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SALINITY/OXYGEN REGIME OF WATER IN THE SOUTH-EASTERN PART OF BALTIC PROPER IN 1992-1995 AND DEMERSAL FISH LIVING CONDITIONS

by

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ABSTRACT

Hydrological features of the south-east Baltic Sea are presented on the basis of materials, obtained in 10 cruises of R/V "Monocristali" from May 1992 to May 1995. Major trends in salinity and oxygen conditions variability of the deep sea water, caused by the most strong for the latest 15 years inflow of Kattegate water in January and weaker one in December 1993, were analysed. Cod spawning conditions are characterized for 1992-1995. The results of bottom trawl surveys in March-April 1993-1995 allow to define major cod distribution features in spring for various hydrological conditions.

INTRODUCTION

In 1992-1995 AtlantNIRO researches on R/V "Monocrystall" revealed significant chainges of hydrological conditions in the South-Eastern Baltic Sea, especially within the deep-water and near-bottom layers. Taking in account scale and amplitude of hydrochemical indices variability observed in 1993-1994 as a result of advection (January, December of 1993), latter may be considered as the most important event for the last 2 decades.

In the paper presented the attempt is made both to reveal water condition variability on the basis of absolute values of hydrological features in the South-Eastern Baltic Sea, and to assess quantitatively spatial and temporal scale of advection and its consequences for cod living conditions within Subarea 26 of the Baltic Sea.

MATERIAL AND METHODS

Analysis of hydrological conditions and temporal variability was carried out on the basis of materials of 10 R/V "Monocrystall" cruises in Subarea 26, restricted westwards by economical zones of Poland and Sweden, during March-June and October-November 1992-1995.

Hydrological researches were performed with a probe STD-1000 from the surface to the bottom with temperature and salinity data printing at every 5-10 m and in near-bottom layer. Totally over [illegible]0 hydrological stations were carried out in the area during the above period. At standard station a complex of hydrochemical measurements was performed. Sampling was made by Nansen's bathometers, dissolved oxygen content is estimated with Vinkler's method (over 500 measurements). Temporal hydrological variability was defined on the basis of observations at 2 deepwater international stations: P-1 in the center of Gdansk Deep and BY9 - in the Southern Gotland Deep (Fig. 1).

Data on cod distribution in the south-eastern part of Subarea ICES 26 in the Baltic Sea are presented based on the results of 114 control hauls with bottom trawls DT/TM 30/30 and DT 28.5/37.6 with vertical opening about 8 m and small-mesh frame in the cod-end with a bar length of 6.5-10 mm.

Trawling was carried out for 30 minutes. In total 10 948 specimen of cod were analysed and measured. Maps of distribution over the trawling survey area for 1993-1995 were drawn up on the basis of cod catch size and composition.

RESULTS AND DISCUSSION

During the last years hydrological conditions of the South-Eastern Baltic Sea was characterized by significant variations, stipulated by advection processes predominance in formation of water column vertical structure. Thus, while during 1992 and early 1993 definite trends of salinity decrease in near-bottom layer and at middle depth of Gdansk and Gotland Deeps, and within a broad area of Gotland Deep an exclusively long-term stagnation period was observed, during March-April 1993 a considerable increase of salinity was found in Gdansk Deep (Zezera, 1993). Therefore, inflow of Kattegate water, observed in the straits area in January 1993 (Anon, 1994), reached the South-Eastern Baltic Sea by April which resulted in above-mentioned chainges of hydrological conditions. Data from the Table 1 allows to assess that process scale both in absolute value and in the average long-term values. The Table shows that absolute increase of salinity in near-bottom layer exceeded 2‰ in March-May 1993 while negative anomalies decreased by above 10 times.

In general advection of highly saline water of the South-East Baltic Sea in 1993 was characterized by restricted and short-term impact to Gotland Deep as compared to Gdansk Deep. In the central part of the latter with a decrease of dissolved oxygen from 0.7 to 0.2 ml/l was observed first in the horisont of 200 m from July to October while that in near-bottom layer decreased from 0.2 to 0.5ml/l and by fall hydrogen sulfide apeared in the near-bottom layer. As referred to the extreme south of Gotland Deep (north-western part of Subarea 26, station BY 9 where no stagnation was observed earlier), only insignificant increase of salinity (0.3-0.5‰) in near-bottom layer (100 m and more) was found.

Maximum advection processes development concerning impact upon water conditions in the area, was observed in spring 1994, though the next Kattegate water inflow (December 1993) was considerably weaker in salinity and volume (45 cub. km versus 135 cub.km)(Anon,1994)

However, taking in account the "trace" of the previous advection, increase of absolute salinity values from spring 1993 to spring 1994 amounted to 1.0-2.5‰ in the layer of 70m-bottom of Gdansk Deep, and 0.9-1.4‰ in the layer of 100m-bottom of Southern Gotland Deep. For the first time during the last years salinity value in the near-bottom layer exceeded 13‰ in Gdansk Deep and 12‰ in Gotland Deep. In the first case average weighted salinity over the total water column was equal to average long-term value while in near-bottom layer the latter was exceeded by 0.8‰ (see Table 1).

The major consequence of transformed Kattegate water advection in spring 1994 was a total replacement of deep water in the Eastern Baltic Sea. In the vast area the most long-term stagnation period in the current centure (over 15 years) was completed. Dissolved oxygen level in the near-bottom layer of Gdansk and Central Gotland Deeps exceeded 3 ml/l at saturation of above 35%. Such high values had been observed in the area for the first time since 1930 (Anon, 1994).

Variations of salinity in near-bottom layer of Gdansk Deep and extreme south of Gotland Deep during 1992-1994 are presented in Fig. 2.

As a result of considerable salinity increase in the deep water during 1994, the higher stratification of water column occured, especially that in Gdansk Deep and northwards where vertical gradients of salinity approached 0.32-0.53‰ per 1 m in individual areas. Increase of gradient in the halocline stipulated considerable decrease of oxygen level in near-bottom layers of deep-water area from summer to fall of 1994 as compared to 1993. Therefore in October 1994 the level of dissolved oxygen amounted to 0.1-0.7 ml/l (saturation below 8%) in near-bottom layer, as compared to 1.0 -1.7 ml/l (18%) last year (Fig. 3). Thus, one of the most important consequences of advection in 1993-1994 was occurence of conditions for development of anoxic condition zone in Gdansk Deep during winter 1994/1995. As is shown by the observations in March 1995, in the area with depth of 80-85 m southwards of 56°N the short-term development of the above-mentioned zones, similar to those in winter 1993-1994, was found in couple with retention of the latter till spring, which also is caus ed by lower winter cooling of surface water and decrease of winter convection depth

.s compared to the previous period.

Thus, hydrological conditions in spring 1995 were characterized by existence of zones with oxygen deficiency (0.1-0.7 ml/l at relative saturation below 8%) over the vast area of Gdansk Deep which have been observed in spring for the first time since 1992. In late May-early June futher decrease of oxygen was observed also in the central Gotland Deep where oxygen level was below 1 ml/l in the near-bottom layer. Analysis of near-bottom temperature and salinity variability from late March to June 1995 revealed inflow of another parcel of "fresh" North Sea water into the area which resulted in near-bottom salinity increase and oxygen level improvement in Southern Gotland and Gdansk Deeps (oxygen level was over 2 ml/l at relative content of 25-33%). However, in the Central Gotland Deep and northwards of Gdansk Deep the conditions persisted to increase oxygen deficiency in the water column below halocline and in near-bottom layers.

As compared to spring observations of 1994, and in spite of advection observed, salinity values in Gdansk Deep were lower than those of the previous year by 0.8-1.1‰ in the near-bottom layer and by 2.3-3.0‰ in the layer of 65-85 m. As compared to long-term average values for the whole area, negative salinity anomalies occured in 1995, as well as in 1992 and 1993 (see Table 1).

Comparison of March and May 1995 surveys results allowed to make conclusion on the dominating advection water flow towards Gotland Deep which by the end of May was clearly traced in the vertical field of temperature, salinity and oxygen up to 56°50'N, i.e. by July oxygen conditions may be expected to improve and salinity of deep water to increase in the central part of the area.

Observations made in Gdansk Deep, including standard stations dublication in March, May and June, showed the oposite situation, decrease of advection in that direction which suppose no improvement of conditions in the area northwards of the Deep.

General dynamics of temporal temperature, salinity and oxygen variability at stations P-1 and BY9 from 1992 to 1995 is presented at Figures 4, 5.

Naturally, such sharp variations of hydrological conditions affected considerably the living conditions of demersal fishes, and oxygen deficiency observed in winter 1994/1995 in the deep layer of Gdansk Deep affected the Baltic herring and sprat wintering conditions. The impact on the Baltic cod is represented by considerable variability of spawning grounds area.

Location of isohaline 10‰ in spring (Antonov, 1987) may be considered as an indirect evidence of advective processes strength and spawning grounds area variability. Assessment of the area of near-bottom water with salinity above 10‰ showed considerable variations of the latter from 1992 to 1995.

Minimum area of saline water was observed in 1992 and in March 1993. During 1993-1994 when Kattegate water inflow approached maximum, the area of saline water was the most one, however in the first half of 1995 the area decreased due to reduce of "fresh" water inflow (Fig. 6). Analysis of the diagramme showed that in 1994 the area of water with salinity over 10‰ was more than twice higher within Subarea 26 as compared to that in 1992. The value within Russian zone from March 1993 to April-May 1994 was more than 4 times higher. Figure 7 shows temporal variations of isohaline 10‰ within Subarea 26.

To characterize conditions of cod living and distribution in spring, it should be noted that isohaline 10‰ occures the extreme border of cod distribution area during spawning period while the optimum spawning and eggs development conditions are observed at salinity above 11‰ (Antonov, 1987; Plikshs, Kalejs, Grauman, 1993; Westin and Nissling 1991; Nissling and Westin, 1991). Oxygen conditions seems also important in this respect. Experiments by Otterlind (1953) and more recent researches (Westin and Nissling, 1991; Nissling and Westin, 1991) showed that normal living conditions of cod require no less than 2 ml/l of dissolved oxygen. Thus, the above-mentioned values of salinity and oxygen in the long run define the thickness of layer, favourable for cod reproduction.

