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THE EKOFISK BRAVO BLOW OUT
Compiled Norwegian Contributions

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Introduction and preliminary findings

by

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The preliminary results from the investigations carried out during and immediately following the Ekofisk Bravo blow-out were published in a previous report (Institute of Marine Research, 1977). The report had a limited distribution, therefore its major parts are included and updated with further results in the present papers. The field observations were completed by the end of July. Considerable material, however, still remains for analytical treatment and these papers are therefore also to be considered "preliminary".

The blow-out occurred on Friday night April 22 at the oil production platform Bravo, situated at 56°33'N, 03°12.2'E within the Ekofisk field in the North Sea. The blow-out resulted in discharge of crude oil and gas in a mixture of 2:1 through an open production pipe about 20 m above the sea surface. The discharge rate was at the time of the accident estimated to be 3 - 4000 tons of oil per day, (loc. sit. 1977). Later evidence of the presence of obstructing items in the pipe suggests that this was an over-estimate, and a more probable rate would be 2 - 3000 tons of oil per day. The mixture had a temperature of more than 75°C at the escape point, and it was blown another 30 m into the air where it partly dispersed and evaporated before the remainder showered down over the sea surface. Depending on wind and surface water movements, the resulting oil spread in different directions and attained varying shapes and consistencies, patches of oil up to 1 cm thick and water-in-oil emulsions interchanging with the more commonly occurring thin film and streamers of oil.

The blow-out lasted for $7\frac{1}{2}$ days until, after several attempts, a team of experts succeeded in capping the well at 1105 on April 30. It is assumed that about 40% of the escaped oil had by then evaporated, indicating that some 9-13000 tons still remained on the sea. This figure is only preliminary, as an official commission is still investigating the accident.

In order to appraise the dimensions of the Bravo accident, a brief review of some previous oil disasters that caused world-wide publicity may be useful:

The "Torrey Canyon" grounding, Scilly Isles	1967	118 000 tons
The Santa Barbara blow-out	1969	15 000 "
The Chevron, Gulf of Mexico blow-out	1970	5 000 "
The "Metula" grounding Straits of Magellan	1974	50 000 "
The "Urquiola" grounding La Coruña, Spain	1976	100 000 "
The "Argo Merchant" grounding Nantucket Island	1976	26 000 "

Viewed in this perspective of recent major oil spills, the Bravo blow-out may seem moderate. However, it all happened in an area of considerable fishing interest and without the success in capping the pipe it might have ended up as a major disaster.

Ekofisk crude oil is of low viscosity and under the described circumstances it spread rapidly over the surface of the sea. It was consequently difficult to recover by mechanical means. The oil had a high content of volatile aromatic hydrocarbons which are also known to include the more toxic compounds to marine living resources. It is easily dispersable into water by chemical means. However, chemical dispersion was assumed to increase the hazard to sensitive components of the living resources, especially drifting eggs and larvae. Since these were most susceptible and no coastal interests seemed to be immediately threatened, it was decided to leave the oil drifting meanwhile, keeping this decision open for reconsideration if the situation should change.

It was additionally decided to apply all available mechanical means to recover as much of the drifting oil as possible, and 800 - 1000 tons were therby recovered. Chemical dispersants were only applied for safety reasons on one occasion when about 50 tons were sprayed onto oil drifting towards the inhabited Ekofisk City.

The North Sea contains fish resources of considerable importance to the coastal countries. International fisheries in this area amount to about 3 mill. tons per year, as exemplified by catches of the major species in 1975:

Saithe	271 148 tons
Herring	365 209 "
Mackerel	317 800 "
Norway pout	559 600 "
Sand eel	424 800 "
Cod	219 976 "
Haddock	190 118 "
Whiting	168 099 "
Plaice	124 193 "
Sole	18 761 "
Blue whiting	41 000 "

These resources reproduce at rather specific spawning sites spread over the entire North Sea, some of which are located around the Ekofisk field. This applies, for example, to the very important mackerel resource, where Ekofisk is centered in the middle of its spawning area (Fig. 10.6).

Several of the fish are spring spawners, where spawning is more or less timed to the vernal development in the plankton. During winter and early spring poor stratification in the waters and the lack of light result in poor plankton production. Stratification in the central North Sea will normally develop in April, and a typical spring bloom of phytoplankton then begins. It is followed by spawning and rapid developments in the zooplankton. Eggs and nauplii of copepods, especially Calanus spp., constitute the most

important food for the fish larvae, and their abundance is a pre-requisite for success in fish reproduction.

It was feared that the blow-out might coincide with this sensitive stage in the biological development of the fish, and especially that products of the mackerel spawning might be exposed to the oil and its effects.
It was recognized to be the task of this Institute to describe the exposed living resources and the possible effects of the oil on their physiology and behaviour as well as the distribution and fate of the oil in the marine environment. An improvised program was developed containing the following elements:

1. The occurrence and distribution of living resources, with emphasis on plankton, including fish eggs and larvae.

2. Recording of ongoing fisheries in the area threatened by the oil spill and the abundance of fish resources on which they were based.

3. Recording of possible irregularities in mortality and development of plankton and fish larvae.

4. Sampling of sea water for chemical analysis of the horizontal and vertical distribution of petroleum hydrocarbons.

5. Sampling of fish and plankton for chemical analysis on contents of petroleum hydrocarbons.

6. Sampling of oil from the surface for chemical analysis of the environmental effects on the oil.
7. Distribution of oil degrading micro-organisms and the effect of oil on the microflora.

8. Experimental studies on acute lethal and sublethal effects of the contaminated waters on larvae of fish and of invertebrates.

9. Occurrence and distribution of particulate oil following the blow-out. Recording of oil drift.

10. Standard hydrographical program to describe the physical environmental condition.

The program did not cover all possible aspects of the encountered pollution situation. It was, however, realistic in relation to available experts and equipment within our own and related institutes, and could be put into operation at short notice. Recognizing the international interests in the pollution effects and also with a view to obtaining a broader expertise, invitations to participate were given to fisheries scientists of other North Sea countries and to experts from other Norwegian laboratories.

With certain adaptions to the continuously changing situation, the above program constituted the basis for a sequence of observations, some of which covered the entire period from 36 hrs after the outbreak until 2 months after its closure (Table 1.1)

Table 1.1. Ships and survey periods

Ship	Date
R/V "Johan Hjort	March 8 - 31
KNM "Sleipner"	April 24 - 25
R/V "G. O. Sars"	April 27 - May 1
R/V "Johan Hjort"	April 27 - May 1
R/V "Johan Hjort"	May 1 - 4
R/V "G. O. Sars"	May 10 - 16
R/V "Johan Hjort"	May 31 - June 17
R/V "Johan Hjort"	July 11 - 30

Based on information on the distribution and drift of the oil, grid systems of stations were planned for each cruise to cover both the polluted waters as well as the neighbouring non-polluted waters, for reference (Fig. 1.1 - 1.7).

In addition to the Norwegian research activities, several of the neighbouring countries offered their cooperation and executed coordinated programs. R/V "Corella" from Lowestoft, R/V "Explorer" from Aberdeen and R/V "Dana" from Copenhagen which were on the scene during or shortly after the blow-out also communicated their activities and findings to the Norwegian research vessels. This information was highly appreciated and enabled us to carry out our additional task of twice daily reporting the developments in the field to the Norwegian authorities in a better way. German and Swedish research vessels also carried out specific research programs, and Phillips Petroleum Co., the operator of the oil field concerned, organized their own research team. The value of these joint efforts is appreciated especially in respect to certain intercalibration purposes, as well as for the discussion of the different approaches and experience gained in the complex problem of recording fate and effects.

The following findings are extracted from the present reports:

Variable winds in the period following the blow-out transported the resulting oil slick back and forth within a rather limited area. During the first 2 - 3 weeks the transport was dominantly in a northerly direction, and then in the next 4 - 5 weeks it was in a southerly direction (Fig. 2.15). Towards the end of June the patch was centered around $54^{o}30'N$ and $2^{o}30'$ - $3^{o}E$, (Fig. 5.3) and had by then drifted over the area between this position and $58^{o}30'N$ and 2^{o} and $4^{o}E$. At the end of July oil was observed near the Ekofisk field but chemical analyses identified this as a mixture of Ekofisk and other oils.

The occurrence and consistency of the oil changed with time, the original patches being broken up and gradually attaining a granulated appearance. From the second week onwards only patches of granulated oil were observed. Three months after the blow-out a minimum of 150 tons or 1.7% of the assumed oil spill remained as drifting tar balls in the surface layers. An unknown amount remained suspended in the water masses and/or sedimented out on the

bottom. The tar balls were for the latter half of the elapsed period scattered over an area of at least 55 000 km^2, in concentrations in June/July averaging 2.5 mg/m^2 sea surface, which has previously been classified as heavy pollution. Follow-up investigations may reveal the lifetime of these tar balls in the North Sea. Oil degrading bacteria were present all over the area, but seemingly the fresh oil had some inhibiting effect, thereby reducing the numbers of bacteria recorded in the surface water near the platform during the initial stages of the blow-out (Fig. 6.1 - 6.3). Total counts of micro-organisms about 1 week later showed even distribution and their abundance did not indicate traceable effects of the oil.

A number of oil samples from the surface of the polluted area, collected either by bucket or by Otter trawl, were analysed chemically. The samples contained from 30 to 70% water. The disappearance of the lighter components of the oil due to weathering processes accounted for a loss of more than 50% of the original weight after a few days. With reference to the relative composition of aromatic hydrocarbons with low volatility, it was possible to identify oil lumps collected in June and July as Bravo oil and to distinguish them from lumps of other origins.

Oil-in-water emulsion was detected in concentrations of up to approximately 300 micrograms/l in water under relatively fresh surface oil in the near surroundings of the Bravo platform. Small but significant amounts of dissolved aromatic hydrocarbons were found over a larger area (Fig 3.2 - 3.5). No vertical gradient could be detected down to 10 m. Except perhaps for the area of very fresh oil pollution, the concentrations recorded in the water column were below those observed in laboratory tests as having acute lethal effects on the more sensitive stages of fish development.

Hydrographic observations indicated that there were various distinct water masses in the Ekofisk area during and immediately after the blow-out. Dominating was a cold core of winter-formed

water in the central part of the investigated area, which was covered by an upper layer of coastal water to the north-east and to the south-west was limited by Atlantic water (Fig. 2.2).

At the outbreak the temperature of the surface layers was below normal, and except for the north-easterly corner of the grid (Fig. 2.2) no stratification existed (Fig. 2.14). From May on, stratification developed gradually and the homogeneous top layer decreased from 50 m in April to less than 20 m in the middle of May.

The hydrographic situation was reflected in the biological development, which during and immediately after the blow-out on average could be characterized as being in an early spring stage. The vertical mixing removed the producing stock of phytoplankton from the euphotic zone and resulted in slow progress and long duration of the primary production in step with the development of the transition layer.

The variations observed in the rates of primary production and the stock of chlorophyll were generally attributable to differences in the physical conditions of the respective water masses. Statistical treatment of the production indices however, revealed that shortly after the outbreak an area limited to a few square nautical miles around and eastwards of the platform had significantly reduced productivity, thus indicating an oil effect (Table 8.2).

The phytoplankton was dominated by larger types (diatoms), where the fraction larger than 30 µm counted for more than 50% of the primary production (Table 9.1). No significant change in the contribution of different size groups of the plankton in the primary production (Table 9.2), was observed under the varying exposures to the oil hydrocarbons.

Similarly, as for the phytoplankton, and possibly as a consequence of the delayed development of the same, the zooplankton biomass during the shortly after the blow-out was low. Krill was most abundant, and Calanus spp. were dominant among the copepods.

The progressive development of the plankton seemed normal, and except for a smaller area near the Bravo platform, no obvious differences were observed in distribution and composition within and outside the polluted areas. Repeated observations, however, showed the presence of dead copepods near the platform, and together with the reduced primary production indices in this locality, this indicates acute lethal effects of the more freshly discharged oil.

There were few fish eggs and yolk sac larvae in the area during the outbreak and immediately following it, and those found were mainly those of long rough dab and the cod family (whiting, haddock and cod), occasionally mixed in with eggs of dab and plaice. A few sand eel larvae were found in the southern part of the region. Mackerel spawning commenced about the middle of May and its further development followed a normal pattern. The ichtyplankton seemed healthy and no obvious effects of the oil were revealed on it.

There was low abundance of fish at the time of the blow-out and for a short time afterwards. Very few pelagic fish were recorded, the main component being 0-group herring scattered more or less over the entire area. Demersal fish occurred in quantities estimated to be approximately 0,5 tons/km^2 on overall average, with the highest abundance to the north-east of Ekofisk (Figs. 11.2-11.4). This picture seemed to change little in the following months, except for pelagic fish where the abundance of mackerel increased markedly. No obvious effects of oil were revealed in relation to fish distribution or abundance.

Not all the observations have yet been reported on, and important data on the contents of hydrocarbons in fish and plankton when analysed, will add valuable evidence as to possible effects.

