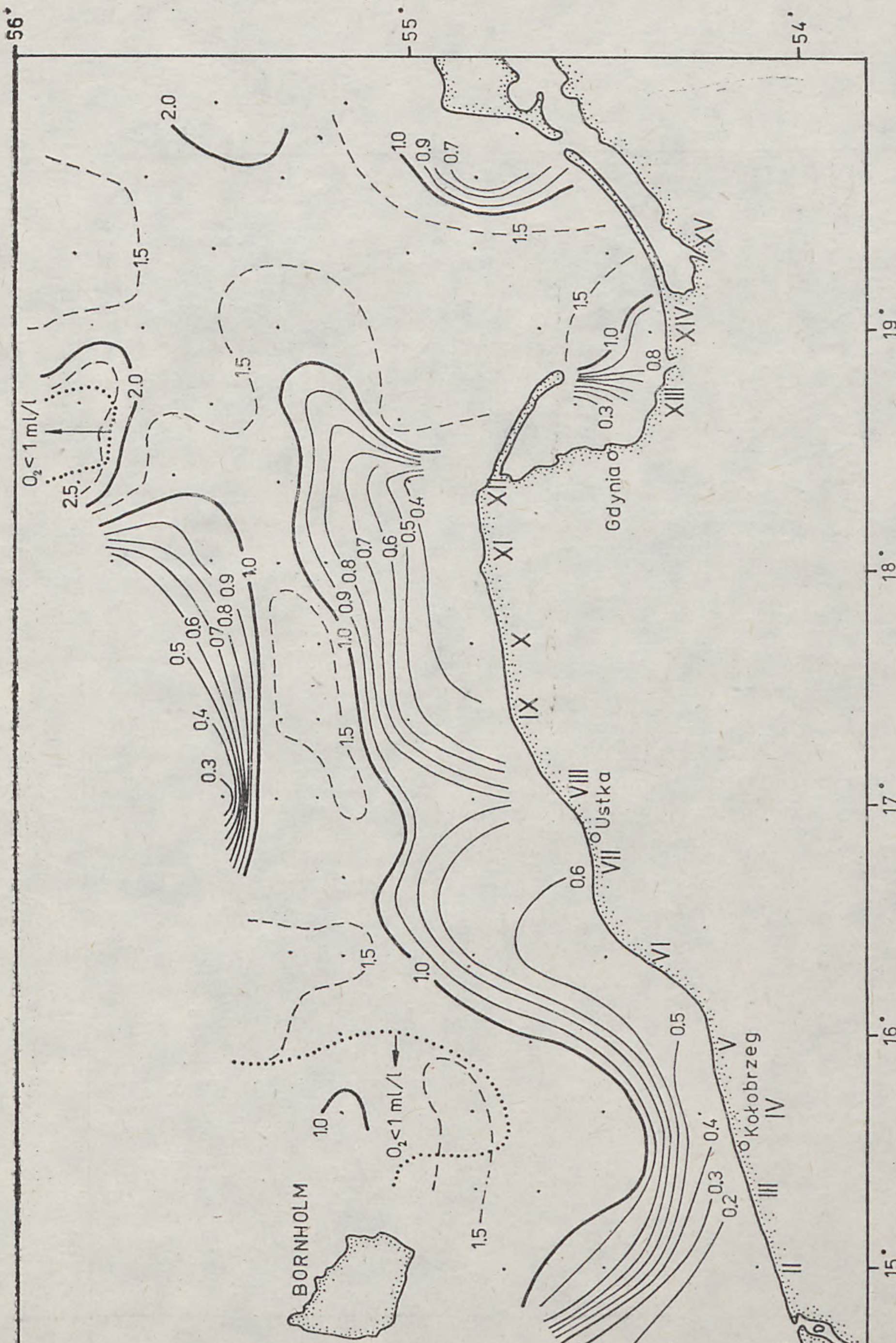

Fig. 10. Bottom distribution of phosphate concentrations (μmol/l) in May 1983.
Roman numerals indicate the numbers of cross-sections; dotted line indicates the oxygen concentration – 1 ml/l