Taking in account the above criteria the depth of isohaline 10‰ and 11‰, as well as isooxygen 1.5 and 2.0 ml/l were estimated for various observation periods from 1992 to 1995. As a result the plots were drawn up for temporal variability of the layer depth favourable (10‰-1.5 ml/l) and optimal (11‰ - 2.0 ml/l) for cod spawning (fig. 8, 9). Dymanics of area occupied by water of salinity above 11‰ in Subarea 26 from 1992 to 1995 is presented in Fig. 10.

Analysis of Fig. 8, 9 evidences that similar to area, occupied by highly saline water, considerable variations of thickness of the layer suitable for cod spawning were observed during the period discussed. Thus, during 1992-1995 that layer thickness varied upon extreme criteria (see above) from 3 m in March 1993 to 30-35 m in April-March 1994 in Gdansk Deep, and from 10-13 m (May 1993, April 1993) to 23-32 m (April 1994, May 1995) in Southern Gotland Deep (see Fig. 8). However, data of Fig. 9 should be considered more representative estimate of optimal for cod spawning thickness of layer, since the layer thickness was estimated with commonly used at present predictors, revealing the best correlation between environment conditions and strength of individual cod year-classes (Plikshs, Kalejs, Grauman, 1993). Figure 9 shows that unlike the layer, estimated by the critical boundaries the best conditions for spawning and hence the higher cod recruitment were observed only in Gdansk Deep and only during strong inflow of "fresh" Kattegate water in April-Mey 1994. During other periods in deep-water areas, the thickness of layer favourable for cod spawning decreased to 5-10 m, or even was totally "wedged out" which was stipulated by limitting effect of salinity in 1992, 1993, especially in the area of Station BY9, and by dissolved oxygen level in near-bottom layer during summer 1994 and early 1995 (see Fig. 3, 9). Thus, assessment of cod reproduction conditions on the basis of those more rigid criteria, allows to conclude that during 1992-1995 spawning grounds area within Subarea 26 were rather restricted while the most favourable conditions for cod spawning and eggs development occured in spring 1994 after two Kattegate water inflows in January and December 1993, as was mentioned above.

Impact of interannual variability of hydrological conditions in near-bottom layers on demersal fishes distribution in 1993-1995 was considered for cod, as one of the major commercial species.

During the second half of April- early May 1993, cod length in control catches varied from 9.4 to 112,0 cm. The largest aggregations of cod occured at depths above 80 m with near-bottom water salinity over 10‰ (Fig. 11), water temperature 4.5-5.3°C and relatively high oxygen level over 4 ml/l.

Fish length in catches from deep-water area varied from 12 to 112 cm while individuals of 30-55 cm in length predominated (average length 40.5 cm). Most fishes had gonades of III-IV maturity stages. About 20% of fishes were of pre-spawning and spawning conditions. The number of spawned females and males constituted up to 4%. Cod catches from the depth up to 80 m with water salinity near-bottom below 9‰, at temperature of 3.2-4.0°C as a rule never exceeded 10 kg per 30-minute haul, inspite of high oxygen level. Cod of 9.4-90 cm in length was fished while 30-55 cm was a predominated length.

Spring 1993 was characterized by major concentration of young codup to 30 cm in length within the same areas, as adult fish (Fig. 12). Total cod catches exceeded no 200 kg (38 kg in average).

In April 1994 cod catches per a haul amounted in average to 84 kg while the major aggregations were associated with near-bottom water salinity 11‰ and over (Fig. 13), at temperature 4.0-5.3°C. Oxygen level in deep-water areas of Gdansk Deep was high (over 2ml/1).

Cod length in catches varied from 7 to 100 cm, however in deep-water area (80 m and more) fishes of 30-60 cm in length predominated while at less depths the length was 25-40 cm.

Fishes with gonades of III-IV maturity stages dominated. Number of pre-spawning and spawning cod was only 2-3 %. Small cod of 7-15 cm in length was caught mainly at depth up to 60 m however those fishes occasionally were found over entire area. Increase of area with higher near-bottom water salinity (above 10‰) due to the North Sea water advection affected the pattern of young cod distribution. The highest catches were found at depth of 40-90 m (Fig. 14) with water salinity of 7.44-12.0‰, water temperature 2.8-5.0°C and oxygen level over 3 ml/l.

In March 1995 oxygen conditions in Gdansk Deep and ajacent areas of 90 m and more in depth were extremely unfavourable. Minimum oxygen level below halocline approached 0.12 ml/l sometimes and in general was below 2 ml/l.

In bottom trawl catches from such areas cod was absent or occured rarely (Fig. 15). Major aggregations were found at the depth of 90 m and less. Average cod catch per 30-minute haul amounted to 109 kg. In the western part of investigation area northwards of

Gdansk Deep at the depth of 83-90 m the length of cod in catches was 19-90 cm, predominated size - 43-63 cm, average length - 54.0 cm. Eastwards and northwards of the poor oxygen area, at the depth of 38-90 m the length of cod in catches was 11-103 cm, predominated size - 26-65 cm, average length - 37.7 cm. The bulk of mature cod had gonades of III, IV stages while the number of pre-spawning and spawning cod was only 1-2 %.

Young cod 30 cm in length distributed mainly in the areas of 38-74 m in depth, at near-bottom water salinity of 7.3-10‰ (Fig.16), temperature - 3-5°C and high oxygen level.

Relation of cod distribution and oxygen level in near-bottom layers was observed by many authors, including M.Berner, R.Schemainda (1958), described similar situation in Bornholm Deep.

Those authors showed that in the areas of low oxygen level in near-bottom layers fish was distributed in pelagic zone and is unavailable to a bottom trawl. Excluding no such situation, we should note, that our data on cod distribution in March 1995 evidence considerable increase of young fish number around anoxic areas at less depth with high oxygen level.

CONCLUSION

In 1992-1995 significant variations of hydrological conditions were found in the South-Eastern Baltic Sea, especially in deep waters which was the result of the Kattegate water inflow in January and December of 1993.

Due to advection aeviation of salinity values from long-term average decreased by 5-10 times. In 1994 salinity in near-bottom layer of Gdansk Deep exceeded the latter. For the first time during last years salinity value in Gdansk Deep was over 13‰, and that in Gotland Deep - over 12‰.

One of the most essential consequences of the Kattegate water inflow was the completion of the most long for the century (over 15 years) stagnation period in the Eastern Baltic Sea in summer 1994.

Assessment of areas, occupied by water of higher salinity (10‰) for Subarea 26 shows total increase by 2 times, and increase in Russian zone by above 4 times from spring 1992, 1993 till May 1994.

Another consequence of high salinity water inflow was the increase of water column stratification which in couple with warm winter of 1994/1995 resulted in anaerobic processes development in a deep part of Gdansk area where oxygen deficiency (0.1-0.7 ml/l) was observed not only in March, but even in May-June 1995.

Analysis of environment variability in cod spawning grounds shows that from 1992 to 1995 the most favourable conditions for spawning and eggs development within Subarea 26 were in spring 1994 during maximum advection for the period concerned.

During spring major aggregations of adult cod were observed in the deep-water areas with salinity of near-bottom layer above 10‰ and oxygen level of 2 ml/l and more. Water salinity and temperature restrict young cod distribution to the less extend while adult pre-spawning and spawning cod prefered higher salinity and temperature of water. Oxygen deficiency resulted in cod migration into nearby areas with oxygen level of 2 ml/l and more. However, pre-spawning and spawning fish which prefer areas with higher salinity, distributed around "anoxic" zones and, possibly, in pelagic zone over oxygen-deficiency layer.

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Table 1.

Water salinity (average four each standard stations) and its deviation from the mean long-term values (o/oo) in spring and autumn 1992-1995 (the Gdansk Deep).

	May 1992	anomaly	October 1992	anomaly	March 1993	anomaly	May 1993	anomaly	October 1993	anomaly	April 1994	anomaly	May 1994	anomaly	October 1994	anomaly	March 1995	anomaly	May 1995	anomaly
Layer 0-50 m	7,2	-0,4	7,3	-0,3	7,5	-0,1	7,3	-0,3	7,4	-0,2	7,4	-0,2	7,2	-0,4	7,2	-0,4	7,4	-0,2	7,4	-0,2
Near-bottom layer	10,2	-1,3	9,8	-1,9	9,1	-2,4	11,3	-0,2	11,1	-0,6	11,7	0,2	12,3	0,8	11,8	0,1	11,0	-0,5	11,2	-0,3
Whole layer	8,1	-0,6	8,0	-0,8	7,9	-0,8	8,5	-0,2	8,7	-0,1	8,5	-0,2	8,7	0,0	8,4	-0,4	8,4	-0,3	8,4	-0,3

LEGENDS

Figure 1. Research area and location of international deep-water stations.

Figure 2. Salinity distribution (‰) in the near-bottom layer (1992-1994).

Figure 3. Salinity and oxygen variations in near-bottom layer from 1992 to 1995 (Subarea 26.).

Figure 4. Spatial-temporal variability of temperature, salinity and oxygen from 1992 to 1995.

Figure 5. Spatial-temporal variability of temperature, salinity and oxygen from 1992 to 1995.

Figure 6. Variability of area (sq.miles) occupied by water with salinity above 10‰ (Subarea 26).

Figure 7. Variability of 10‰ isohaline location in spring 1992-1995.

Figure 8. Dynamics of the layer favourable for cod spawning from 1992 to 1995 (Subarea 26).

Figure 9. Dynamics of the layer, optimal for cod spawning from 1992 to 1995 (Subarea 26).

Figure 10. Variation of 11‰ isohaline in spring 1992-1995.

Figure 11. Water salinity in near-bottom layer and cod catches per 30-minute hauls in April-May 1993.

Figure 12. Water salinity in near-bottom layer and catch of cod of 30 cm in length in April-May 1993.