On summarizing the findings so far, however, they all indicate that the acute effects were small. Although sublethal effects cannot be excluded, the low concentrations of hydrocarbons in the water columns outside the immediate neighbourhood of the platform, combined with the scarce availability of sensitive resources, makes it unlikely that serious acute harm on the resources should result.

It is evident that several factors account for this: the high temperature of the oil on escape, and the fact that winds and rapid surface spreading caused efficient evaporation of the most volatile and toxic compounds. Furthermore, the unstable conditions of the water masses resulted in effective dilution of dispersed and dissolved hydrocarbons.

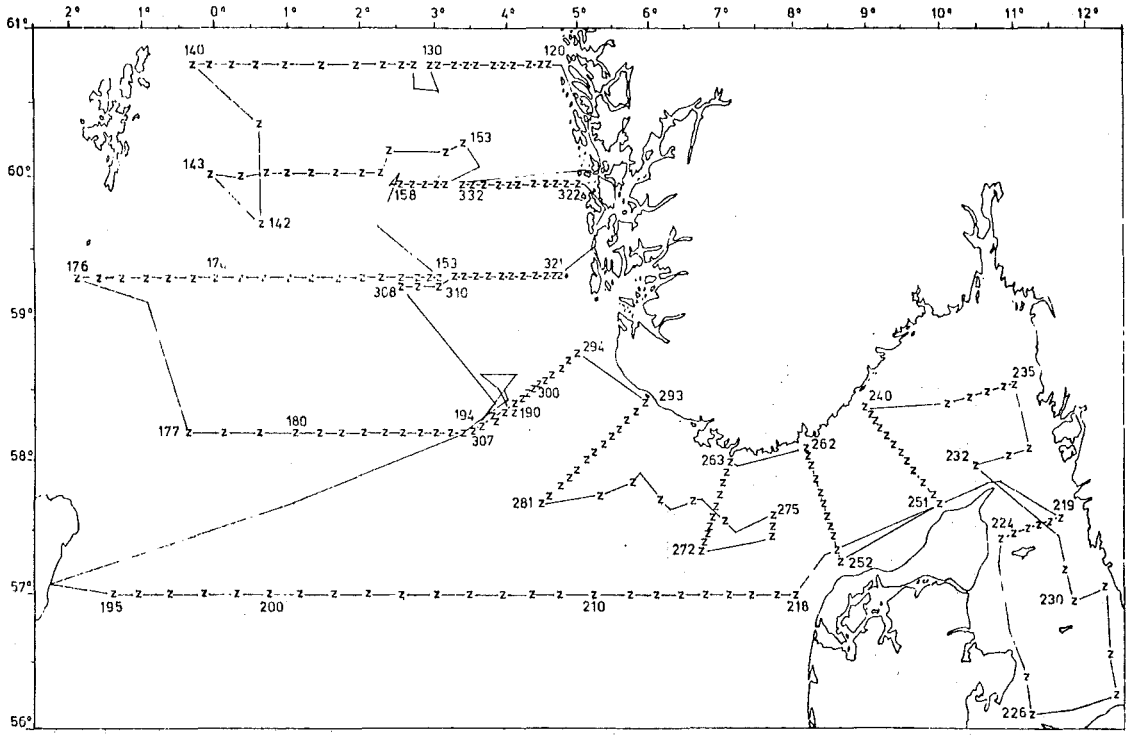


Fig. 1.1. CTD-stations, R/V "Johan Hjort" March 8 - 31, 1977.

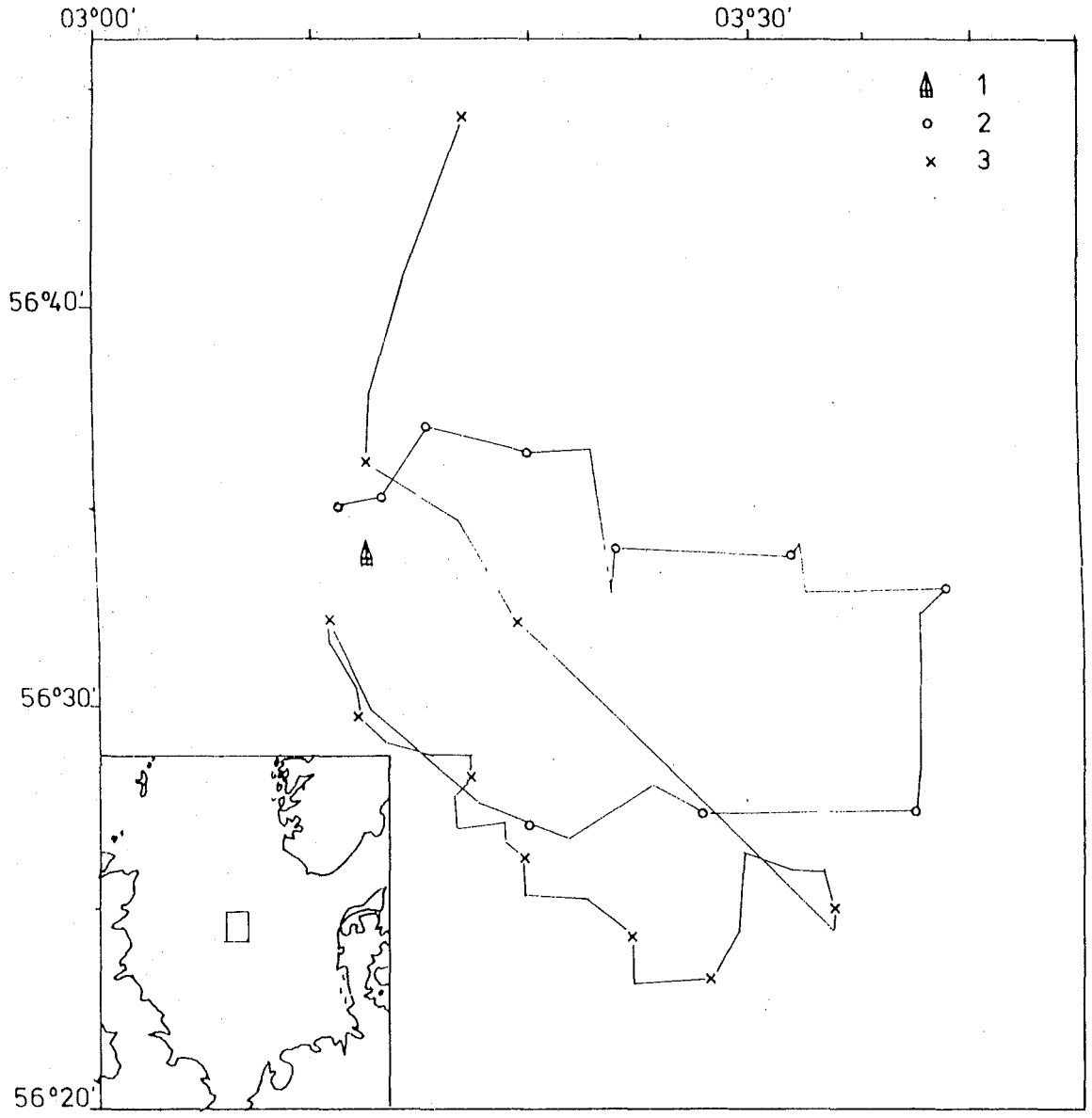


Fig. 1.2. Station grid system for KNM "Sleipner",
1: Bravo platform, 2: Stations Sunday 24.4.,
3: Stations Monday 25.4.

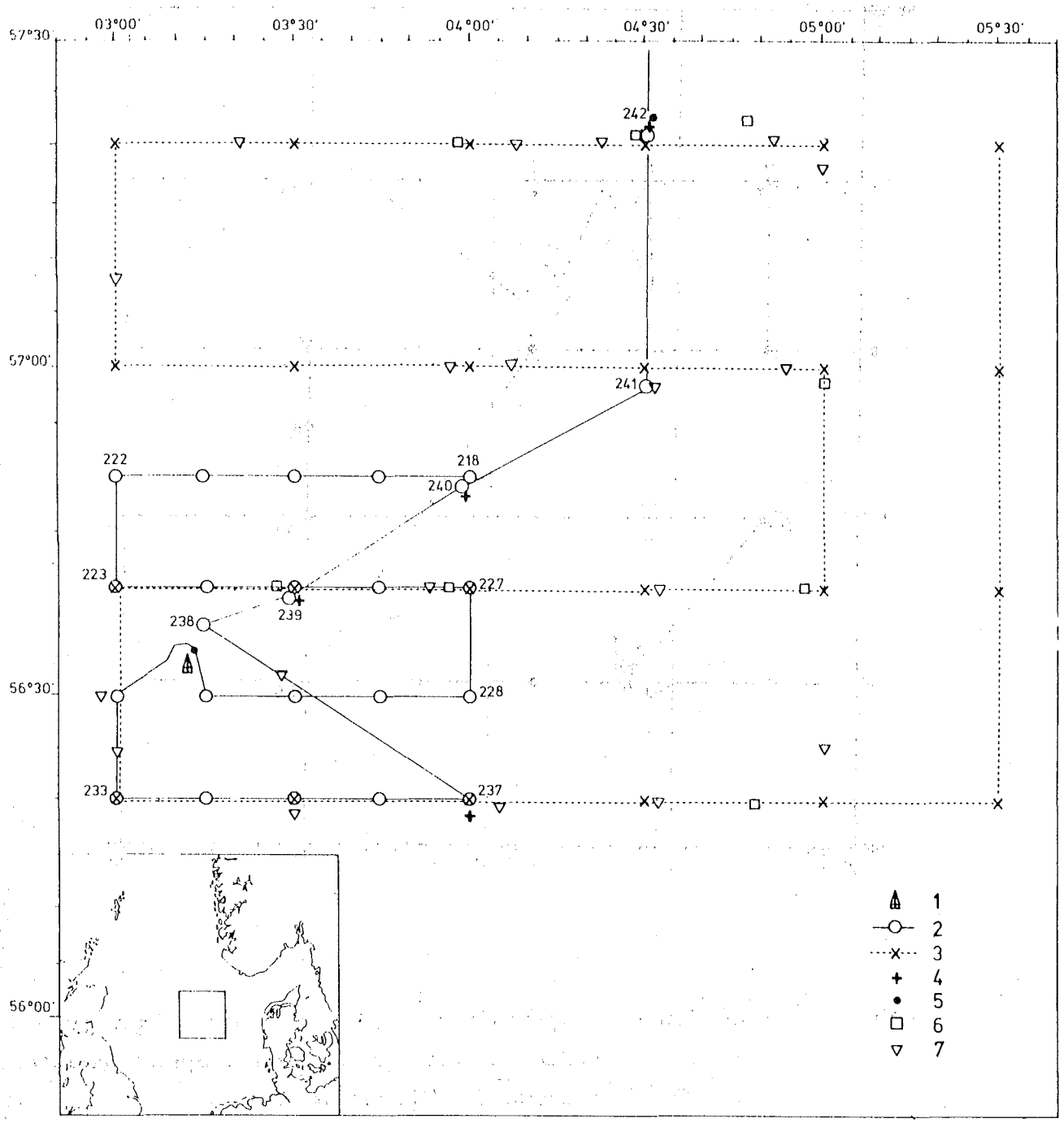


Fig. 1.3. Station grid systems for R/V "G.O.Sars" April 27 - May 1, 1977 R/V "Johan Hjort" April 27 - May 1 and May 1 - 4, 1977. 2: "G.O.Sars" stations, 3: "Johan Hjort" stations, 4: Current meter moorings, 5: Telemetric buoys, 6: Bottom trawl stations, 7: Pelagic trawl stations.