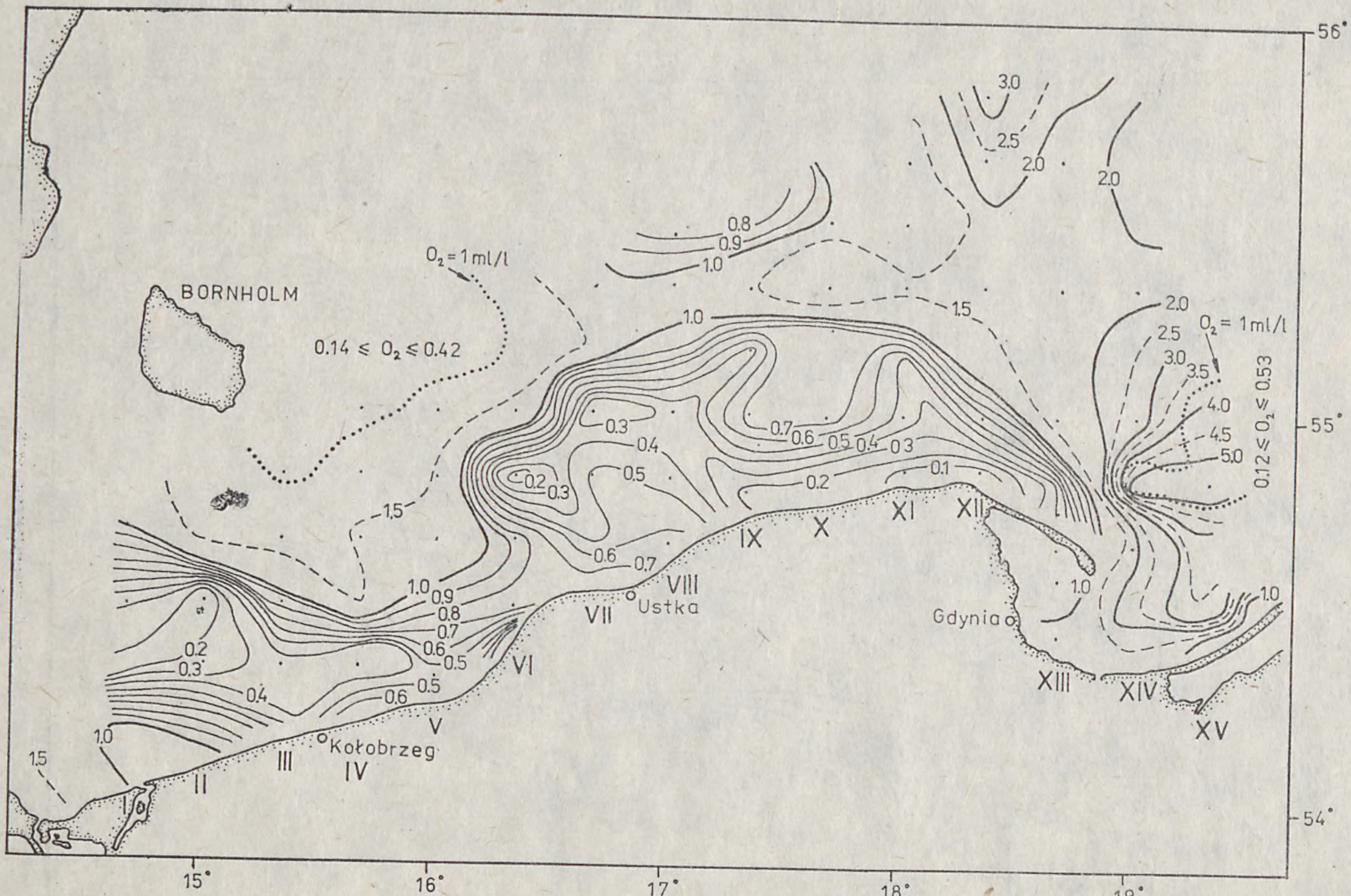

Fig. 11. Bottom distribution of phosphate concentrations (µmol/l) in August/September 1983. Roman numerals indicate the numbers of cross-sections; dotted line indicates the oxygen concentration – 1 ml/l

ml/l in the Bornholm Deep and of about 1 ml/l in the Gdańsk Deep. This led Wojewódzki (in press) to the conclusion that on the turn of April the stagnation in both basins began again. In May 1983 the stagnation was probably more advanced in the Bornholm Deep. This could be indicated by the fact that the oxygen content in this Deep was lower by 0.5 ml/l than in the Gdańsk Deep and that there started a new phosphate accumulation in the bottom layer. In May 1983 the phosphate concentration was very close to that before the inflow. Phosphate accumulation in the region of Gdańsk Deep began sometime between May and August 1983, just when the oxygen content dropped to below 1 ml/l (Figs. 7, 8).

Comparison of horizontal distribution of phosphate concentration in bottom layer in July 1981, in May and August/September 1983 (Figs. 9, 10, 11) indicates that there was in Gdańsk Basin in July 1981 the extensive region of the oxygen content being below the 1 ml/l O_2, lack of such regions (oxygen content higher than 1 ml/l) in May 1983 and its appearance in August/September 1983. The above facts evidence the beginning of a new stagnation period in the Bornholm Basin and the Gdańsk Basin.