Figure 13. Water salinity in near-bottom layer and cod catches per 30-minute hauls in April 1994.

Figure 14. Water salinity in near-bottom layer and catches of cod of 30 cm in length in April 1994.

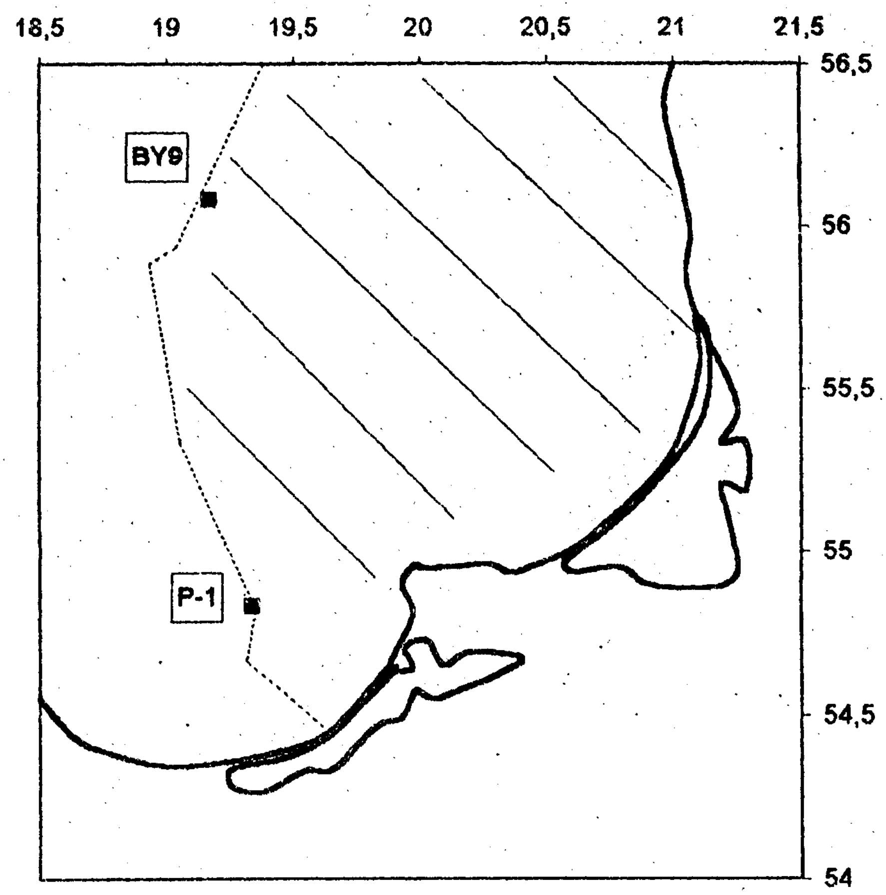
Figure 15. Water salinity in near-bottom layer and cod catches per 30-minute hauls in April 1995.

Figure 16. Water salinity in near-bottom layer and catches of cod of 30 cm in length in March 1995.

Table 1.

Water salinity (average four each standard stations) and its deviation from the mean long-term values (o/oo) in spring and autumn 1992-1995 (the Gdansk Deep).

	May 1992	anomaly	October 1992	anomaly	March 1993	anomaly	May 1993	anomaly	October 1993	anomaly	April 1994	anomaly	May 1994	anomaly	October 1994	anomaly	March 1995	anomaly	May 1995	anomaly
Layer 0-50 m	7,2	-0,4	7,3	-0,3	7,5	-0,1	7,3	-0,3	7,4	-0,2	7,4	-0,2	7,2	-0,4	7,2	-0,4	7,4	-0,2	7,4	-0,2
Near-bottom layer	10,2	-1,3	9,8	-1,9	9,1	-2,4	11,3	-0,2	11,1	-0,6	11,7	**0,2**	12,3	**0,8**	11,8	**0,1**	11,0	-0,5	11,2	-0,3
Whole layer	8,1	-0,6	8,0	-0,8	7,9	-0,8	8,5	-0,2	8,7	-0,1	8,5	-0,2	8,7	**0,0**	8,4	-0,4	8,4	-0,3	8,4	-0,3



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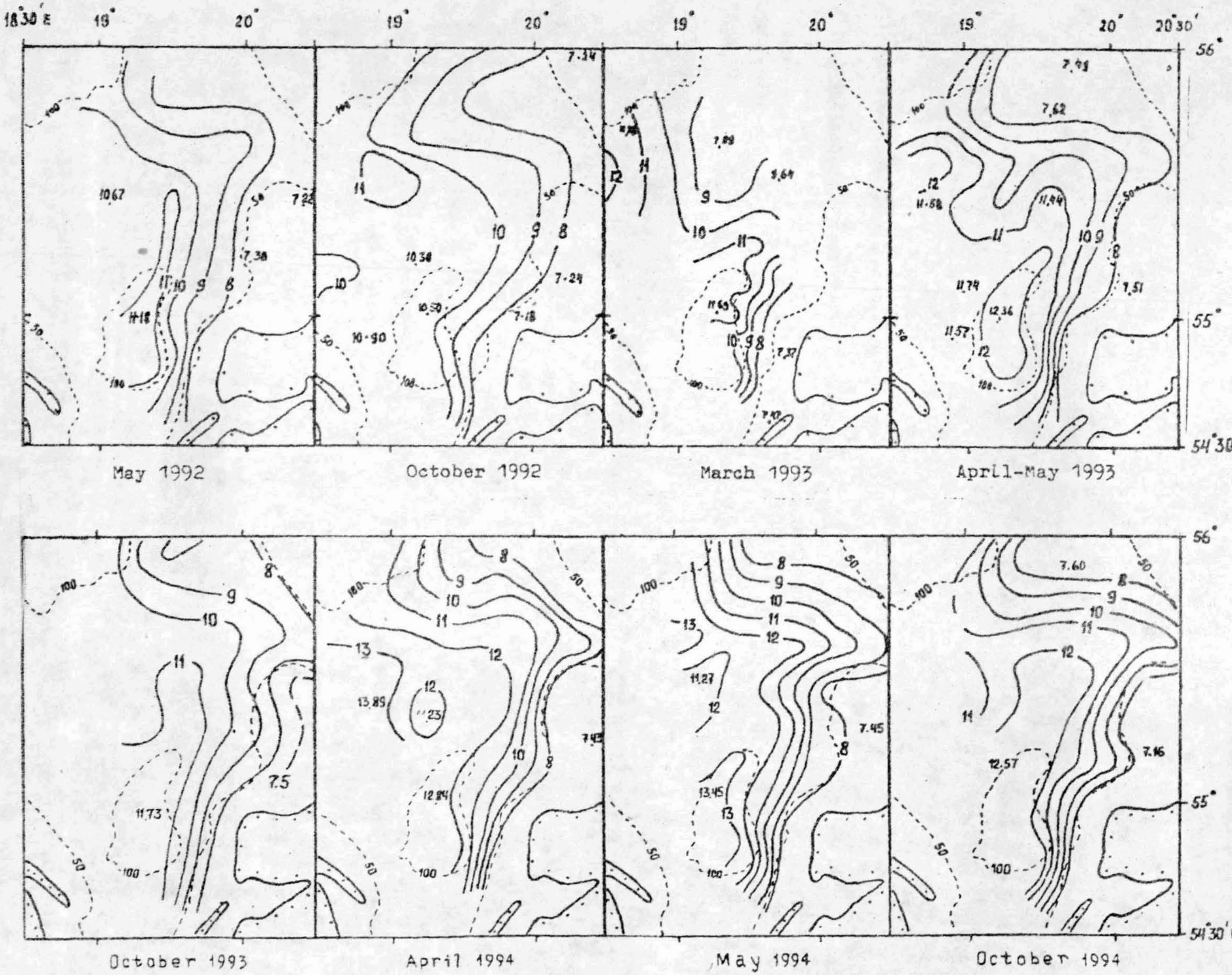
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Fig. 2.

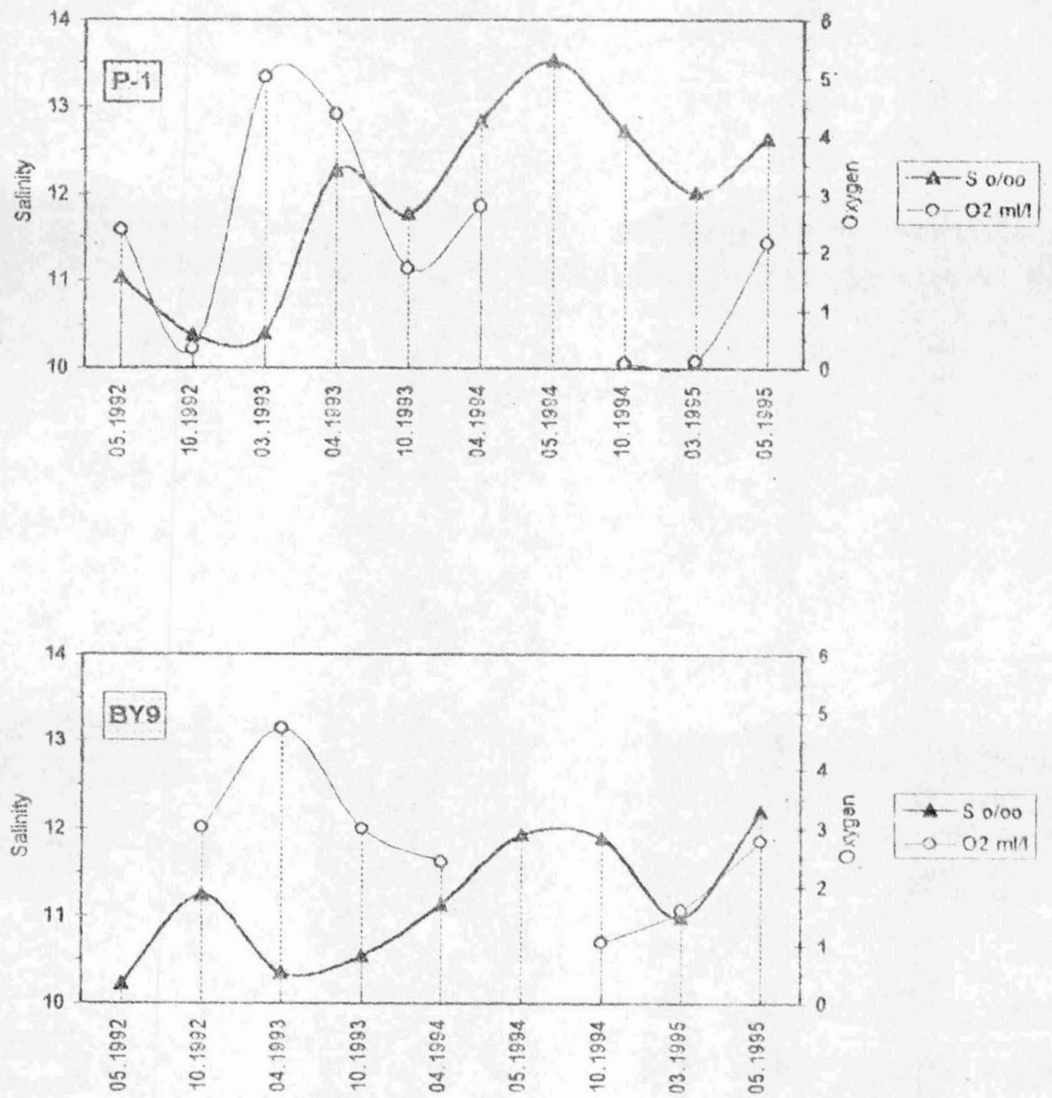
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Fig. 3.

