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Distribution of highly saline waters observed in April 1993 – after the inflow into the southern Baltic

by

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Abstract

The investigations were carried out on board r/v "Oceania" on 1–4 April, 1993 and included CTD measurements and oxygen analysis. The maximum values of salinity, reaching 19.07 PSU, were observed in the central part of the Bornholm Deep, while the middle and northern part of this region were characterized by waters having salinity above 18 PSU. The measurements showed that the inflowing water with salinity in the range of 14–15 PSU, reached as far as the eastern part of the Słupsk Furrow.

Water with a salinity of 11.4 PSU was present in the Gdańsk Deep (in October, 1992 – 10.73 PSU), with oxygen level of 4.16 ml/l (in October, 1992 only 0.24 – 0.42 ml/l). This water was pushed out of intermediate layers of the Słupsk Furrow. At the bottom of the main areas, with high oxygen levels were recorded (5 – 6 ml/l). Water temperature decreased by 2 – 2.5°C as a result of the inflow. As a result of the radical change in the salinity – density structure and oxygenation of the water, the area of occurence of a layer enabling the development of cod eggs increased several times. Calculations of water volume with specified salinity (>12, >15, >18, >20 PSU) show that in comparison with previous inflows, there was more water with higher salinity in the main areas. In the Bornholm Deep water with salinity >18 PSU after the inflow of 1971 had a volume of 25.8 km^3, after the inflow of 1982 – 10.1 km^3 and in February 1993 – 79.7 km^3. As a result, the inflow water reached the southern slopes of the Gotland Deep faster (already after 3 months), beginning the reneval of the near–bottom layer in that area.

Introduction

In the second half of January, 1993, an inflow of water with high salinity from the Kattegat into the Baltic took place. First information on parameters of the inflow water came from the German research vessel ALEXANDER VON HUMBOLDT (Cruise Report No. 1/93). It appeared from the report that the inflow water with

a salinity of about 19 PSU and a temperature of 3.5°C was already beyond the Darss Sill, filling the Arkona Basin. In the central part of this area water had a salinity of 23–24 PSU as it had a shorter distance to cover and moved faster through the Sound. The report indicated that investigations point to a "major event of moderate intensity."

Subsequent cruise reports and information about the current range of the inflow suggested that the volume of inflow waters could be estimated at 200–300 km^3 (Report of u.f. ARGOS, 16.03.1993). The programme of our research in April (conducted jointly with the Institute of Oceanology, Polish Academy of Sciences, Sopot) was elaborated on the basis of information about the range of the inflow. The research was a response to an appeal of the Institut fur Ostseeforschung in Warnemunde asking other Baltic states to join in investigations of the inflow.

Material and metod

The paper was prepared on the basis of temperature and salinity measurements with a CTD sounder (Guildline 8755) and oxygen level measurements by the Winkler method. The plan of transects took into account information about the inflow range at that time. Besides the Gulf of Gdańsk–Słupsk Furrow–Bornholm Gate transect, the research was extended onto the southern part of the Bornholm Deep (Hano Bay–Kolobrzeg transect). Along the line Bornholm Deep–southern slope of Gotland Deep, additional transects with denser stations were taken into account, to determine precisely the salinity in this area. Distribution of sampling stations is presented in Fig. 1. Masurement data were processed on a computer and presented graphically on charts and transects. Water volume was calculated with the help of the DNO (bottom) programme, made especially for the Sea Fisheries Institute. Accuracy of calculations (results) was +/–0.5 km^3.

Results

The results of temperature, salinity, and oxygen level measurements in the deep layer from a period before the inflow (October, 1992) and after the inflow (April) are presented on charts and transects (Figs 2, 3, 4, 5). Before such an initial state preceding the inflow took shape, two important facts had taken place. In February, 1992, a seasonal renewal of the deep layer in the Bornholm Deep occurred, as a result of which salinity increased by 2.44 PSU to 16.51 PSU. Oxygen level increased to 2.45 ml/l (previously 0.21 ml/l). This small volume of new water (about 28 km^3) stirred the deep layer to activity, leading in May to an increase in salinity in the Gdańsk Deep by 1 PSU to a value of 11.2 PSU.