Difficulty of determination of inorganic nitrogen compounds and hence the lack of such number of data as in the case of phosphates does not allow to monitor the changes in nitrogen content over the period of several last years. Nevertheless, the data collected by Nehring (1979) and by Milewka and Andrulewicz (1982) led to the conclusion that inorganic nitrogen, especially the nitrate content increased recently.

According to many authors (*Assessment...*, 1981), the evidence obtained hitherto does not permit to state unambiguously whether the phosphate accumulation in deep basins of the Baltic Sea is a result of natural processes or the result of increase of the Baltic contamination. Nevertheless, as state the authors of this elaboration, the phosphate accumulation is evident and, as an example, the phosphate concentration at the depth of 100 m in the Gotland Deep increased from 1 μmol/l in 1958 to over 2.5 μmol/l in 1978. The nitrate content (Nehring, 1979) at the same depth and in the same region increased and approximately doubled in the period of 1969–1978. Analysis of data from 1969–1978 allowed Nehring (1979) to come to the conclusion that in the mixed surface layer in winter the phosphate concentration increased by 0.04 μmol/l and the nitrate concentration by 0.2 μmol/l annually, whereas the salinity increased annually by $0.05 \cdot 10^{-3}$.

Our data obtained during three cruises on board of 'Prof. Siedlecki' and the lack of data for periods between cruises do not allow to perform complete analysis of changes in the nitrate content with time as was done in the case of phosphates. The analysis of the data has shown that the nitrate isoline of 1 μmol/l shallowed in August/September 1983 in comparison with its position in July 1981 and May 1983. This meant considerable increase of the nitrate concentration (even by 5 μmol/l) in intermediate and deep layer. Particularly high nitrate concentration was found in deep layer in the Bornholm Basin (11 μmol/l) and in the Gdańsk Basin (13 μmol/l).

It seems that a number of factors had an effect on rise of nutrient-rich water in August/September 1983 and simultaneously on the increase in nutrient concentration. These factors included the inflow in October 1982, which resulted in initiation of nutrient reservoir in deep-water layers, intensified decomposition of organic matter caused by the inflow of well oxygenated water as well as an increase of the mineralization coefficient (*Assessment...*, 1981) which begins in August/September and lasts during the winter.

The inflow contributed to the decline of denitrification process in bottom layer, which was observed at many stations in deep-water region of the southern Baltic in July 1981. Denitrification is a respiratory process in which some bacteria, in the near absence of oxygen but in presence of nitrate, are capable of producing energy for biosynthetic processes and growth. When such conditions prevail, the nitrates are reduced to nitrogen gas. In this process, which depends, among other factors, on the pH, concentration of organic matter, nitrates concentration—nitrites and nitrogen constitute intermediate products (Grasshoff, 1976; *Assessment...*, 1981). The process was interrupted in the moment of inflow of well oxygenated water from the North Sea. However, the presence of a concentration maximum at numerous stations of the Bornholm Deep should be noted. The maximum occurs a dozen or so meters above the sea bottom followed by the decrease in NO_3 content towards the bottom (the difference reaches several µmol/l). A probable cause of this phenomenon is the decrease of oxygen content at the bottom and initiation of stagnation.

The nitrite content as well as presented part of a seasonal cycle of NO_2 is in full accordance with the data published by Gundersen (*Assessment...*, 1981), who recorded the maximum NO_2 concentrations in water column in September. They were on the order of 0.5 µmol/l and occurred at the depth of about 40 m. According to Grasshoff (1975) and Grasshoff and Voipio (1981), the maximum occurs just over the halocline and above the maximum of nitrate concentrations and is a result of the nitrification process taking place there. Grasshoff (1975) reported that in addition to the maximum mentioned above another one may occur, and it takes place during phytoplankton bloom with simultaneous relatively high NO_3 concentration. So-called 'luxury feeding' leads to excretion of nitrites by organisms.

Nitrates and nitrites do not constitute the only source of nitrogen in the entire marine ecosystem. An essential role is also played by ammonia. According to Niemi (1975) in the case of depletion of nitrates in the period April—June ammonia becomes the main source of nitrogen. Tarkiainen *et al* (1974) claim that in summer the nitrogen originating from ammonia is preferred by phytoplankton population.

As a rule, well oxygenated surface waters contain below 1 µmol/l of NH_4, whereas badly oxygenated deeper layers may contain 5 or even 9 µmol/l (Grasshoff, Voipio, 1981). The ammonia content of the order of 10 µmol/l was found in stagnant deep water in July 1981 (Pastuszak, 1982, in press).