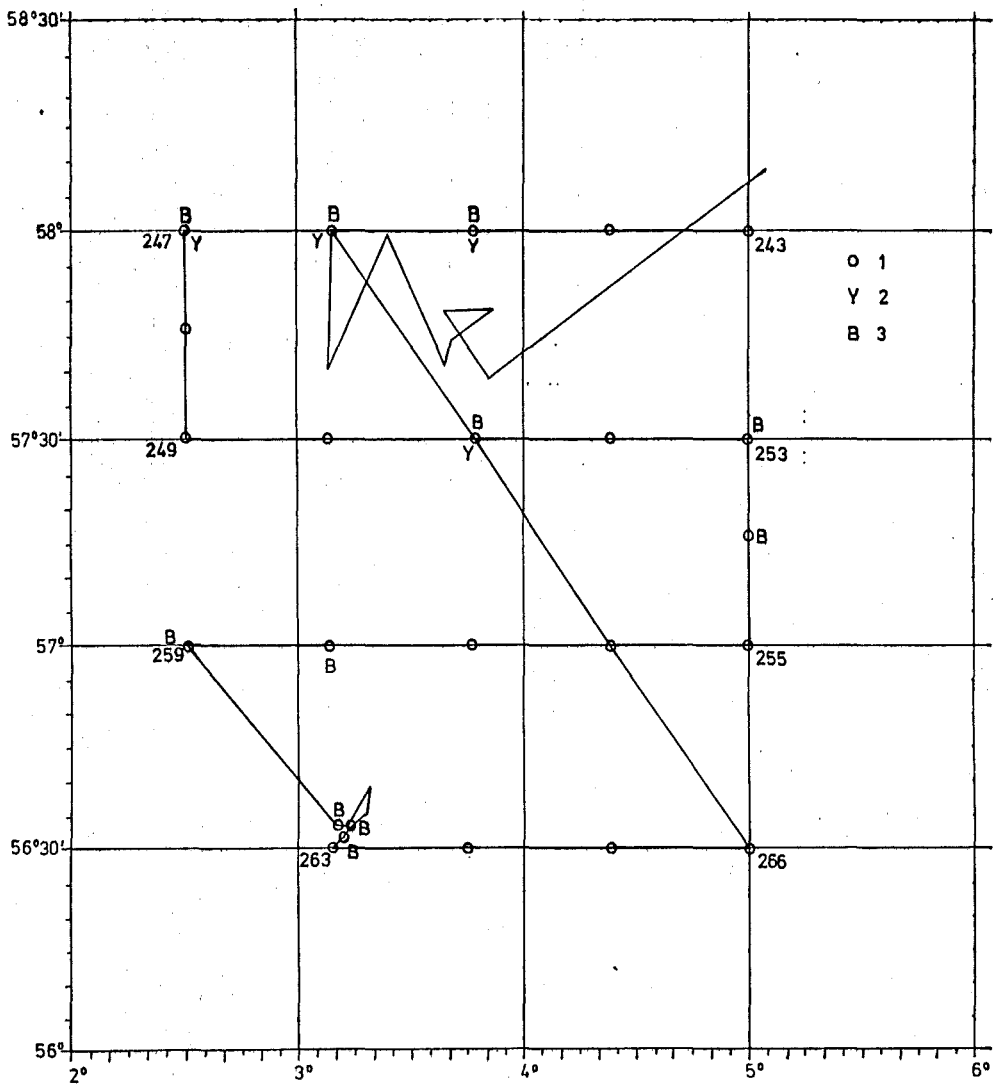


Fig. 1.4. Station grid systems for R/V "G. O. Sars" May 10 - 16, 1977. 1. CTD - sonde, phyto- and zooplanktonstation, 2. Grab stations, 3. Biotest stations.

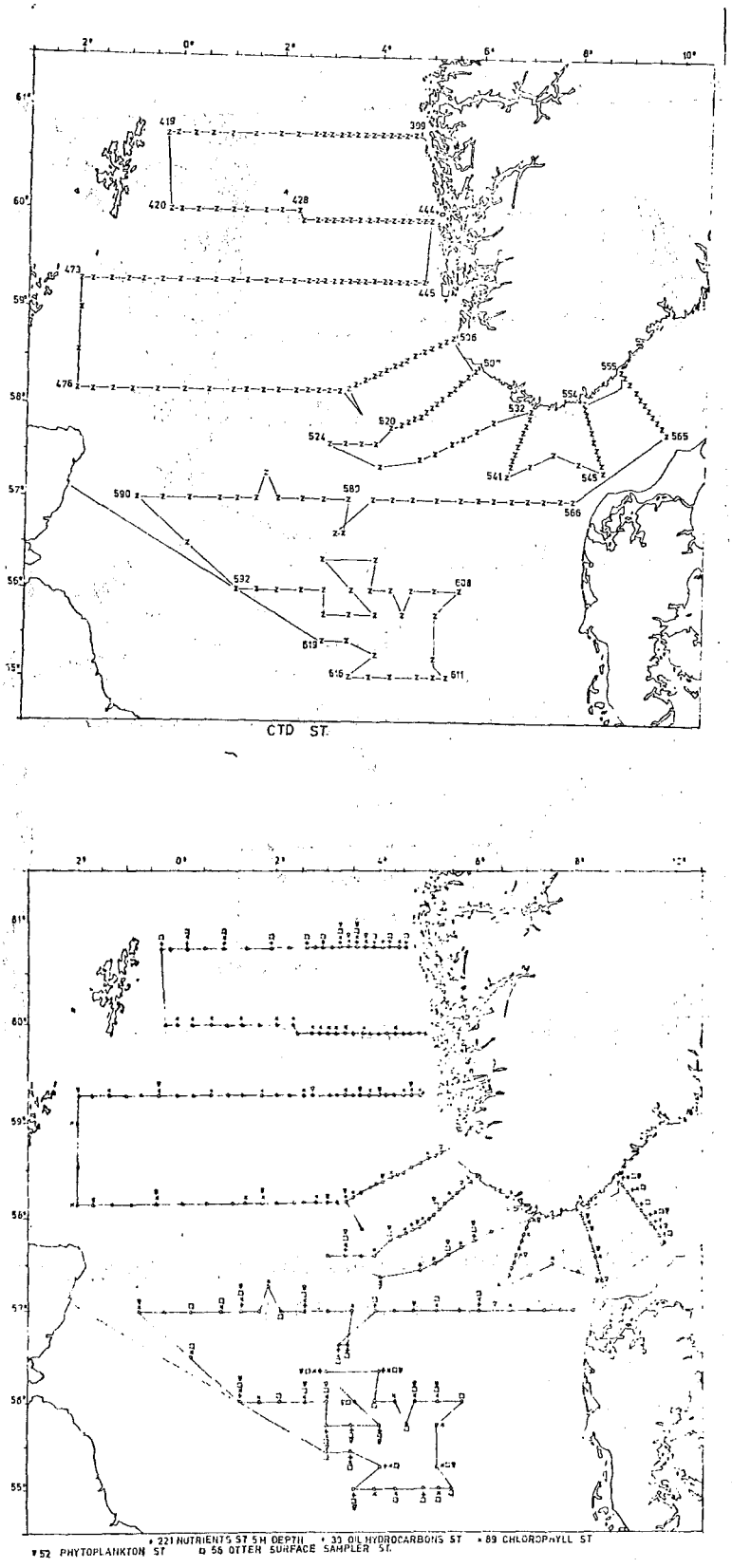


Fig. 1.5. Station grid systems for R/V "Johan Hjort" May 31 - June 17, 1977.

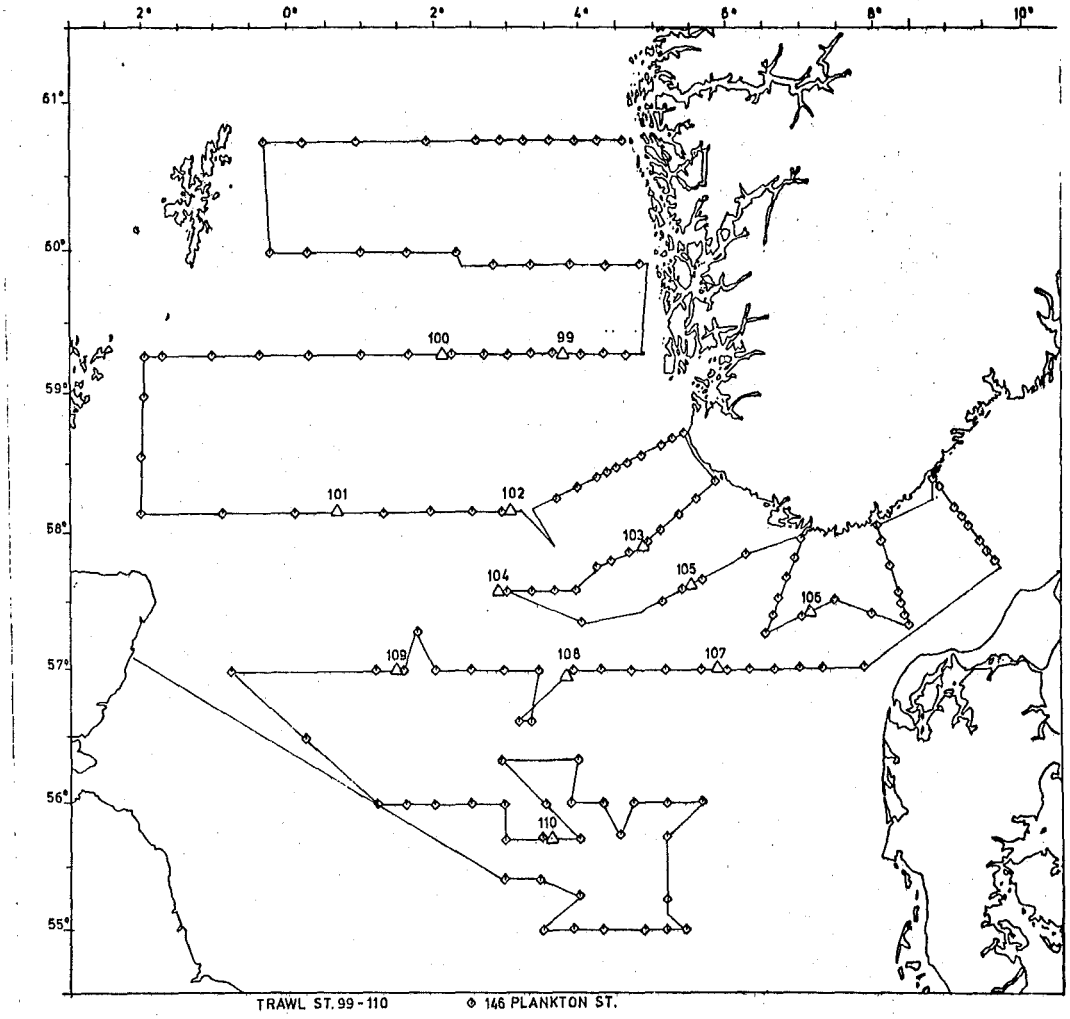
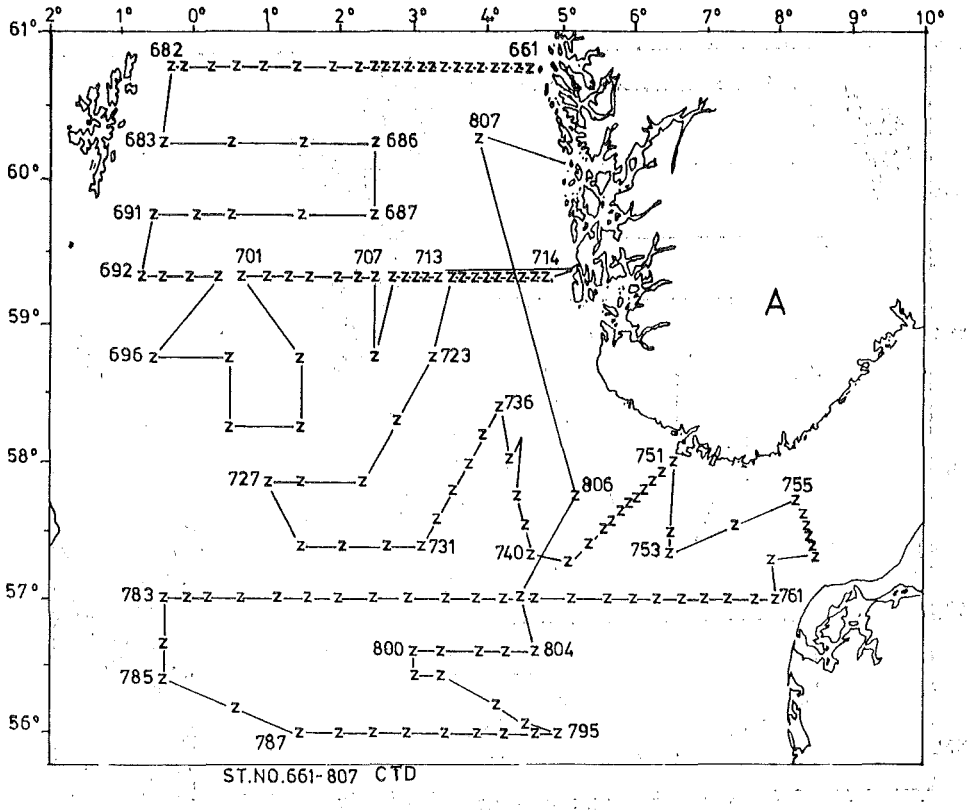


Fig. 1.6. Zooplankton stations for R/V "Johan Hjort". May 31 - June 17, 1977.