In July, exceptionally warm water (10–12°C) with a salinity of 12–13 PSU flowed into a layer of 40–60 m of the north-western part of the Bornholm Deep. Water from this inter-layer inflow, after transformation, led to an increase in temperature of the deep (near-bottom) layer in the Słupsk Furrow by 2°C to 7.5°C.

After the inflow (April) this thermal-salinity situation and oxygenation were drastically different (Fig. 2, 3). Water temperature decreased by about 2–2.5°C, and in the north-western part of the Bornholm Deep – by as much as 6oC. In this place, warm water from the inflow in July was still present in October. On a large near-bottom area of the Bornholm Deep, water with a salinity of about 15.5 PSU was replaced with water > 18 PSU, with a maximum value in the centre of 19.07 PSU. In the Słupsk Furrow, instead of water with a salinity of 11–12 PSU there was water with a salinity of 13–14 PSU, with a maximum of 14.55 PSU in the vicinity of station RS2 (Figs 2 and 3). Oxygenation in the entire deep layer was 5–6 ml/l, as far as the eastern part of the Słupsk Furrow. Before the inflow, trace amounts of oxygen were noted in the Bornholm Deep and Gdańsk deep: 0.47–0.58 and 0.24–0.42 ml/l, respectively (Figs 4, 5). In the central part of the Gdańsk Deep no change in temperature was observed, while salinity increased by 1 PSU and the amount of oxygen reached 4.16 ml/l. It is probable that a certain amount of water from intermediate layers of the Słupsk Furrow, forced out by the forefront of inflow waters, flowed in there. These changes are visible on the transect in Fig. 5.

In comparison with the situation in October, 1992, the depth of occurrence of water with a conventional salinity index > 12 PSU decreased from 65–70 to 50–65 m (Fig. 6). This resulted from the fact that the deep layer increased in thickness because of the inflow.

Table 1 presents water volumes (km^3) before selected inflows from the past and changes during this year's inflow in the Arkona and Bornholm Deeps. The values given should be treated as the result of the inflow, recorded at a certain point in time. For comparisons of inflows, the values for the Bornholm Deep are more appropriate, as the time during which the given conditions persist is longer there. As an intermediate area, a natural "shelf," the Arkona Deep keeps inflow waters for a very short time only. This changeability was clearly visible during this year's inflow. In the Bornholm Deep, water with a salinity > 12 PSU increased the most in volume after the 1971 inflow, water with a salinity > 15 PSU – after the 1976 inflow, water with a salinity > 18 PSU and > 20 PSU – after this year's inflow.

Discusion

Our studies were conducted after about 70 days from the moment of the inflow occurrence and depict a certain momentary state of the hydrological situation. In April, the changes in thermal/salinity and oxygen structure covered a considerable part of the Baltic, including the Słupsk Furrow and souther slopes of the Gotland Deep. Already in this phase of the inflow, the area favouring the development of cod eggs increased many times. After the January/February, 1969 inflow, so far best documented, (IBY 1969/1970) the same changes in the Gotland Deep began after 8–9 months (Francke and Nehring 1971). There is also an analogy between the parameters of the inflow water from February, 1969 and January, 1993. It was estimated that during the 1969 inflow 30 km^3 of water with a salinity of 20–25

PSU found their way into the Arkona Deep (Francke and Nehring 1971). According to our calculations (Table 1), in February, 1993 49.1 km^3 of water with a salinity > 18 PSU were present in this area, including 21 km^3 of water with a salinity > 20 PSU. However, a part of the water with a volume of 10.1 km^3, and a salinity > 20 PSU, was earlier present in the Bornholm Deep, which together equalled 31 km^3.