Numerous authors (Reinne *et al*, Sen Gupta—after Grasshoff and Voipio, 1981) think that an important role in the marine ecosystem is also played by molecular nitrogen, hydroxylamine and urea.

Distribution and range of the silicate concentration in August/September 1983 remained at the level of concentrations prevailing in July 1981 and did not deviate from the literature data (Grasshoff, 1975; Grasshoff, Voipio, 1981; *Assessment...*, 1981). Substantial decrease in the silicate concentrations in May 1983 with respect to July 1983 was associated with the bloom of doniflagellates and diatoms (Ringer, 1984).

According to Grasshoff and Voipio (1981) silicate accumulates during periods of stagnation, because the selections of diatoms with the fine structure dissolve more rapidly under anoxic conditions. In addition, large amounts of silicate are dissolved from the bottom sediments when the overlying water is deoxygenated.

Many recent authors (Majewski *et al*, 1974; Trzosińska, Andrulewicz, 1977; Dybern, Fonselius, 1981; *Assessment...*, 1981; Piechura, in press) brought attention to discharges, of among others, nutrients, which influence the entire Baltic ecosystem. In the Polish fishing zone particular attention is paid to the regions of the Gulf of Gdańsk and the Pomerania Bay, which are exposed to permanent inflow of nutrients from the Vistula and Odra rivers, respectively. It follows from the studies by Trzosińska (1977) that in the inner part of the Gulf of Gdańsk (from mainland to the Hel promontory) in the years 1974—1976 the average phosphate concentration in the isohaline layers was higher by 50%, nitrate—by 64%, nitrite—by 35%, ammonia—by 108% in comparison with the remaining part of the Gdańsk Basin. According to this author, the increase in content of phosphates and nitrogen compounds was also observed in the Pomerania Bay and it was approximately twofold in the case of phosphates and sixfold in the case of nitrogen salts relative to the five-year period of 1968—1973.

In August/September 1983, as in previous cruises, coastal regions with increased concentrations of phosphorus, nitrogen and silicon compounds were found. The increased concentrations zone in the western part of the investigated region reached far eastwards (to the profile IV), beyond the Pomerania Bay and this concerns particularly phosphate and silicate. The highest input of silicate in August/September 1983 was observed in the inner part of the Gdańsk Bay (up to the end of Hel Peninsula).

In all discussed cruises nutrient concentrations in the coastal zone considerably exceeded the values reported for the surface layer of the open sea. For example, in May 1983 in the region of Vistula estuary the surface concentrations of nitrate were of the order of 50 μmol/l.

According to Mikulski (see Ehlin, 1981) the inflow of river water to the Baltic exhibits substantial seasonal variability which is associated with melting of snow and ice in spring, and hence with an additional amount of water coming from this source. According to the author, the maximum inflow of fresh water to the Baltic Sea falls on the period April—June. This fact has an evident effect on the amount of nutrients transported to the Baltic. It follows from the studies by Andrulewicz (see Grasshoff, 1975) that the maximum discharge of phosphate through the Vistula and Odra takes place in April—June, and the phosphate concentration in water of these rivers exhibits cosiderable seasonal variations.

Although the mechanisms of transportation of pollutants towards the open sea are not fully elucidated it seems that the river run-off of nutrients must affect the conditions in the Gulf of Gdańsk and the Pomerania Bay. The amount of phytoplankton biomass in the region of Vistula mouth in May 1983 was higher by about 100 times than the values observed in the region of the Gdańsk Deep during this period (Ringer, 1984).

Additional amounts of nutrients supplied—among other—by rivers result in enhancement of biological production, but increased amount of organic matter formed requires increased amount of oxygen necessary for its destruction. So-called 'secondary oxygen utilization' may be from two to five times as great as the 'primary oxygen utilization' (Dybern, Fonselius, 1981). Total average Biochemical Oxygen Demand, calculated by these authors, for the Baltic equals to 0.43 mg $O_2 \cdot m^{-3} \cdot day^{-1}$. At the same time, the authors point out that in the case of supplying of additional amount of organic matter this demand will increase to 1—2 mg $O_2 \cdot m^{-3} \cdot day^{-1}$, whereas in highly polluted regions it may even be 10 to 100 times higher.