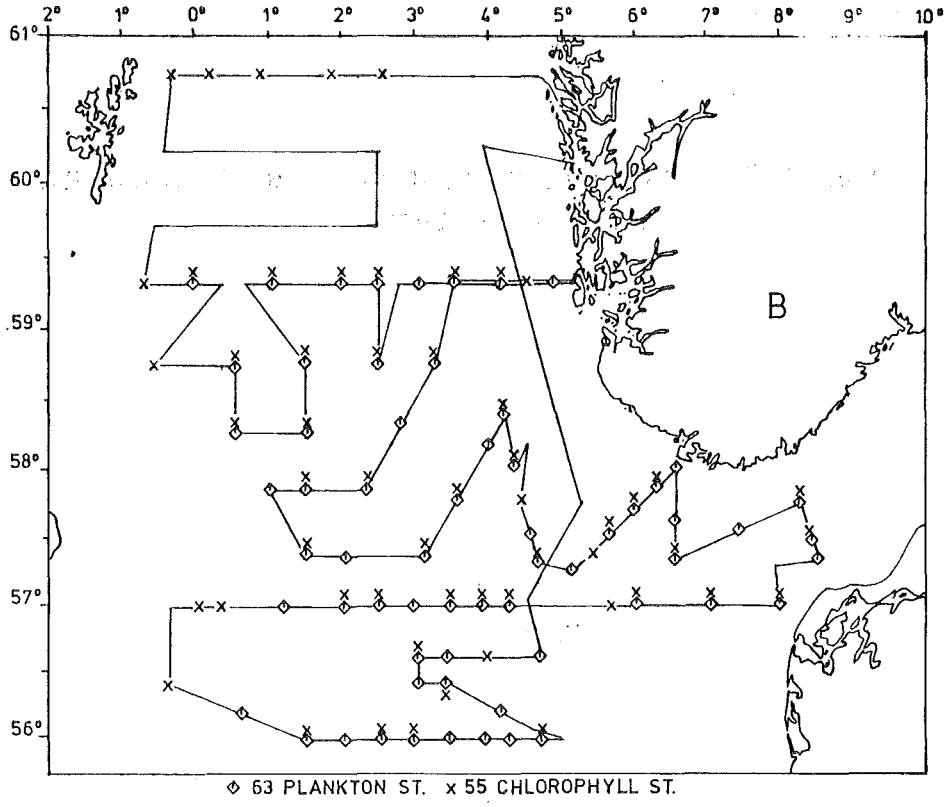


Fig. 1.7 a og b. Station grid systems for R/V "Johan Hjort" July 11 - 29, 1977.

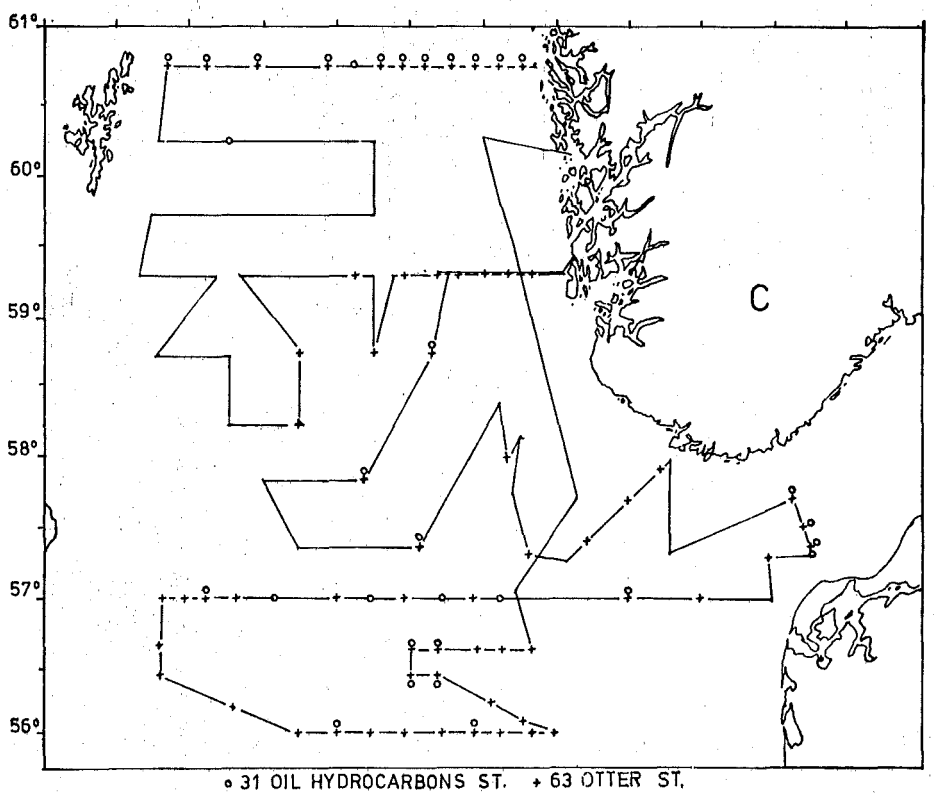


Fig. 1.7.c. Station grid system for R/V "Johan Hjort" July 11 - 29, 1977.

2. The physical ocean environment and drift of oil

by

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METHODS

The description of the hydrographic situation is based on observations from six cruises during the period from the beginning of March to the end of July 1977. The station grids from the cruises are shown in Figs. 1.1, 1.3, 1.4, 1.5 and 1.7 A. On the cruise with R/V "Johan Hjort" from April 27 to May 5 Nansen casts were made at standard depths to obtain water samples for salinity determination and to measure temperature. A CTD sonde was used to record salinity and temperature versus depths on the other cruises.

Recording current meters were moored and drift bouys were put out to measure the wind drift (Fig. 1.3). The signals transmitted from the drift buoys were picked up by the NIMBUS 6 satellite in order to establish the positions of the buoys. The drift was recorded at the NASA center and sent to the Norwegian Meteorological Institute, Oslo.

The occurrence of oil was regularly recorded by aircraft and ships up to May 20, and later, more occasionally.

The Norwegian Meteorological Institute and the Continental Shelf Institute jointly with The Norwegian Veritas both separately and in cooperation used computer programs to simulate and predict the oil drift, based on wind and current observations. The sightings of drifting oil (patches, slicks, tar lumps etc.) were used to recalibrate the prediction models.

Reports on these activities will be given by the institutions mentioned.

RESULTS AND DISCUSSION

Hydrography. Fig. 2.1 shows the temperature and salinity at the sea surface in March, which represents a typical winter situation. The water column was nearly homogeneous down to the bottom except at the Norwegian Rinne. The transition zone between Atlantic water and Norwegian Coastal water was narrow. The movement of Atlantic water towards Skagerrak was shown by a tongue of water of relatively high salinity and temperature following the western and southern edge of the Rinne. The temperature of the surface waters increased from below 3°C near the Norwegian coast to 6-7°C in the Atlantic water.

During and immediately after the blow out the hydrographic condition in the area around EKOFISK were characterized by four distinct water masses. A core of cold water was observed between the sea surface and the bottom in the central part of the investigated area. The core temperature was around 5°C and the salinity slightly below 34,8‰ (Figs. 2.2, 2.3 and 2.11). This core was probably locally formed by winter cooling. The observed vertical and horizontal temperature and salinity condition indicated the presence of an eddy. The character of the water masses towards the south-western corner of the grid approached that of North Atlantic water e.g. high salinity and high temperature (Figs. 2.2 and 2.3). In the northern area , a subsurface water body was found which, according to t-S analysis, must have had a origin different from the other two water masses. Above this water body, especially in the eastern area, a 10 m thick typical coastal water layer was found with salinity well below 34,0‰ and temperature above 6°C (Fig. 2.2).
The water masses were nearly homogeneous vertically, except for in the northern part of the investigated area. The sea surface temperature was approximately 1°C below the mean value for this time of year.

The main features of the hydrographic situation did not change during the first week of May. The temperature of the cold core, however, increased by approximately 0,4°C (Figs. 2.4, 2.5 and 2.11).

By the middle of May the coastal water masses had moved further north (Fig. 2.6). The temperature of the upper layers, and to a lesser degree also of the bottom layers, had increased signifi-

cantly (Figs. 2.6, 2.7 and 2.11).

The hydrographic situation at the sea surface in the first part of June is shown in Fig. 2.8. The mean feature is that the Skagerrak waters flowed along the southern and western edge of the Norwegian Rinne during this period. These waters had a relatively low salinity and high temperature condition, and their movements had been very complex, resulting in a convection layer 10-15m thick off the south western coast of Norway. A zone of upwelled water of relatively low temperature was observed between the Skagerrak water and the Norwegian coast. This condition was caused by a stable northerly wind before and during the time of observations. Except for the south-eastern area the temperatures were well below the mean value for this part of the month.

Corresponding main features occurred at the sea surface during the last part of July (Fig. 2.9). The movement of the Skagerrak waters, however, had a significant southerly component and a bulk of Continental Coastal water had moved north-west. Jointly these two water masses covered the south-eastern part of the investigated area.

Figs. 2.10, 2.11, 2.12 and 2.13 show the vertical distribution of temperature and salinity along the 57°N parallel and demonstrate the development of a thermocline. The lateral movement of the low salinity coastal waters is also indicated. Both these processes contributed to an increasing vertical layering of the water masses in the EKOFISK area which is demonstrated in Fig. 2.14. Stability $10^3 \frac{d}{dz}\frac{\sigma_t}{}$ versus time of the transition layer between the upper and bottom homogeneous water masses is plotted in the figure. The homogeneity is defined as the vertical variation of density being within 0,1 σ_t. The abscissa to the left gives the average stability between 3° and 5°E, approximately, along the 57°N parallel.

Obviously the layering was insignificant until the middle of May, and then increased rapidly during June and July. The figure also shows the thickness of the upper homogeneous layer (abscissa to the right). Vertical mixing had occurred down to the bottom in March, but only down to approximately 17 m after the full development of the transition layer in June-July.

The Atlantic water in the section was observed only as a subsurface bulk in June and July (Figs. 2.12 and 2.13). The amount of this water mass also seemed to be small compared to that of the years 1968-1973 at corresponding season and section (unpublished data).

Recordings from moored current meters from April 28 to June 14 stated that the semi-diurnal tide current was then dominant (ANON b 1977). A non-periodic component, obviously mainly wind-driven, was superimposed on this oscillation. Average speed of the current calculated from all observations was 20 cm/sec. and 10 cm/sec. in the upper layers and at the bottom respectively. Up to May 5 at the southernmost mooring, the current at 10 m depth had a speed of 5,5 m/sec. and was directed towards the north. Between May 5 and 13 the current had a velocity of 3 cm/sec. and had an easterly direction. From this date until June 6 the residual current again turned west and obtained an average speed of 10 cm/sec. during the last week of the period. On June 6 the current again changed direction towards the east, the speed being only approximately 2 cm/sec.

The recordings from the moored meters, together with current profiles from May 13 and 14, demonstrate the existence of a significant vertical current shear.

Drift of oil. Calculation of oil drift was mainly carried out at the Meteorological Institute in Oslo, using computer-based models. This activity has been preliminarily reported (ANON a 1977) and the computed data kindly put at the author's disposal.

The wind at the positions at which oil was observed was calculated every third hour, based on observations from ships and from weather maps. In cases where no oil observations were available, calculated positions were used. Twenty-four hour averages of wind force and direction were used in order to eliminate tidal effects, and the probable Ekman drift was then computed. A wind stress factor of 3 and a deflection angle of 15^{o} to the right of the wind were introduced into the model. Residual current was not included. Whenever well defined oil patches were reported, the model was evaluated and the trajectories corrected. The agreement between the calculated drift,

based on the original stress factor and deflecting angle, and the observed drift of oil were as acceptable as could be expected from the uncertainty of the calculated wind, of observed floating oil, and disregarding Stokes velocity and pure wind drift.

Fig. 2.15 demonstrates the best approach to the theoretical drift of an "approximate center" of the oil slicks. Fig. 2.16 shows the N-S and E-W components of the wind. Evidently the N-S component of both wind and drift was dominant. Up to May 12 the wind was southerly, and at the end of this period the oil reached its northernmost position. From then on the wind was mainly from the north and the oil drifted south, except for a short interval of time, June 6 to 15, when the wind and the oil drift oscillated in a NE-SW direction. The calculated drift seemed to correlate satisfactorily with the findings of oil on June 11-14 (Fig. 5.3).

It seems evident that the oil drift, at least up to the end of June, was caused mainly by the wind forces. This supports the hypotheses that the residual current at the sea surface is dominantly wind driven in the central part of the North Sea (DOOLY 1974).

These specific wind conditions also contributed to the oil not approaching the coastal current systems and the shores. A comprehensive experiment with drift cards carried out in 1972 indicates that the opposite could easily have occurred a few weeks after the blow out (DONS 1977).

The drift buoys mentioned previously moved with a somewhat higher speed than the oil (ANON a 1977). Due to the simple method for recording the position of the buoy, however, this type of drifter may still be useful for first hand information on oil drift.