Our knowledge about the exchange of water between the Kattegat and the Baltic increased considerably in the past several years (Svansson 1975, Jacobsen 1980). On the basis of historical data, the pattern of all inflows in this century, their statistics, and volumes (Franck et al. 1987, Matthaus and Franck 1990), as well as the relationship between inflow volume and the difference in levels between the Kattegat and the Baltic were determined (Franck and Matthaus 1992). It is known now that the inflow period is preceded by a precursory period, during which a considerable amount of water with a lower salinity enters the Baltic. Between the inflow of December, 1982 and this year's inflow, seven situations, when instead of an inflow, a seasonal renewal of the deep layer of the Bornholm Deep took place, were noted (Wojewodzki and Grelowski 1992). During the last of them, in February, 1992, the highest increase in salinity (by 2.44 PSU) took place (in previous cases, the increase ranged from 0.7 to 1.5 PSU) and 28.6 km^3 of water > 15 PSU were found in the Bornholm Deep. Despite the insignificant inflow of new water in comparison with a large inflow, favourable changes in the near-bottom water took place in the Gdańsk Deep (a slight increase in salinity and a distinct increase in oxygen level). Thanks to these inflows, during the period of stagnation the Gdańsk Deep has been characterized since mid-1980s by positive salinity and oxygenation trends, despite a continuous drop in salinity in the Baltic (Wojewodzki and Grelowski 1992). The volumes of water in those minor inflows were too small to change the situation in the Gotland Deep, where stagnation kept increasing.

The positive results of this year's inflow will be determined in greater detail than previous inflows after it ceases to influence the situation in the Gotland Deep.

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TABLE 1

CHANGES IN SALINITY (PSU) AND WATER VOLUMES (km³) BEFORE AND AFTER THE RECENT INFLOWS

Dates of inflows		S>12	S>15	S>18	S>20
1971/XII	A	34.1	—	—	—
	B	82.2	25.1	—	—
1972/V	A	99.1	20.8	13.1	9.9
	B	282.7	67.3	25.8	—
1975/XII	A	—	—	—	—
	B	63.8	—	—	—
1976/I-III	A	34.1	16.8	—	—
	B	201.6	96.8	—	—
1982/IX	A	—	—	—	—
	B	104.5	35.9	—	—
1982/XII	A	—	—	—	—
	B	229.4	67.3	16.7	—
1992/IX-X	A	17.2	—	—	—
	B	203.4	—	—	—
1993/I	A	—	—	—	9.3
	B	—	—	—	—
1993/II	A	56.5	—	49.1	20.8
	B	256.9	81.2	55.4	10.1
1993/III	A	—	—	—	25.0*
	B	—	—	40-60*	—
1993/IV	A	—	—	—	—
	B	268.1	88.6	16.5	—

A - ARKONA DEEP

B - BORNHOLM DEEP

* - estimated (Rap. U/F "ARGOS", 93.03.16)