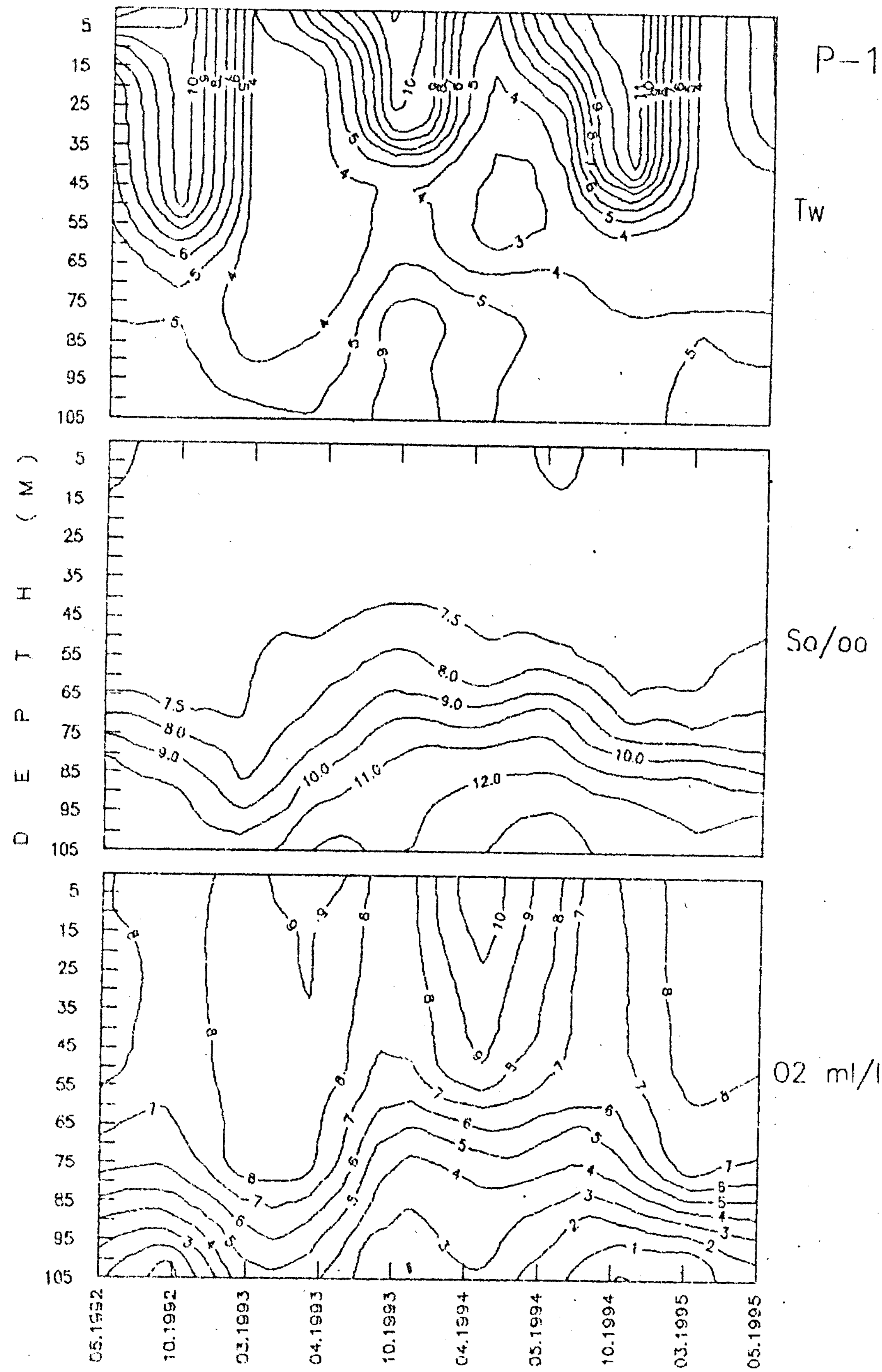
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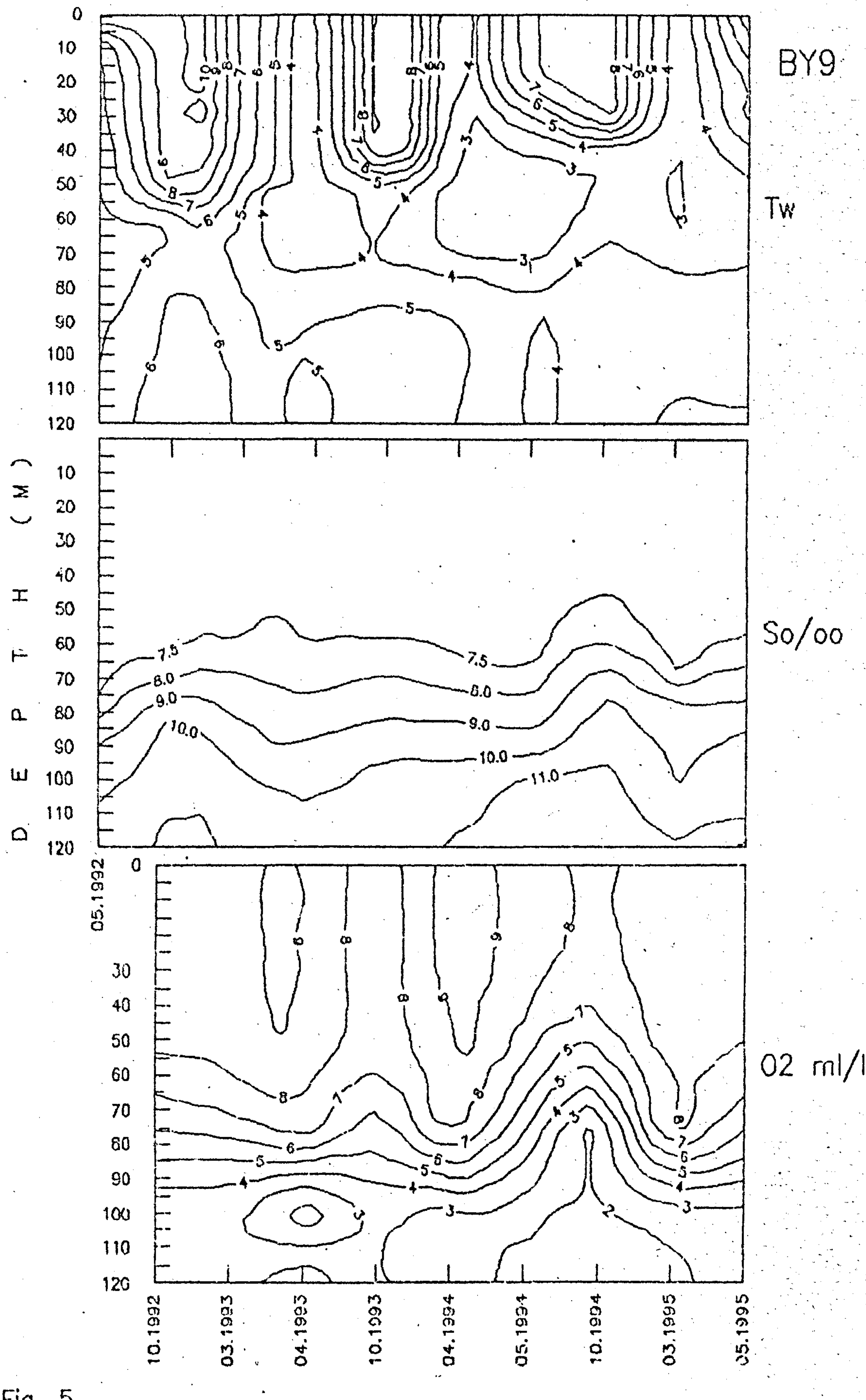
Fig. 4.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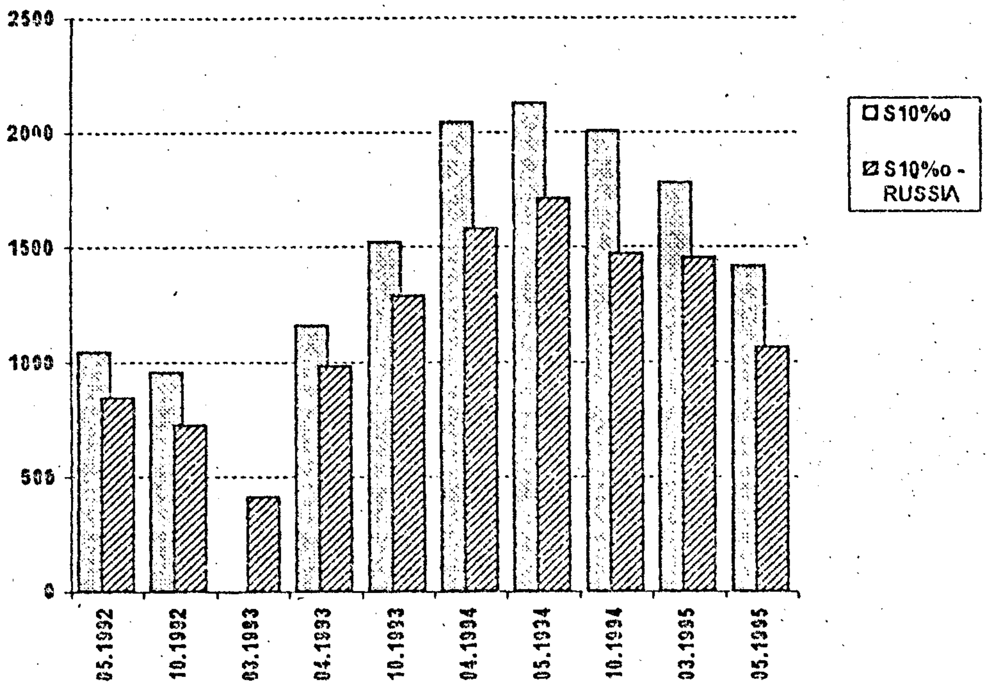
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Fig. 6.