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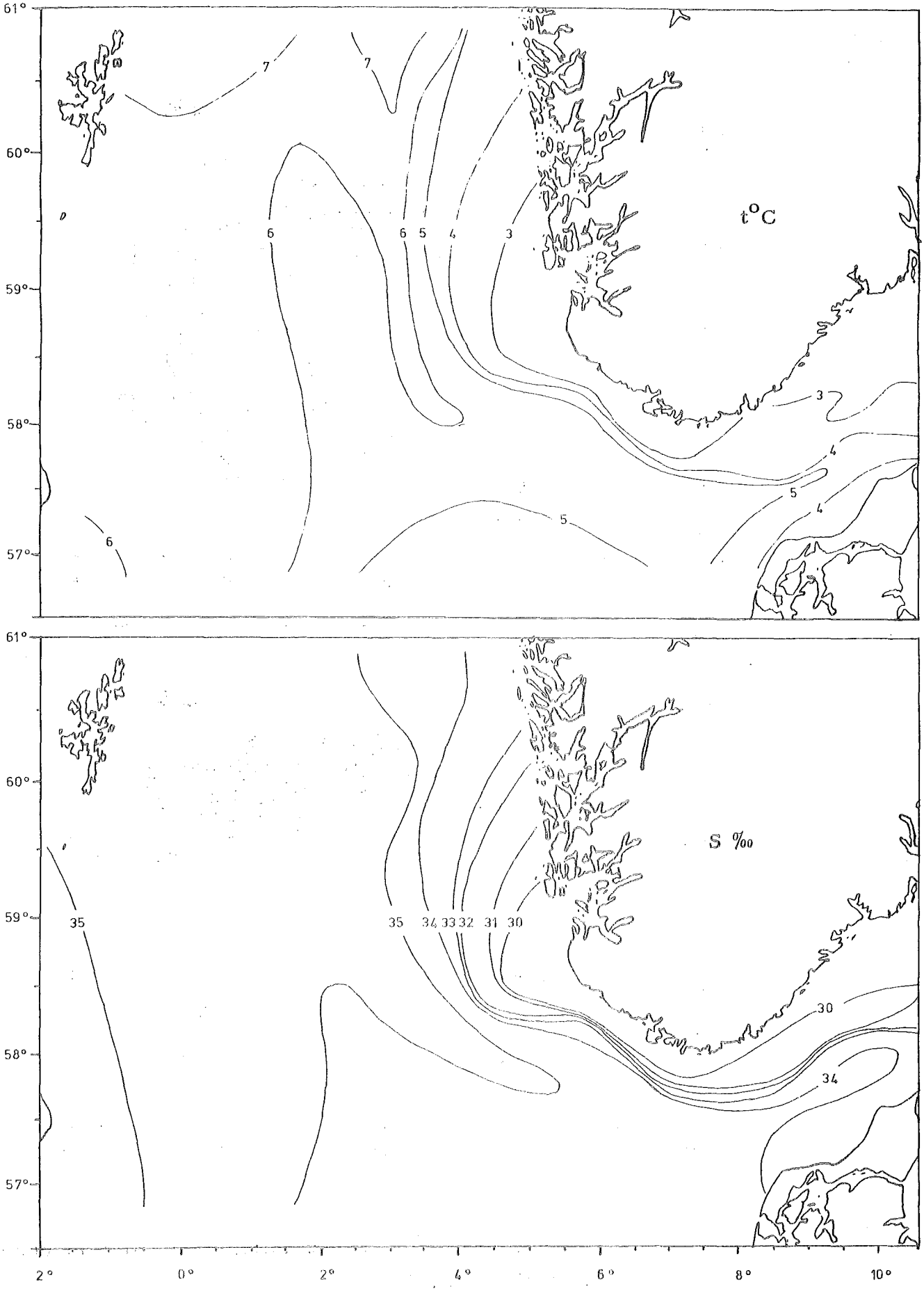


Fig. 2.1 Temperature, $t^{o}C$, and salinity, S ‰, at the sea surface, March 8 - 31.

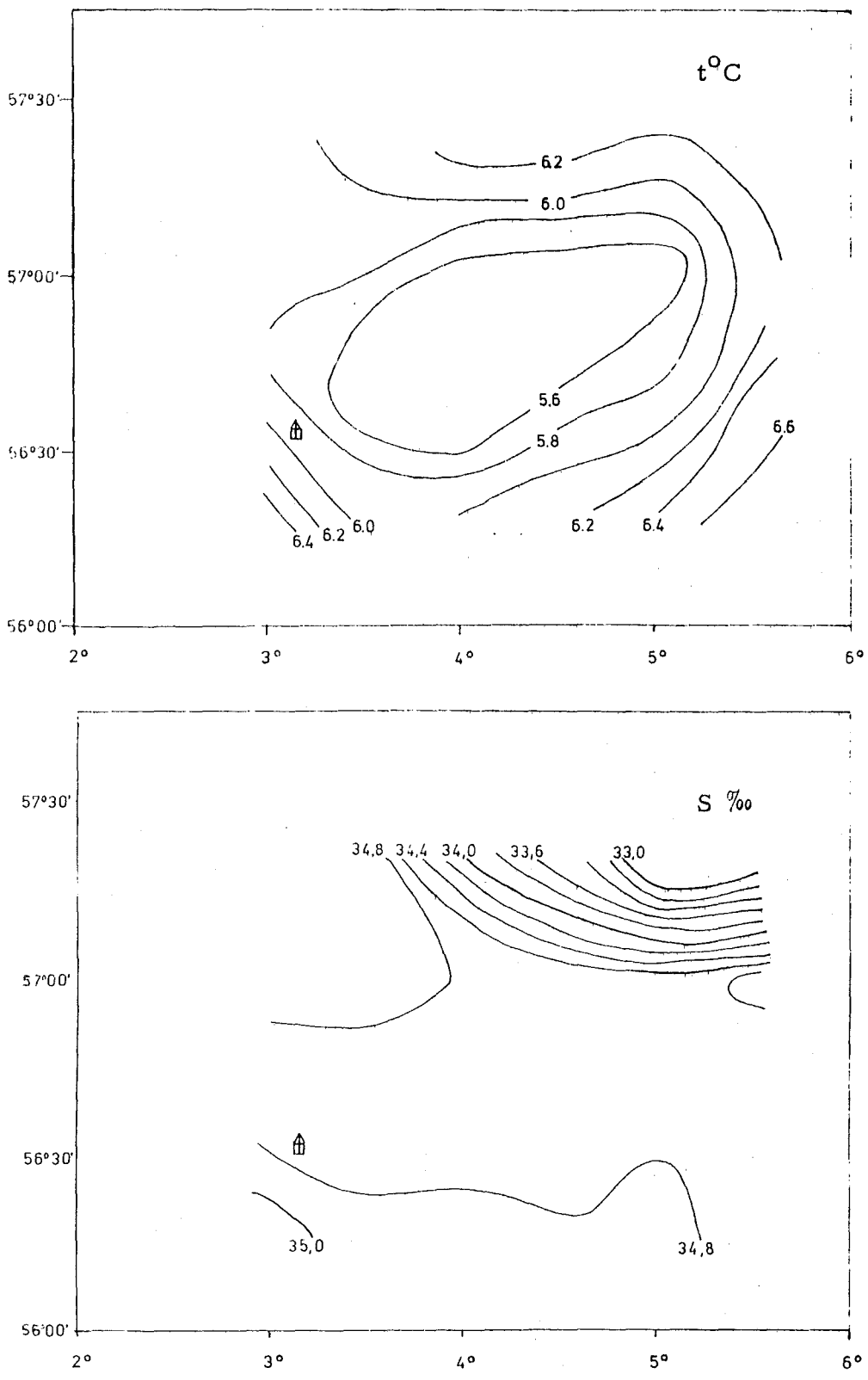


Fig. 2.2 Temperature, t°C, and salinity, S ‰, at 5 m depth, April 27 - May 1.

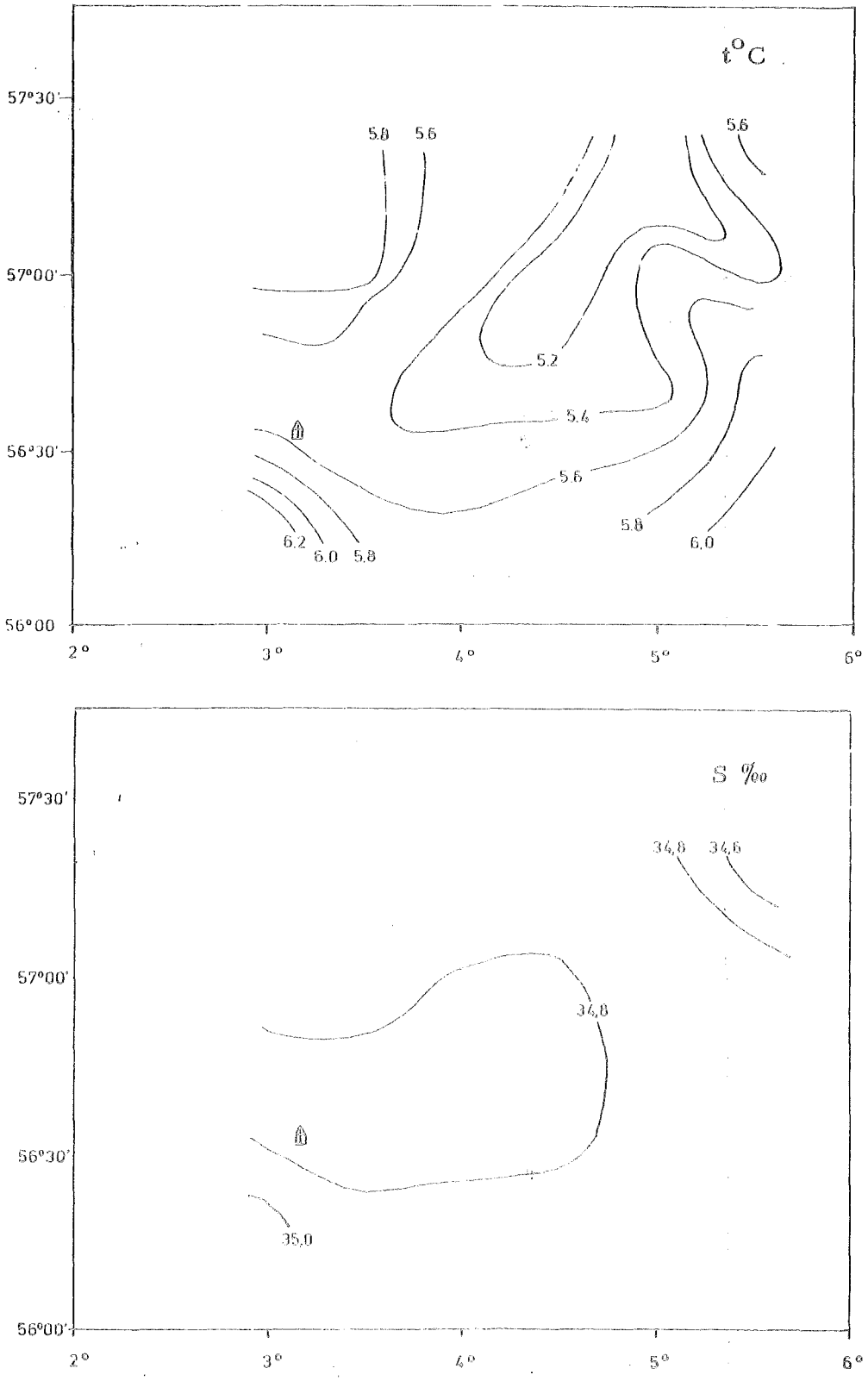


Fig. 2.3 Temperature, $t^{o}C$, and salinity, S ‰, at 30 m depth, April 27 - May 1.