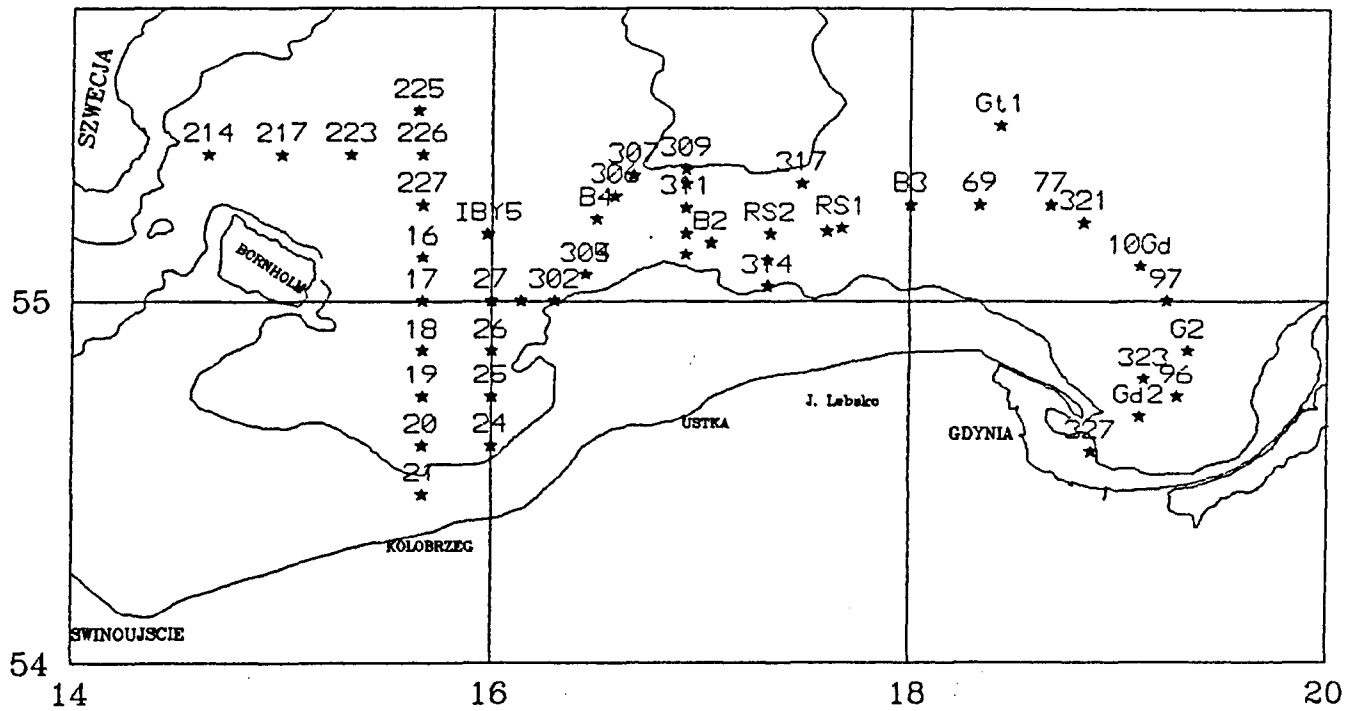

Fig.1. Location of oceanographic stations. April 1993.