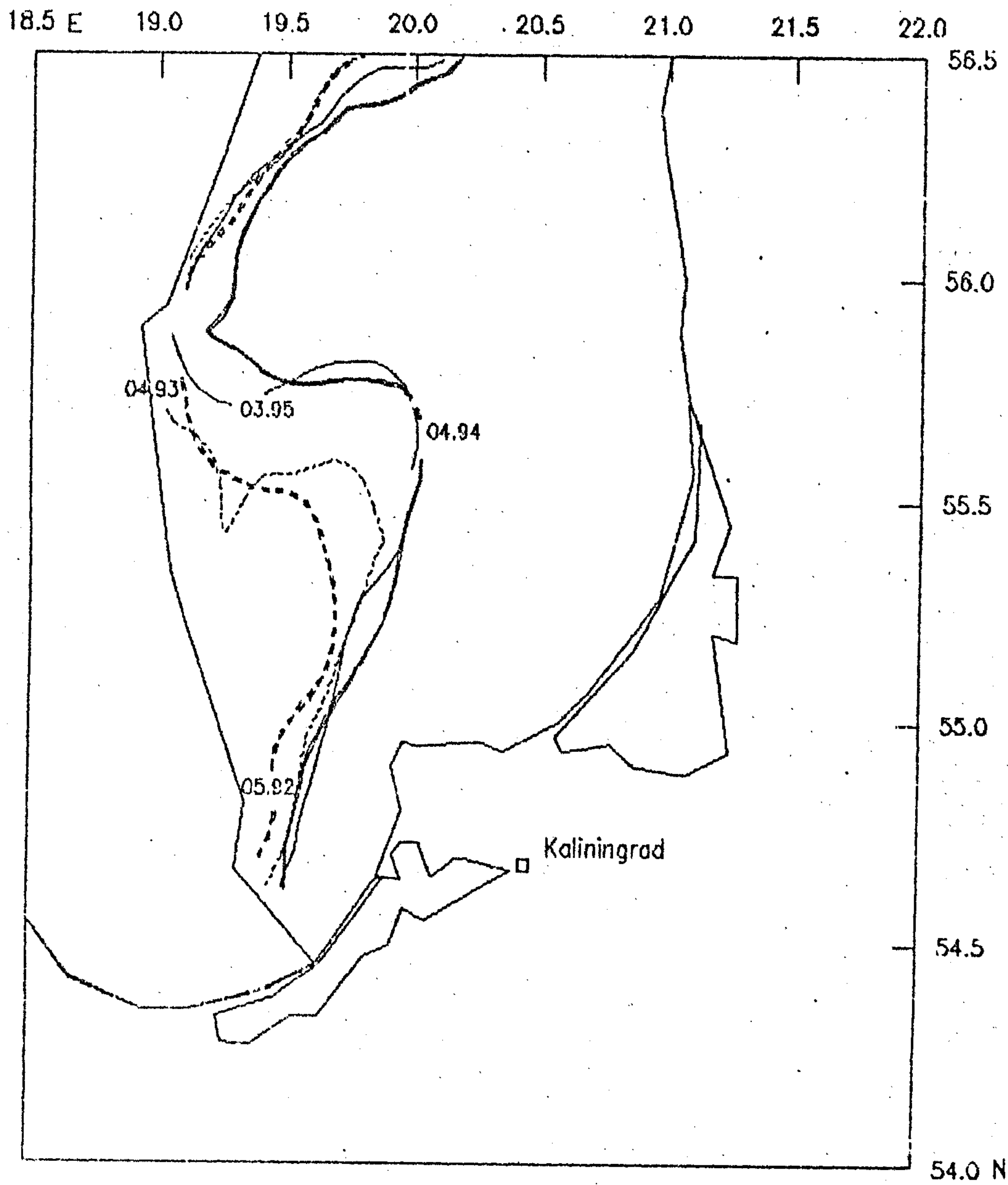
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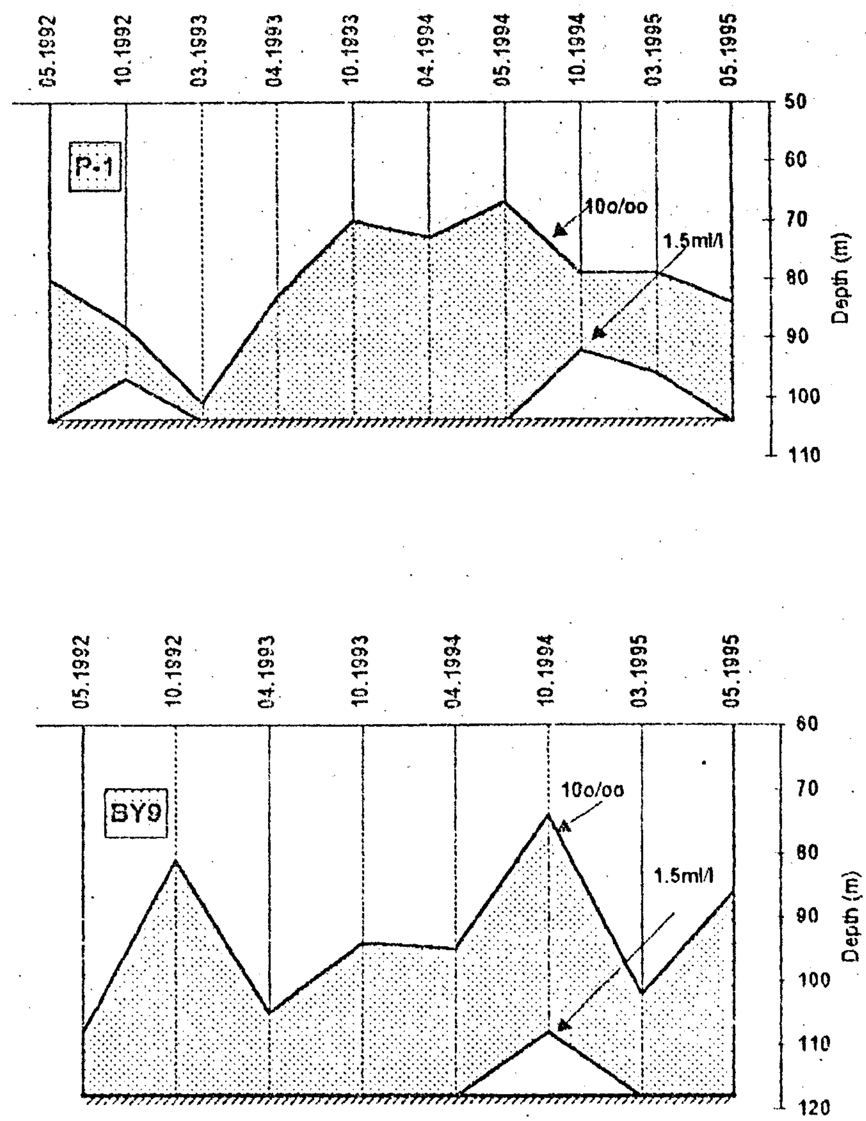
Fig. 7.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Depth (m)
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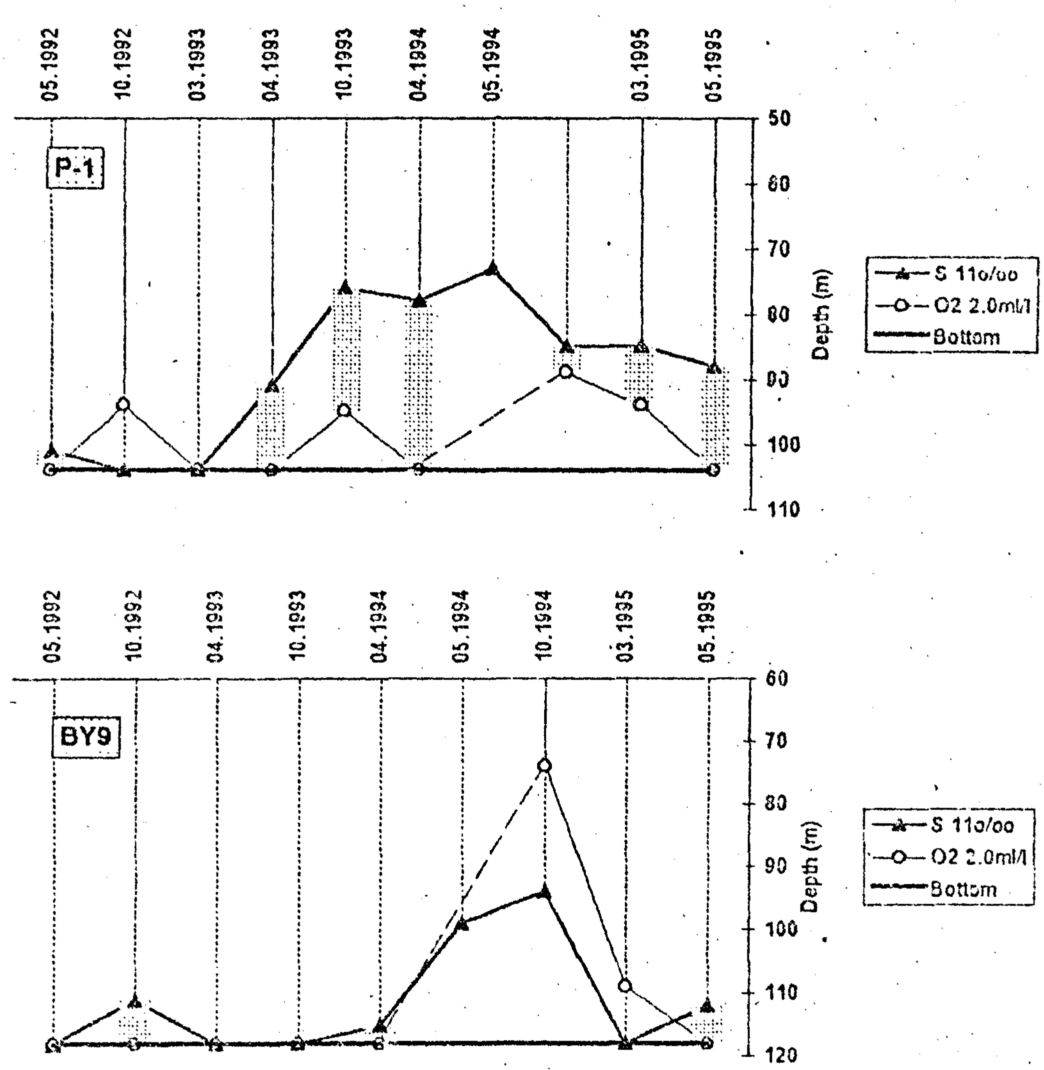
Fig. 8.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03.1995