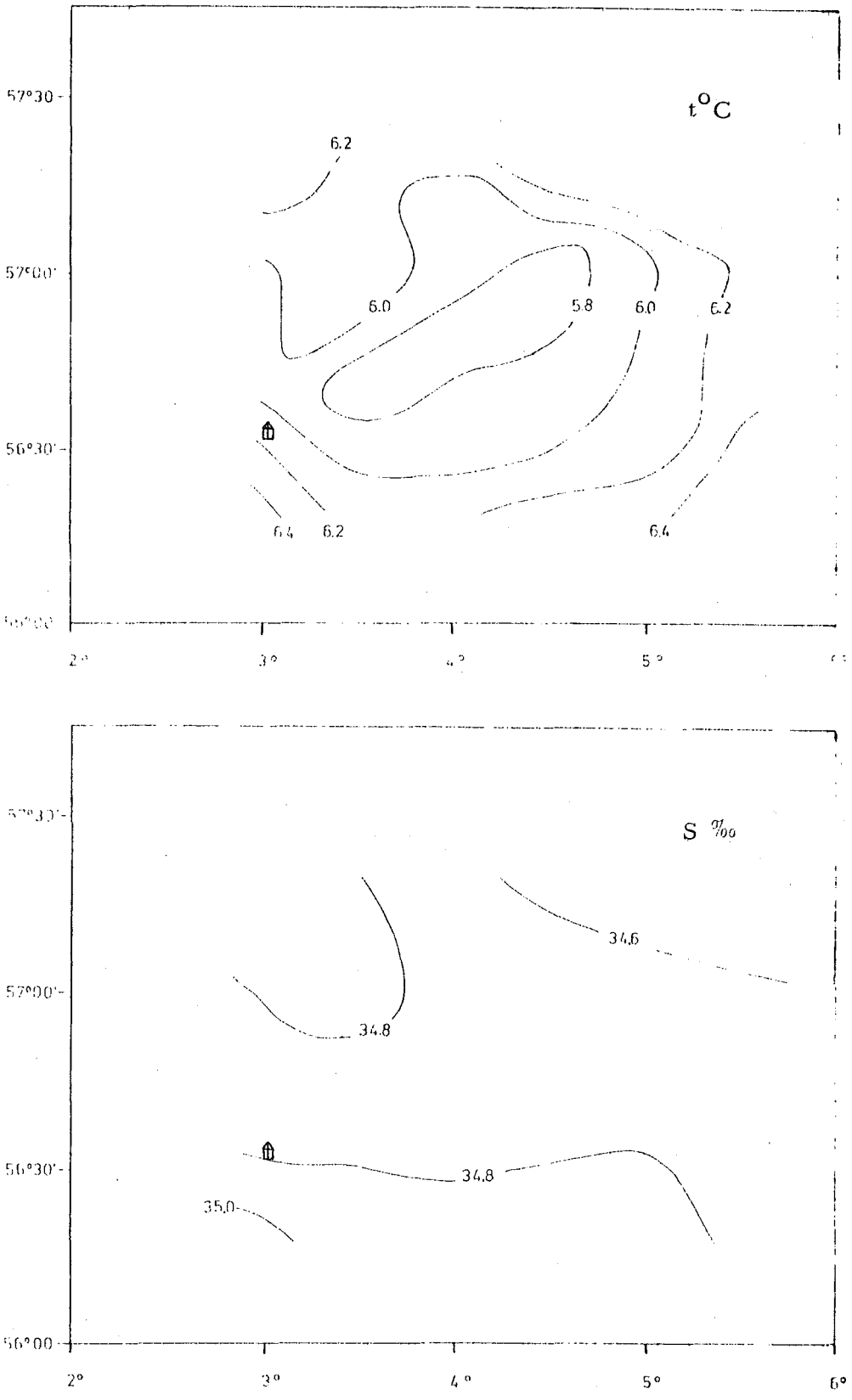


Fig. 2.4 Temperature, $t^{o}C$, and salinity, S ‰, at 5 m depth, May 1 - 4.

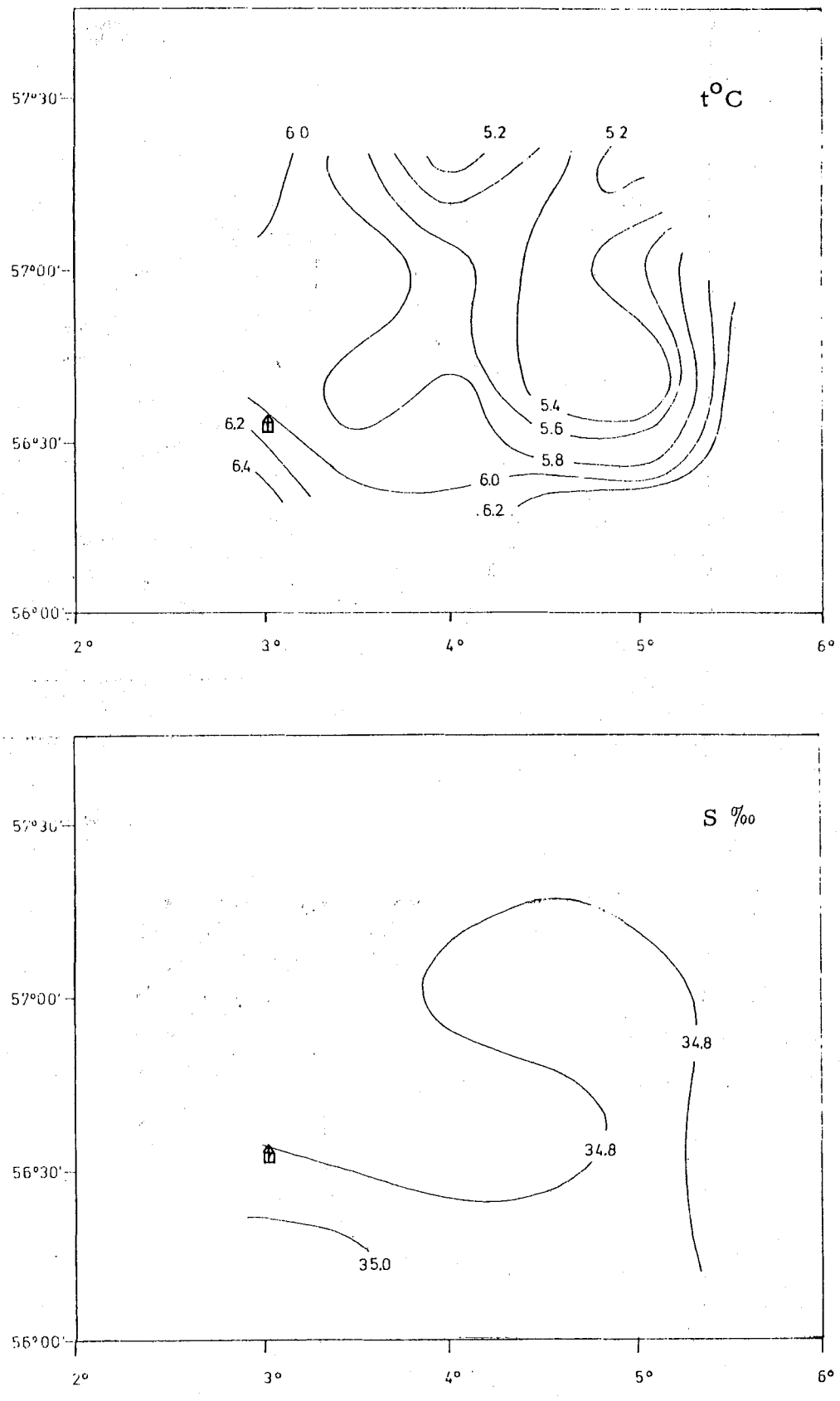
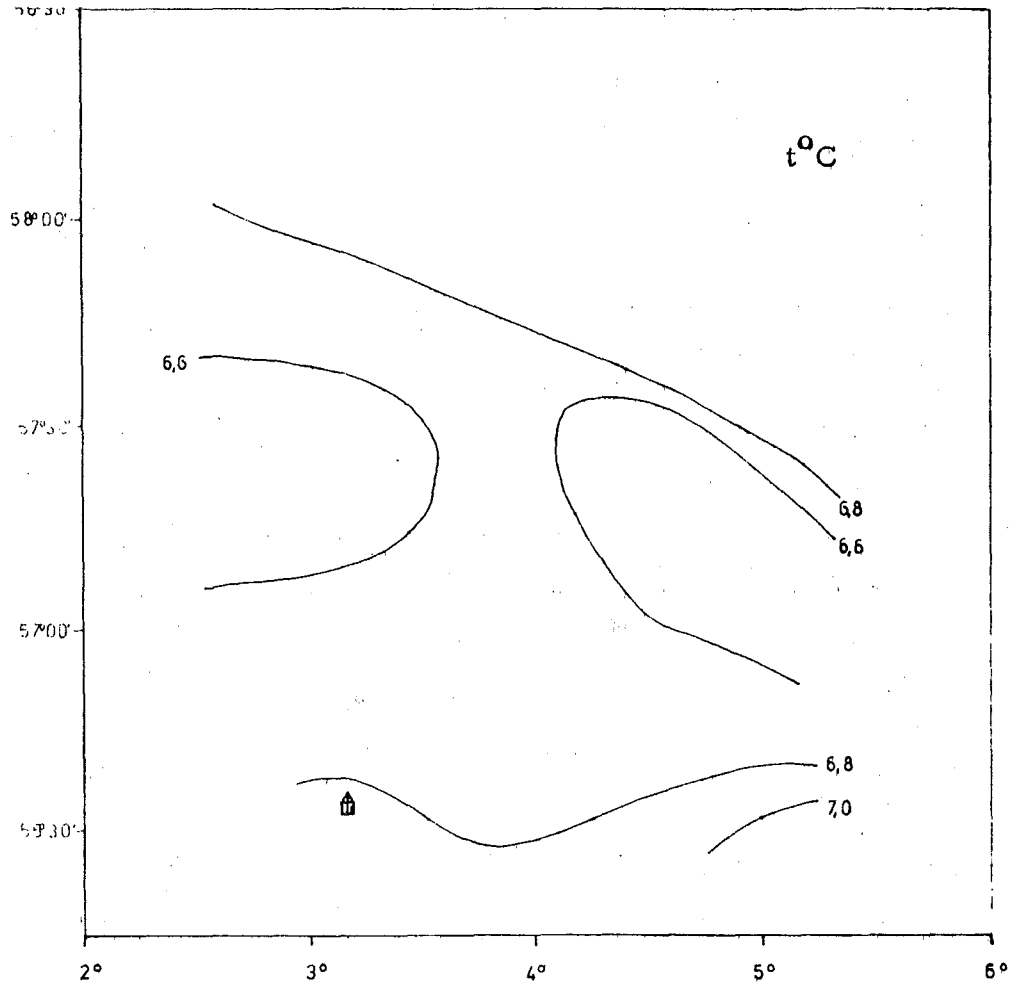


Fig. 2.5 Temperature, $t^{o}C$, and salinity, S ‰, at 30 m depth, May 1 - 4.



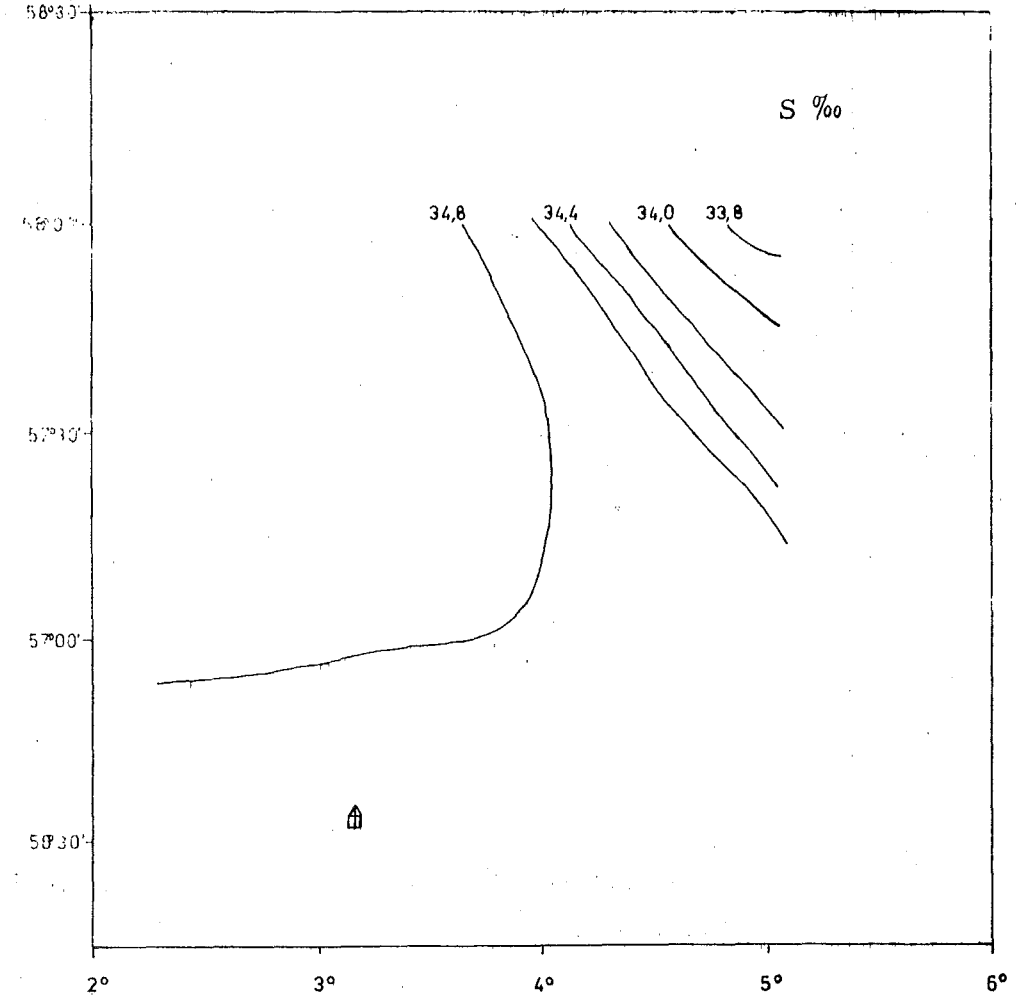


Fig. 2.6 Temperature, t°C, and salinity, S ‰, at 5 m depth, May 11 - 14.