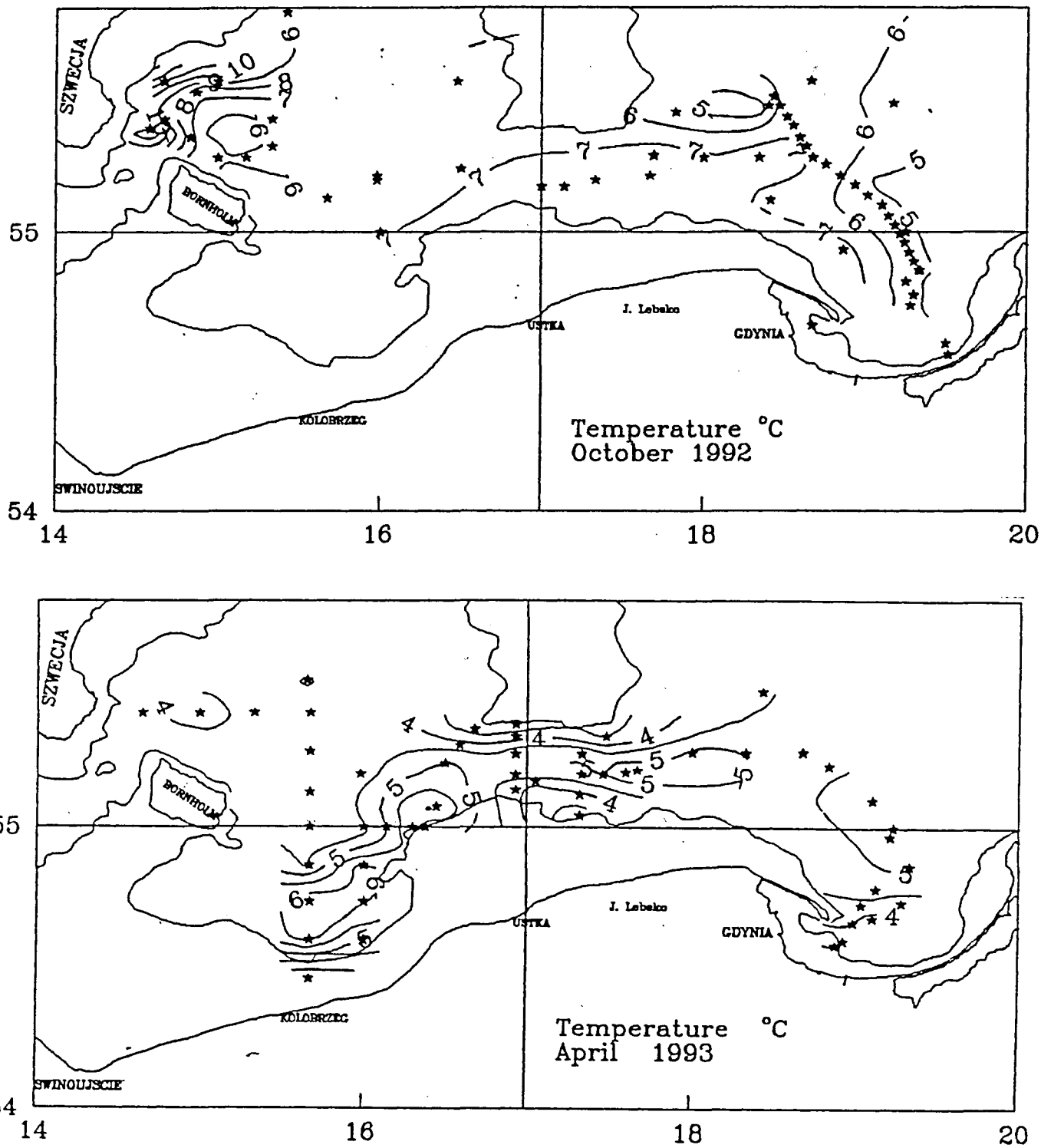

Fig. 2. Temperature in the near-bottom layer; Southern Baltic,

October 1992 and April 1993

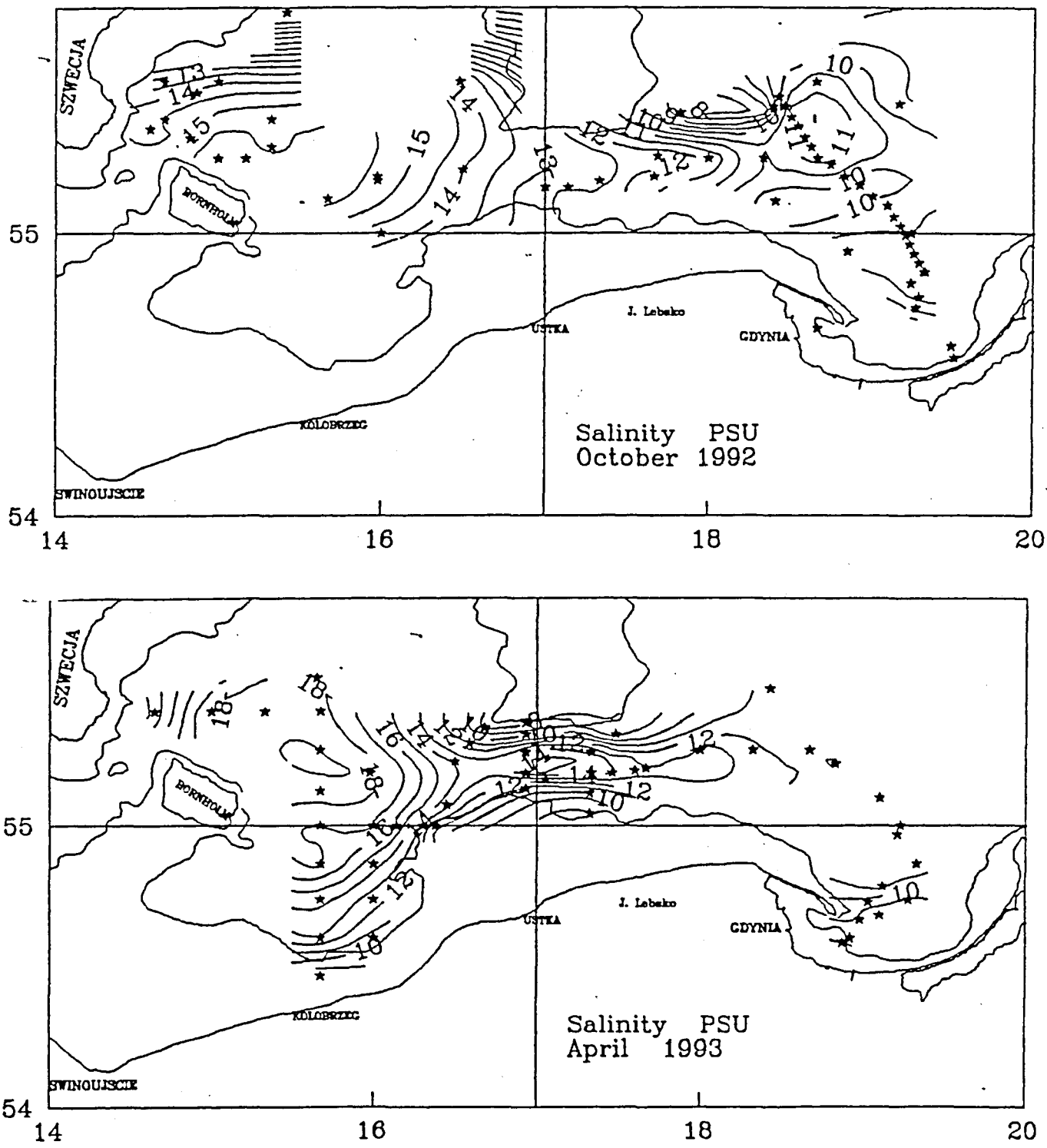