Fig. 9.

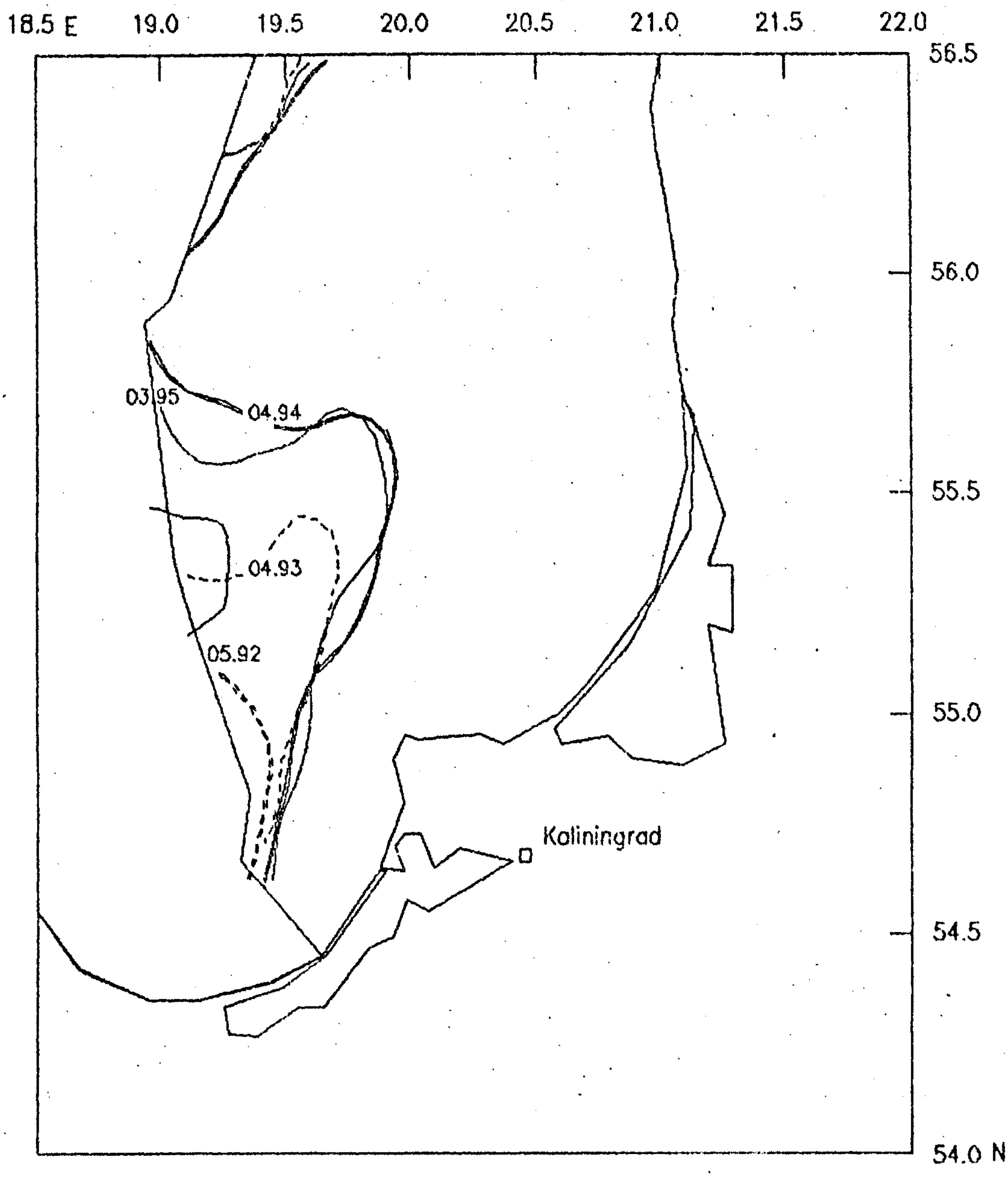
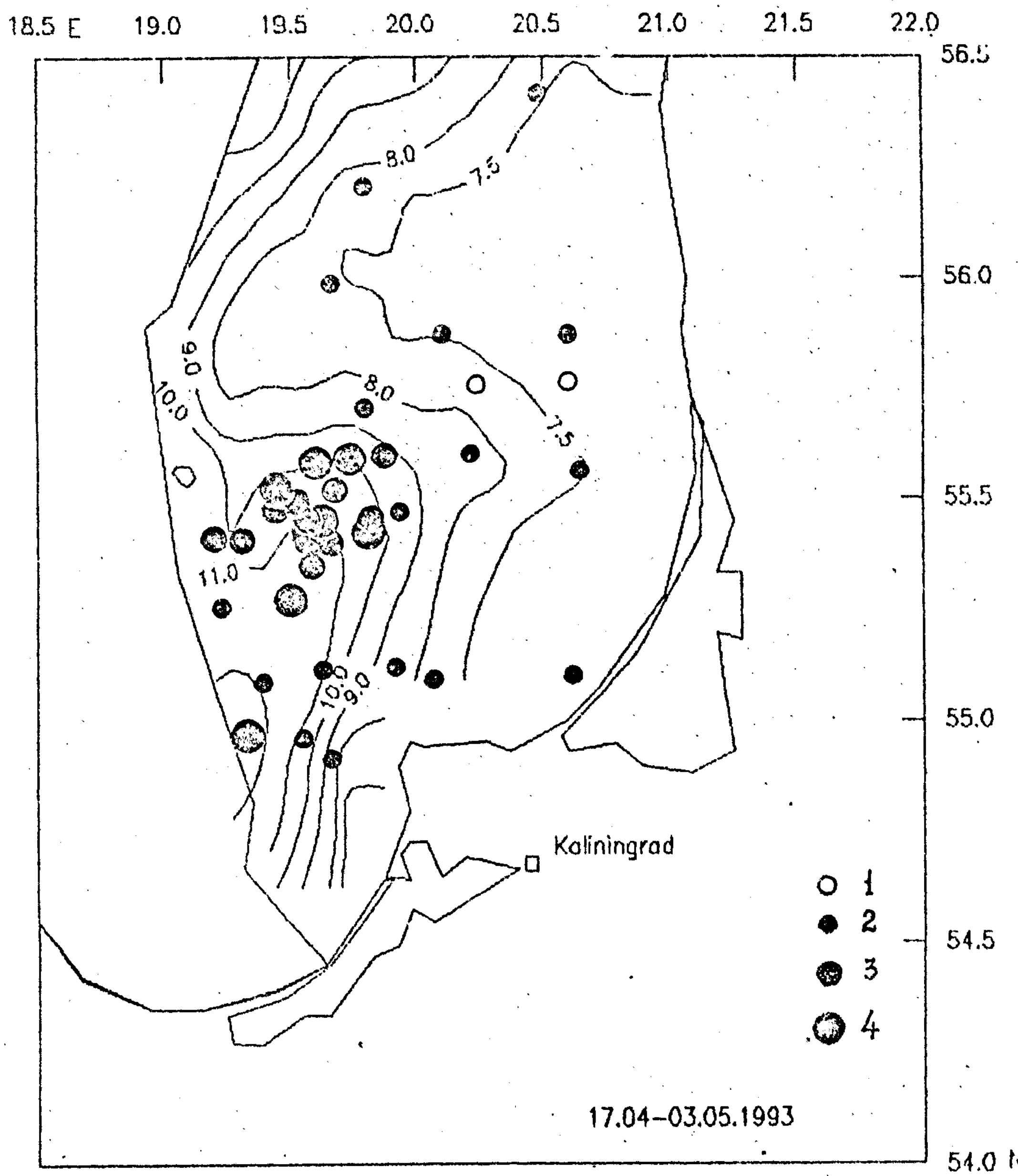