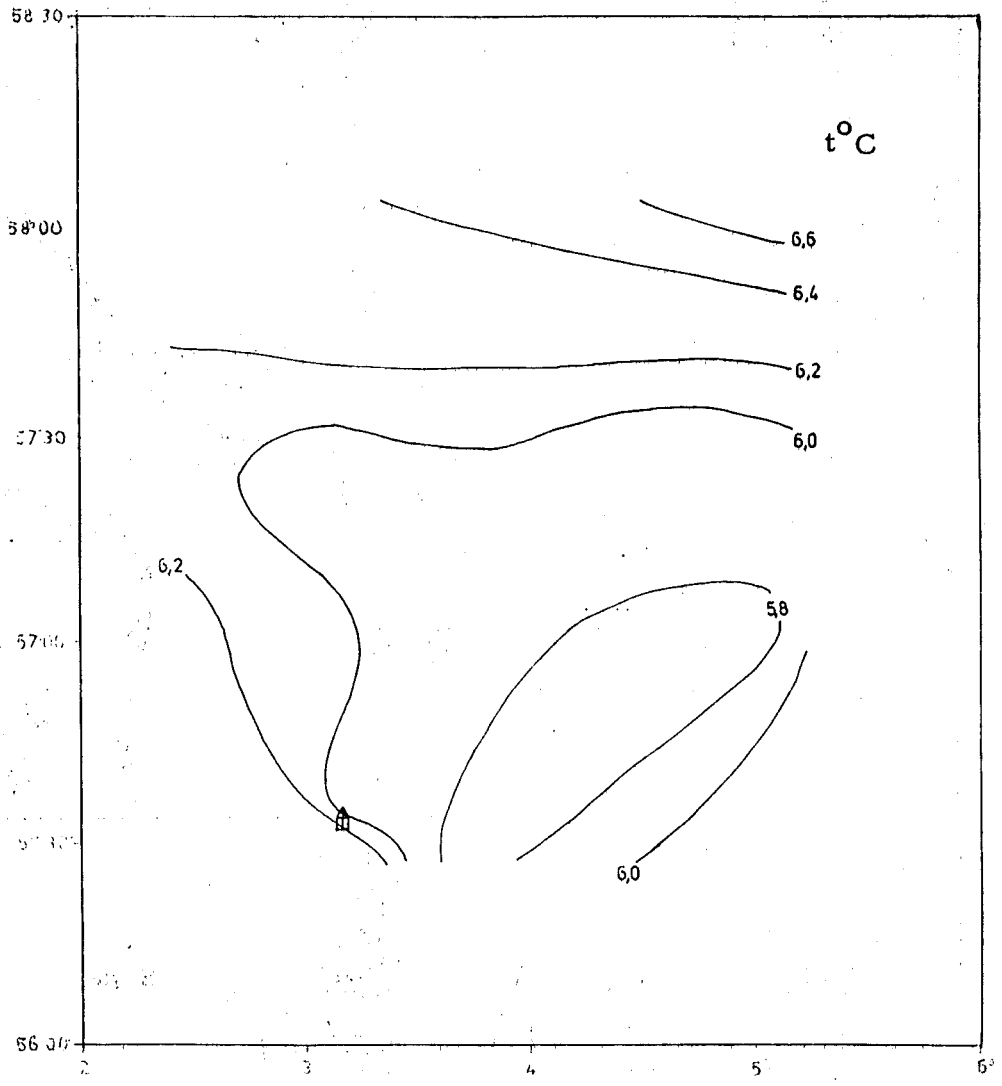
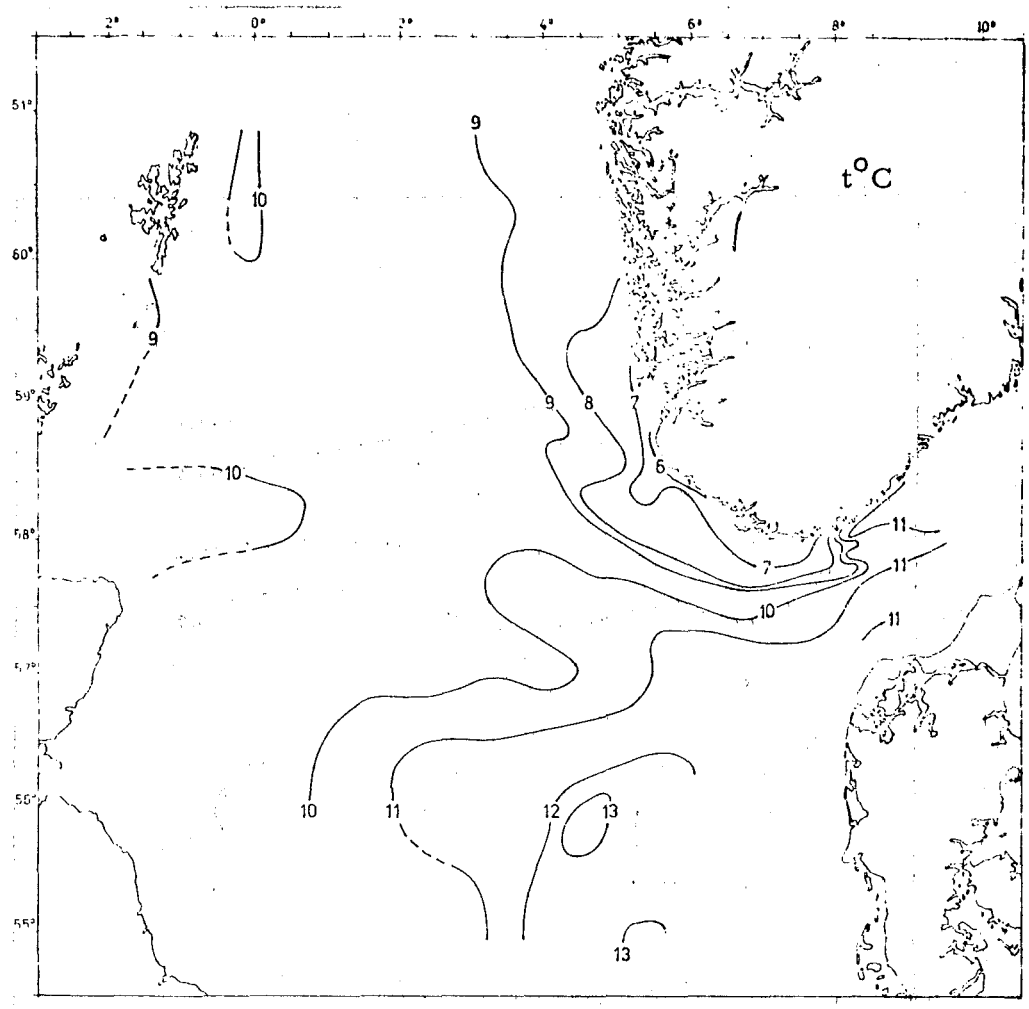


Fig. 2.7 Temperature, t°C, at 30 m depth, May 11 - 14.



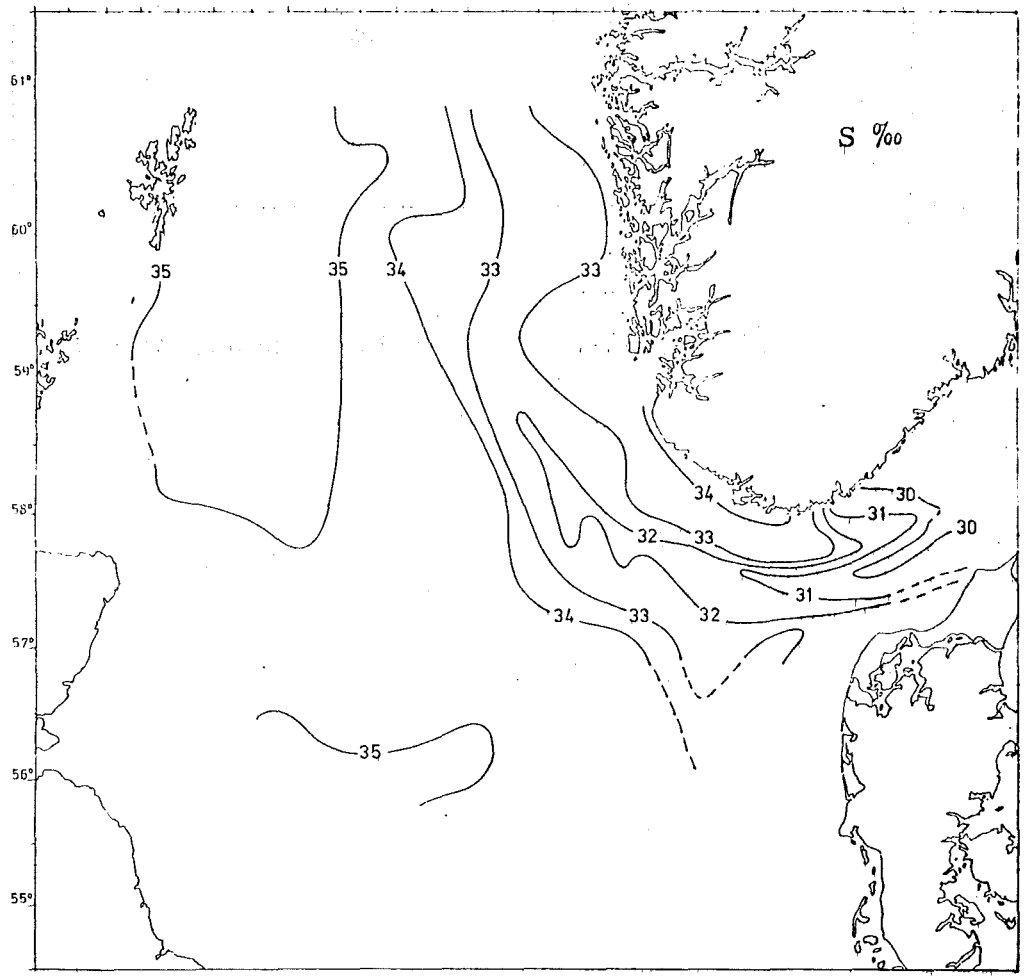


Fig. 2.8 Temperature, t°C, and salinity, S ‰, at the sea surface, May 31 - June 17.

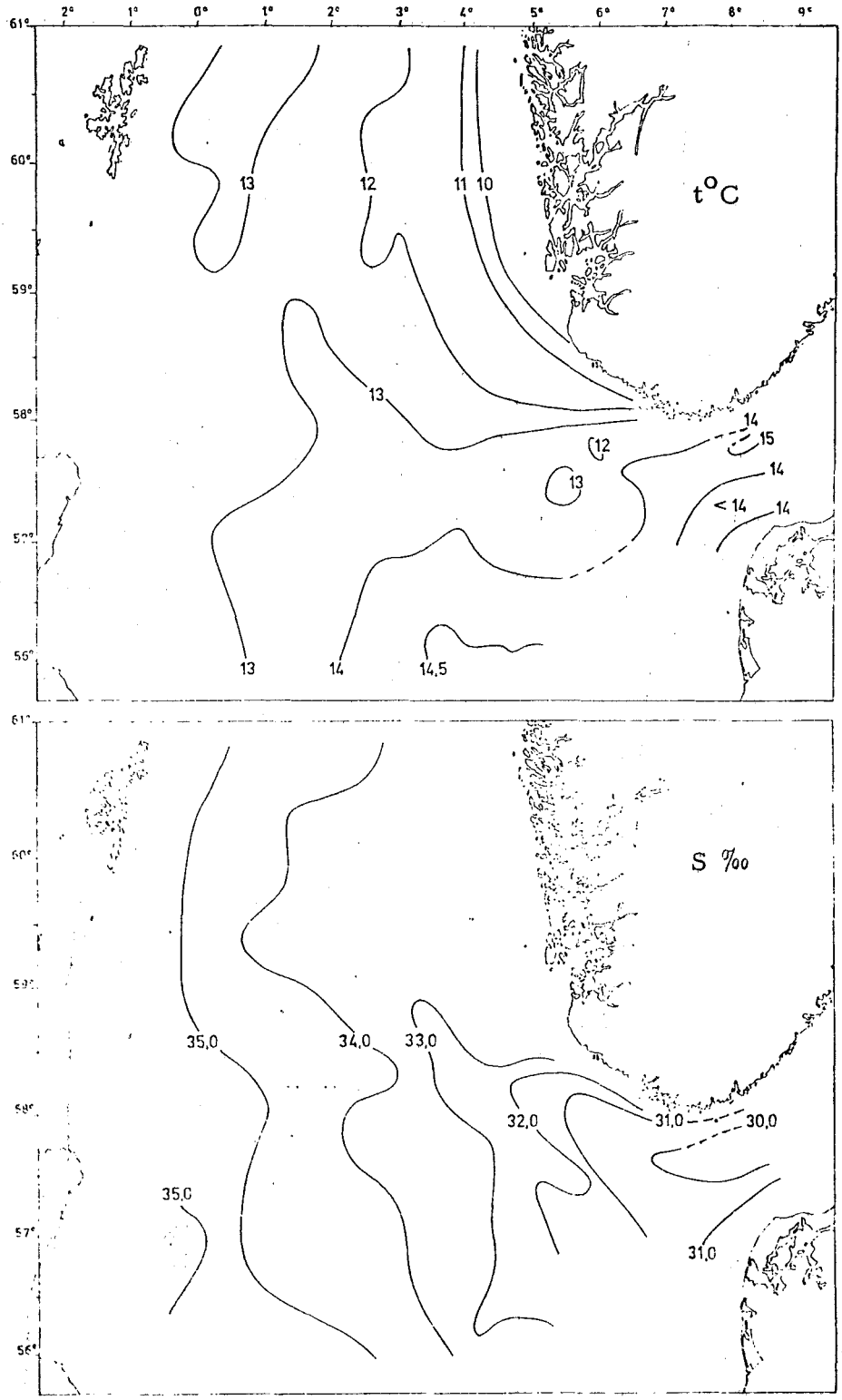


Fig. 2.9 Temperature, t°C, and salinity, S ‰, at the sea surface, July 11 - 29.