Fig. 3. Salinity in the near-bottom layer; Southern Baltic, October 1992 and April 1993.

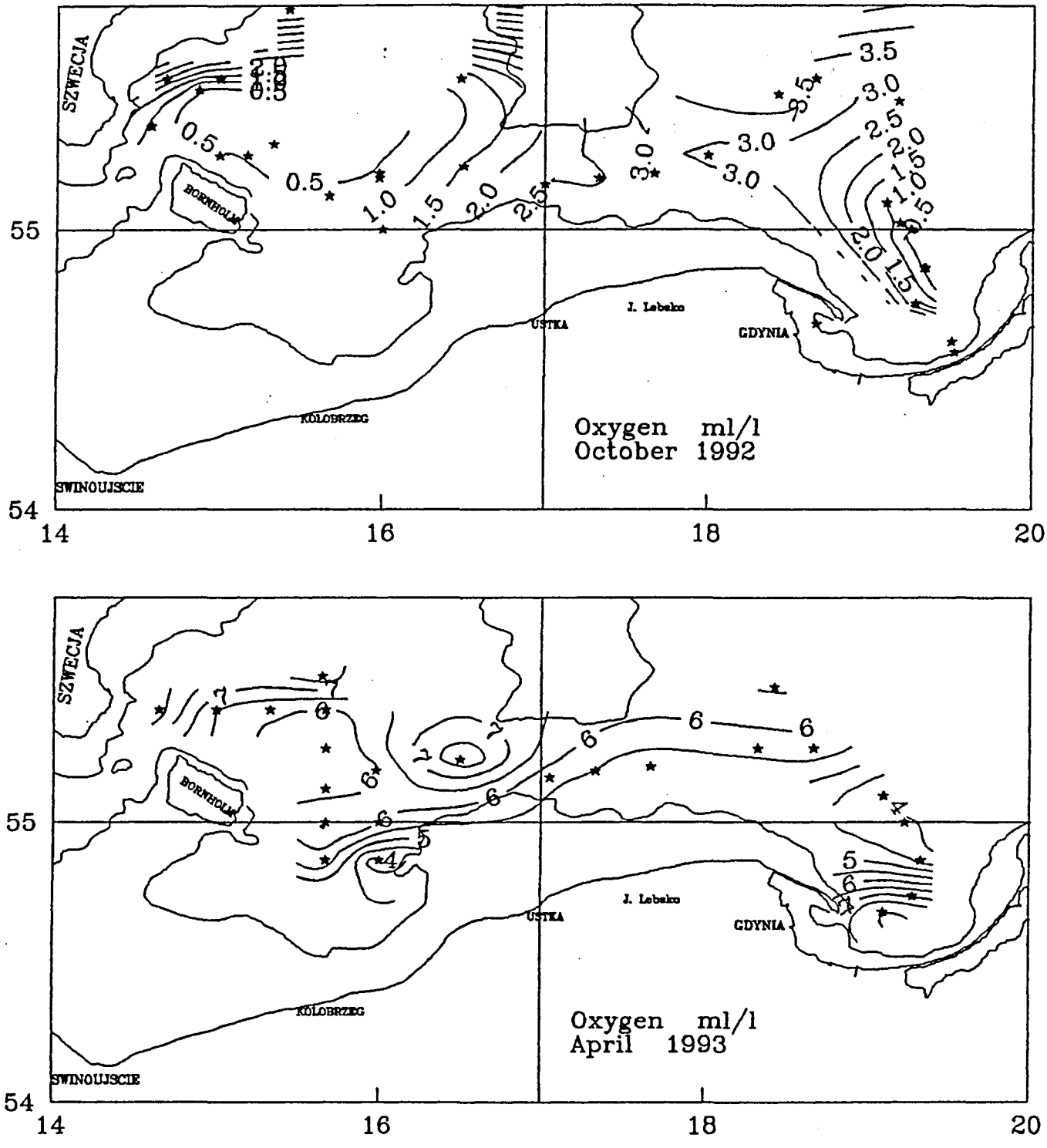

Fig. 4. Oxygen distribution in the near-bottom layer; Southern Baltic, October 1992 and April 1993.