References

1. *Assessment of the effects of pollution on the natural resourses of the Baltic Sea*,1980,Baltic Sea Environ. Proc., 5, Eds.: Melvasalo T., Pawlak J., Grasshoff K., Thórell K., Tsiban A., Helsinki 1981.
2. Calberg S. R., 1972, *New Baltic Manual with methods for sampling of physical, chemical and biological parameters*, ICES Cooper, Res. Rep., Ser. A, p. 29.
3. Dybern B. I., Fonselius S. H., 1981, *Pollution*. [In]: *The Baltic Sea*, Ed. Voipio A., Amsterdam, 351—376.
4. Ehlin U., 1981, *Hydrology of the Baltic Sea*. [In]: *The Baltic Sea*, Ed. Voipio A., Amsterdam, 124—134.
5. Fonselius S. H., 1980, *A long time variation of phosphorus in Baltic surface water*. ICES C. M., 1980/C, 36.
6. Grasshoff K., 1975, *The hydrochemistry of landlocked basins and fiords*. [In:] *Chemical Oceanography*, Eds. Riley J. P., Skirrow G., 455—597.
7. Grasshoff K., 1976, *Methods of Seawater Analysis*, Verl. Chemie-Weinheim, New York.
8. Grasshoff K., Voipio A., 1981, *Anomalies in composition of Baltic Sea Water*. [In:] *The Baltic Sea*. Ed. Voipio A., Amsterdam. 183—213.
9. Holm N. G., 1978, *Rates of phosphate release in exchange processes between sediments and bottom water*, Dep. Geology, Univ. Stockholm, Microbiol. Geochem., 3, 79—110.
10. Horstmann U., 1983, *Distribution Patterns of Temperature and Water Colour in the Baltic Sea as recorded in Satellite Images: Indicators, for Phytoplankton Growth*, Ber. aus dem Inst. für Meereskunde, 1, 106, Kiel.
11. Kaiser W., Schultz S., 1976, *Zur Ursache der zeitlichem und raumlichen Differenzen des Beginns der Phytoplankton in der Ostsee*, Fischerei — Forsch., 4, 77—81.
12. Majewicz A., Grelowski A., Mountain D., *Phenomenon of counter-current geostrophic eddies observed in the Baltic Sea in August 1983*, Nature (in press).
13. Majewski A., Trzosińska A., Żmudziński L., 1974, *Warunki środowiskowe Bałtyku w okresie 1971—1973*, Wiad. Meteor. i Gosp. Wod., 1 (XXII), 4, 1974.
14. Milewska E., Andrulewicz E., 1982, *Proceedings of the XIII Conference of the Baltic Oceanographers*, *2*, Helsinki.
15. Nehring D., 1979, *Relationship between salinity and increasing nutrient concentration in the mixed water surface layer of the Baltic from 1969 to 1978*, ICES C. M. 1979/C, 24.
16. Niemi A., 1975, *Ecology of phytoplankton in the Tvarminne area, SW coast of Finland. II. Primary Production and Environmental Conditions in the Archipelago and the Sea Zone*, Acta Bot. Fenn., 105, 1—68.

17. Pastuszak M., *Zawartość soli biogenicznych w Bałtyku południowym w lipcu 1981.* [In:] *Stan zdrowotny polskiej strefy rybołówczej Bałtyku i jej żywych zasobów w lipcu 1981*, Pr. MIR (in press).
18. Piechura J., *Zawartość rozpuszczonego tlenu w wodach polskiej strefy wyłączonego rybołówstwa w lipcu 1981.* [In:] *Stan zdrowotny polskiej strefy rybołówczej Bałtyku i jej żywych zasobów w lipcu 1981*, Pr. MIR (in press).
19. Ringer Z., 1984, *Fitoplankton Bałtyku południowego w latach 1982–1983*, Rap. MIR. 1982/1983, MIR Gdynia.
20. Tarkiainen E., Reinne J., Niemistö L., 1974, *On the chemical factors regulating the primary production of phytoplankton in the Baltic Proper*, Merentutkimuslait Julk. Havsforskingsist. skr., 238, 39–52.
21. *The Baltic Year 1969–70, Program Manual*, 1968, Göteborg.
22. Trzosińska A., 1977, *Phosphorus and nitrogen in the Gdańsk Basin.* [In:] *Hydrological, chemical and physical processes affecting pollution of the Baltic Sea, Final Report on project PR. 05.532.13*, Inst. of Meteor. Water Managem., Gdynia–Warszawa.
23. Trzosińska A., Andrulewicz E., 1977, *Występowanie i przemiany soli odżywczych w Bałtyku*, Stud. i Mater. Oceanolog. KBM PAN, 7, 182–203.
24. Wojewódzki T., Piechura J., 1983, *Inflow(s) of North Sea waters in Baltic Sea during November 1982–May 1983.* ICES C. M. 1983/C, 6.
25. Wojewódzki T., *Changes of hydrological conditions in Southern Baltic in years 1981–1983*, (in press).