18.5 E
19.0
19.5
20.0
20.5
21.0
21.5
22.0
56.5
56.0
55.5
55.0
54.5
54.0 N
03.95
04.94
04.93
05.92
Kaliningrad

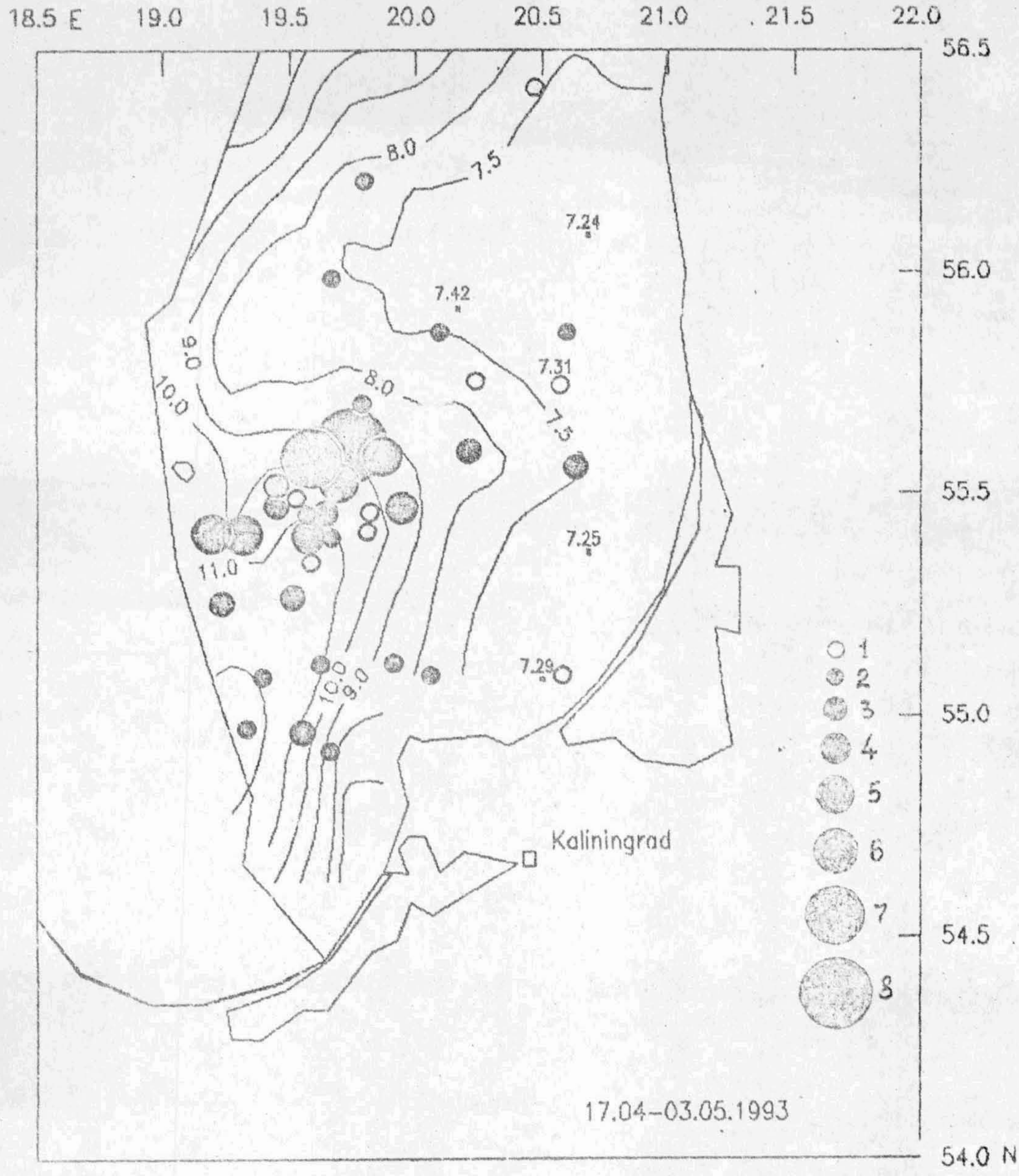
Fig. 10.



Catch in kg

1) 0 ;
2) ≤ 50 ;
3) 50-100 ;
4) 100-200 .

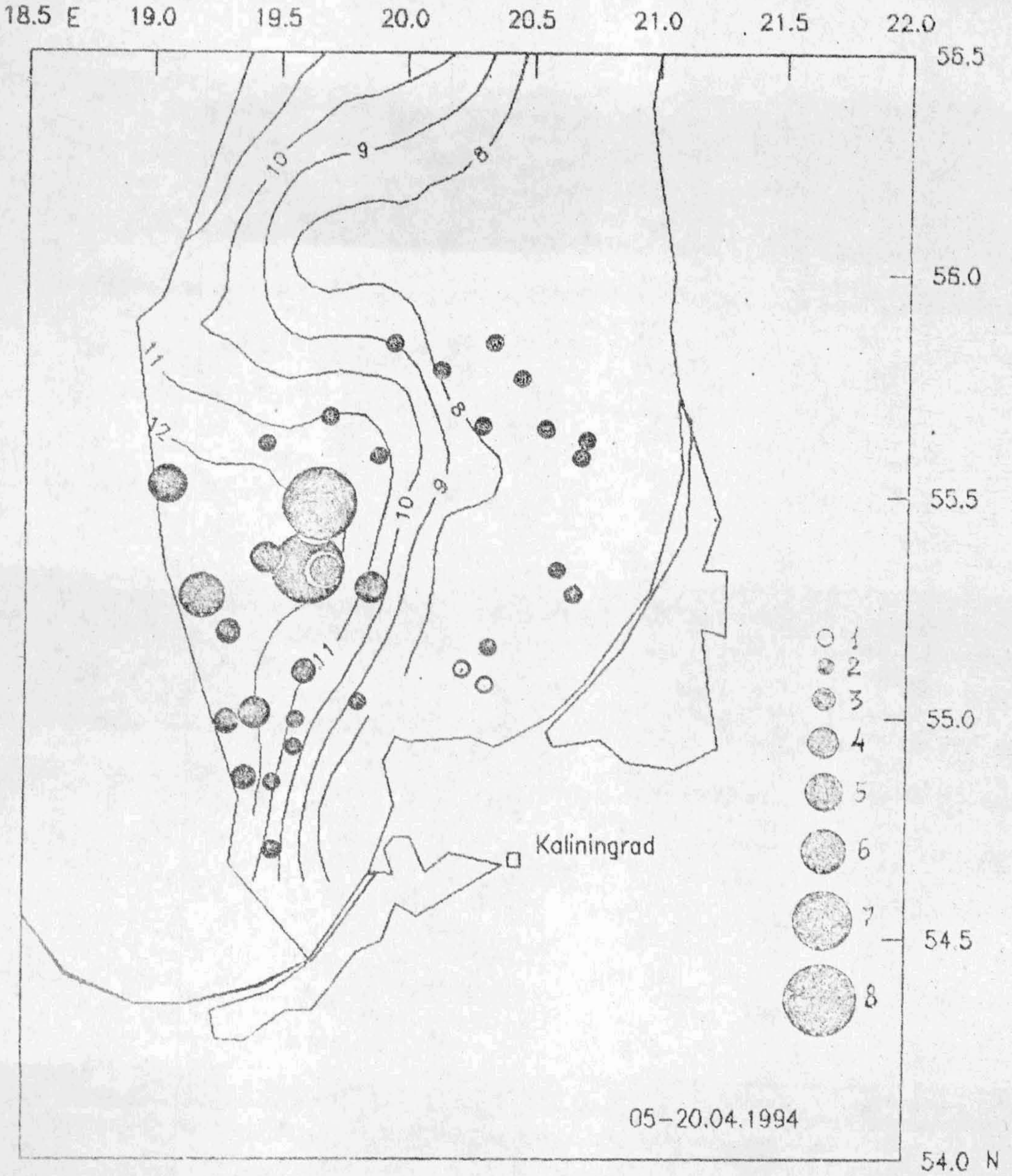
Fig. 11.



Catch in members

1) 0 ;	5) 31-50 ;
2) ≤ 10 ;	6) 51-80 ;
3) 11-20 ;	7) 81-120 ;
4) 21-30 ;	8) 121-150 .