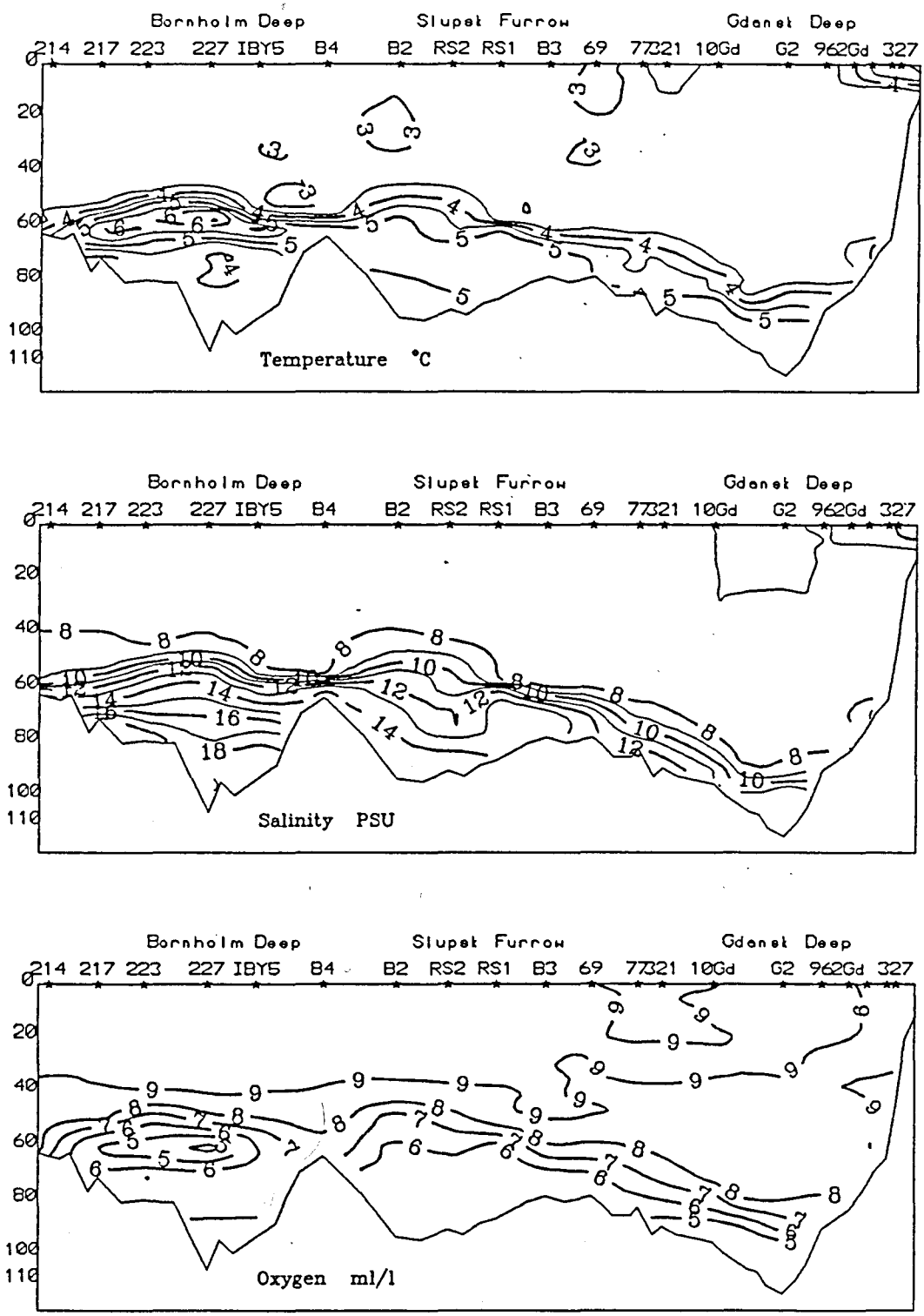

Fig. 5 Distribution of temperature, salinity and oxygen content at the section from Gdańsk Bay to Bornholm Gate in April 1993.

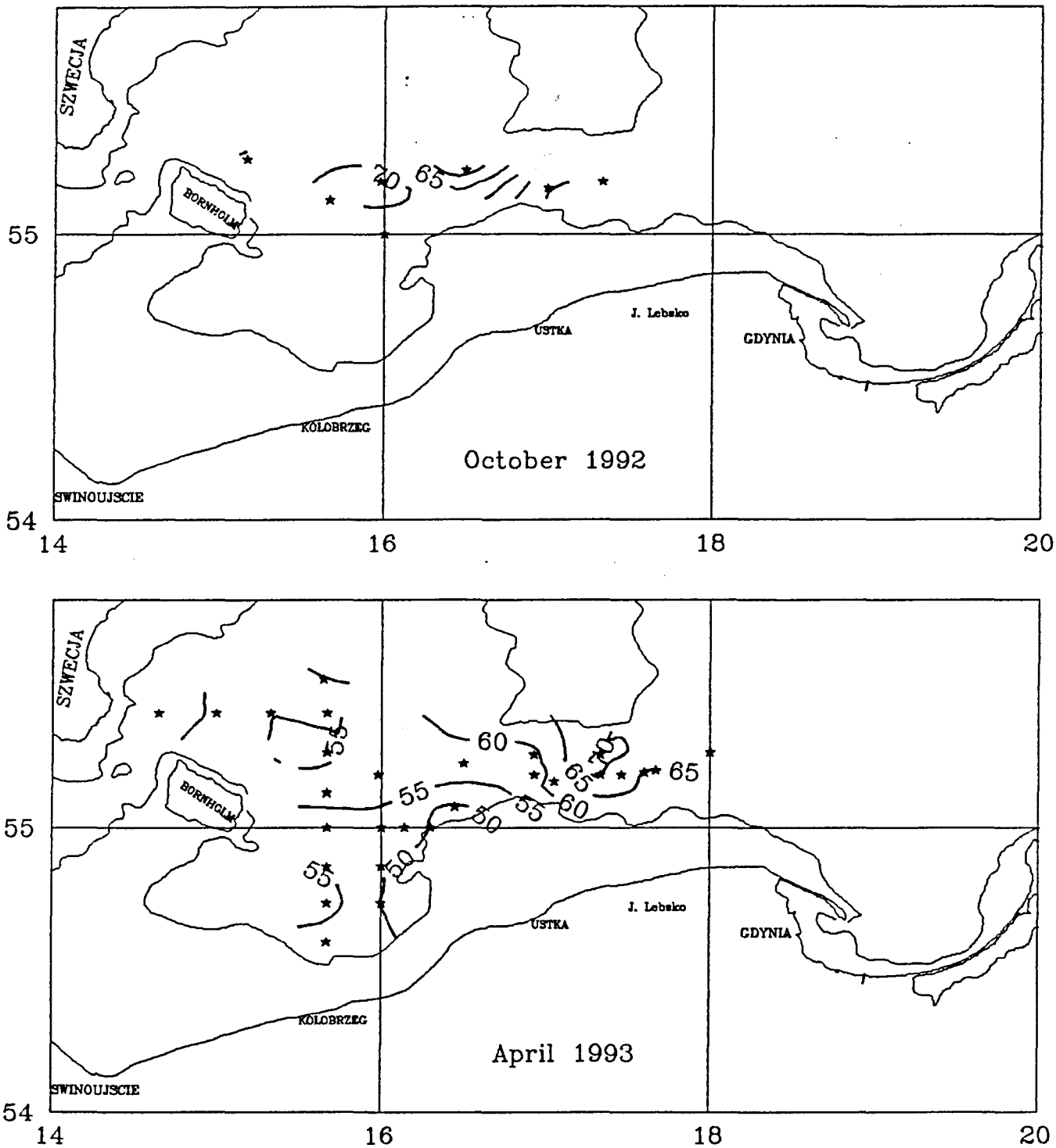

Fig. 6. Depth of occurrence of water with salinity > 12.3 PSU in October 1992 and April 1993.