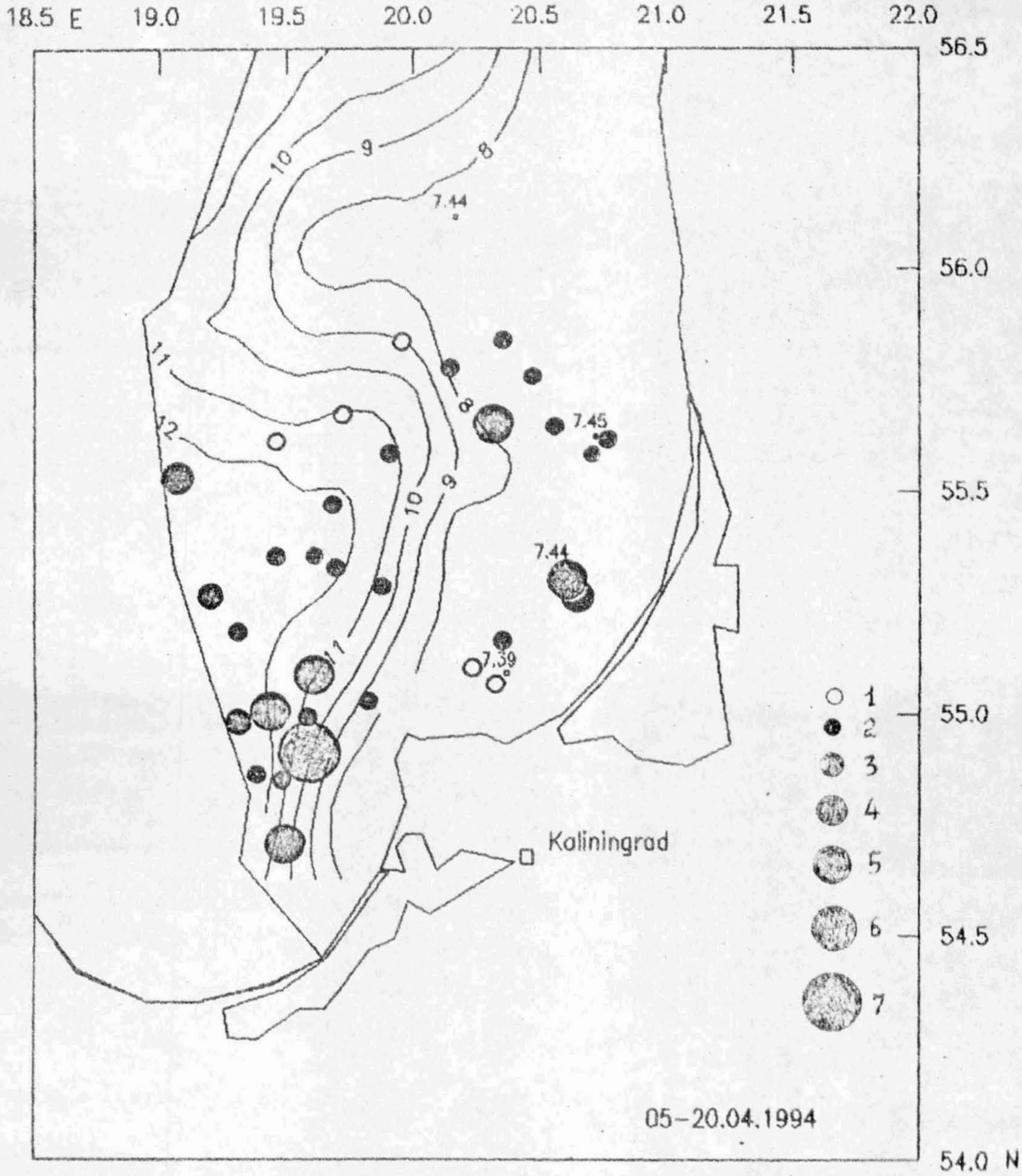
Fig. 12.



Catch in kg

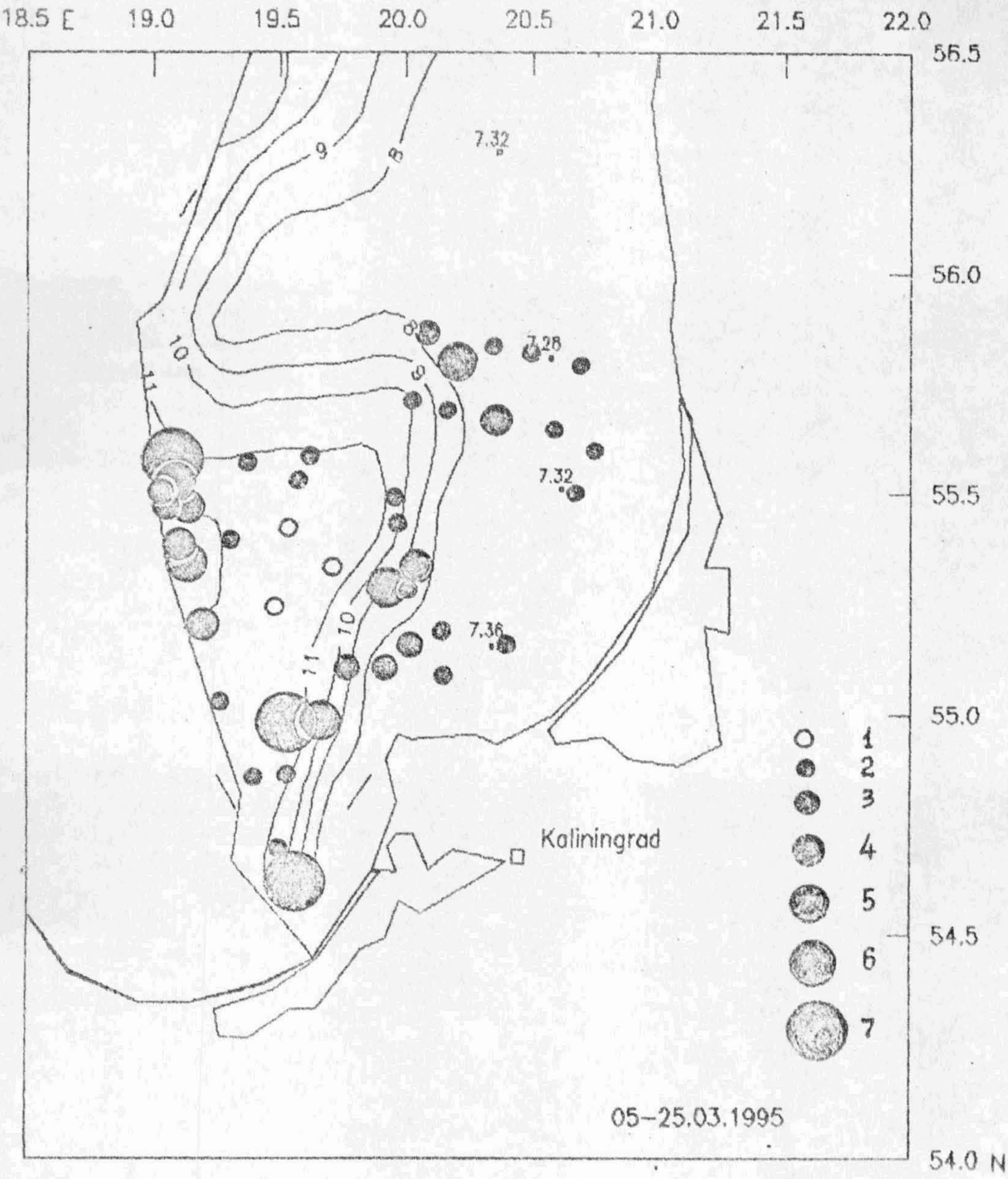
1) 0 ; 5) 200-300 ;
2) ≤ 50 ; 6) 300-400 ;
3) 50-100 ; 7) 400-500 ;
4) 100-200 8) > 500 .

Fig. 13.



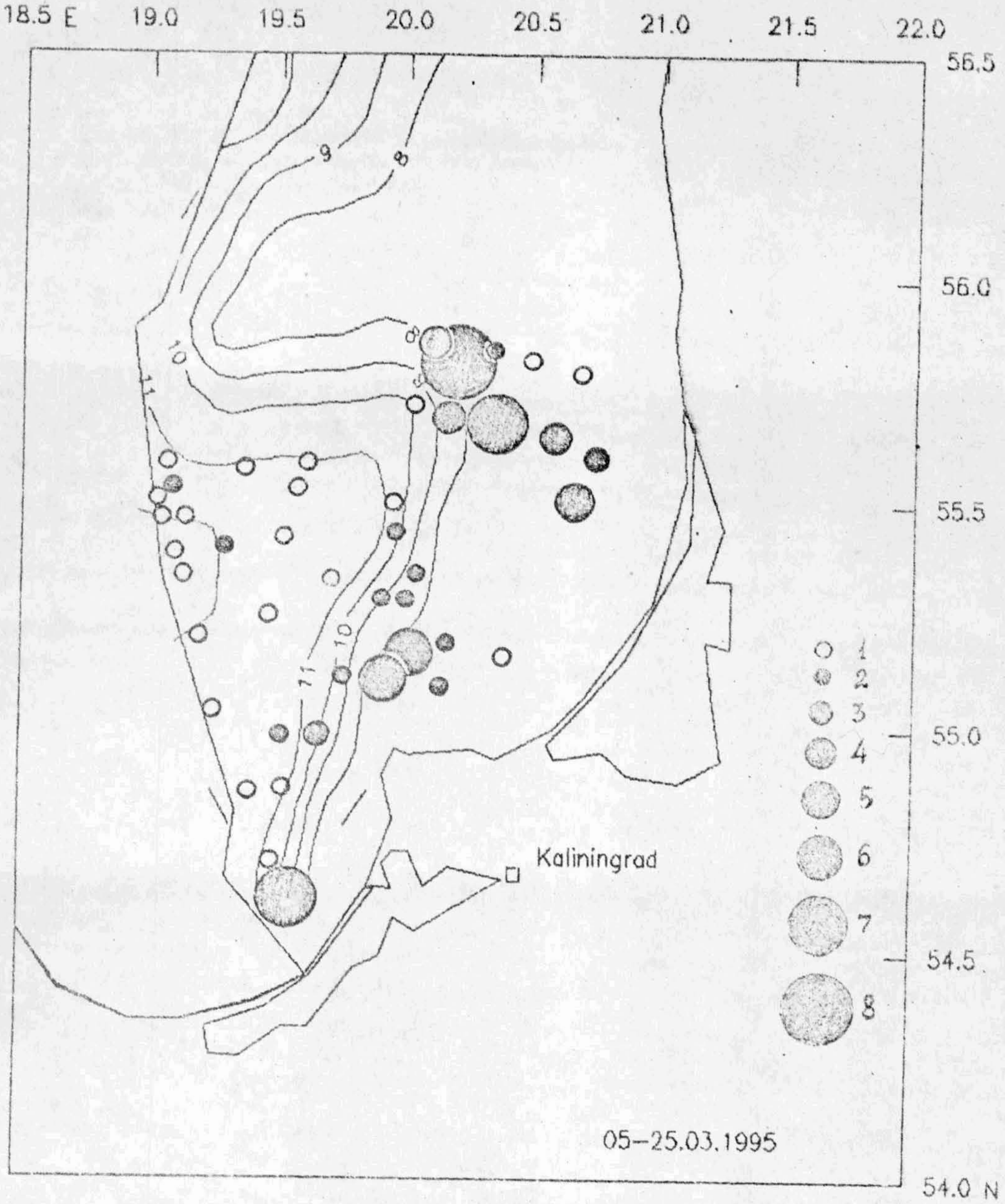
The same, as on the Fig. 12.

Fig. 14.



The same, as on the Fig. 13.

Fig. 15.



The same, as on the Fig. 12.

Fig. 16.