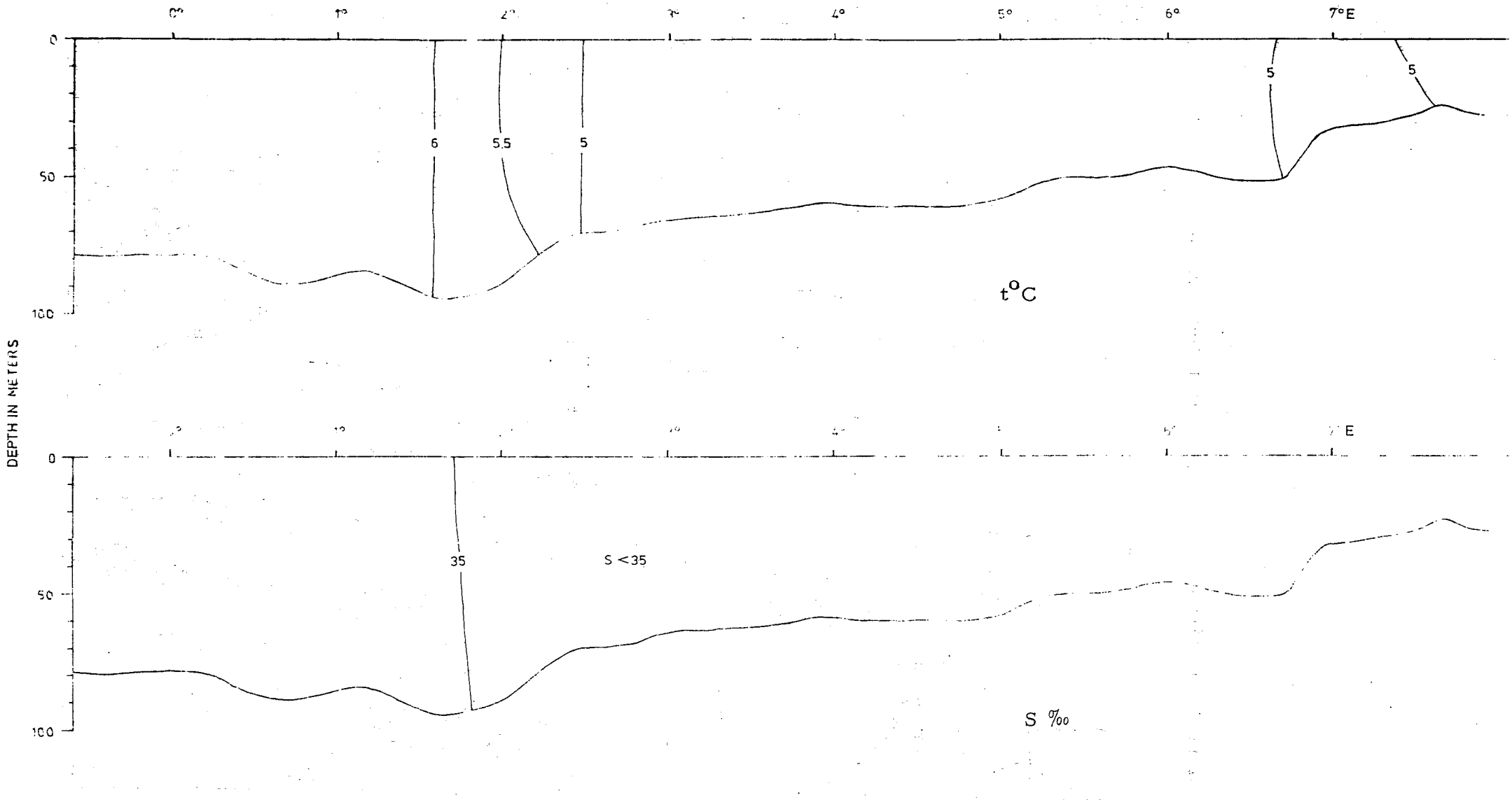


Fig. 2.10 Temperature, $t^{o}C$, and salinity, S ‰, along the 57° N parallel, March 18 - 19.

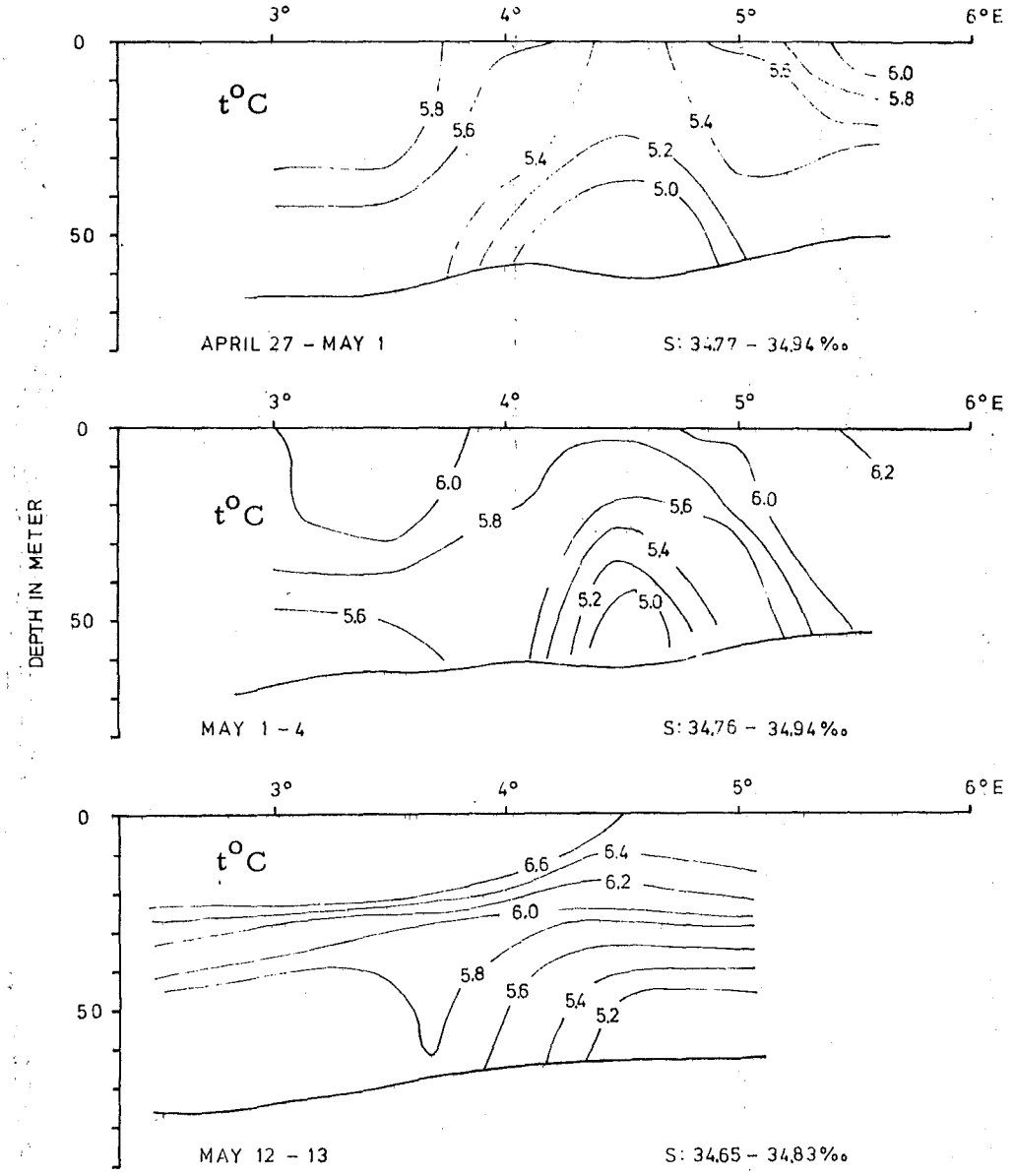


Fig. 2.11 Temperature, $t^{o}C$, along the 57^{o} N parallel, April 27 - May 13. Salinity variation indicated by numbers.

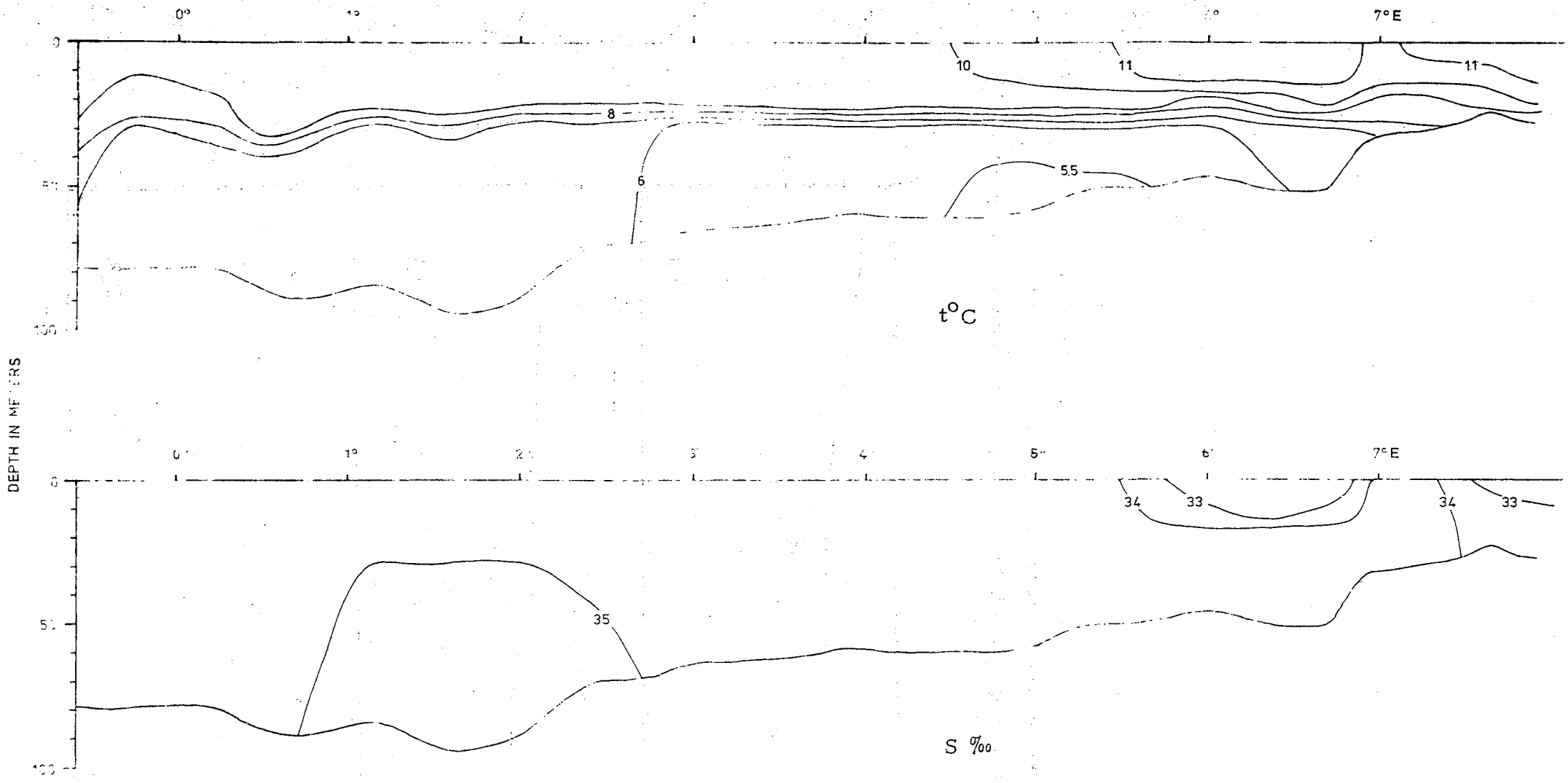


Fig. 2.12 Temperature, t°C, and salinity, S ‰, along the 57° N parallel, June 10 - 12.

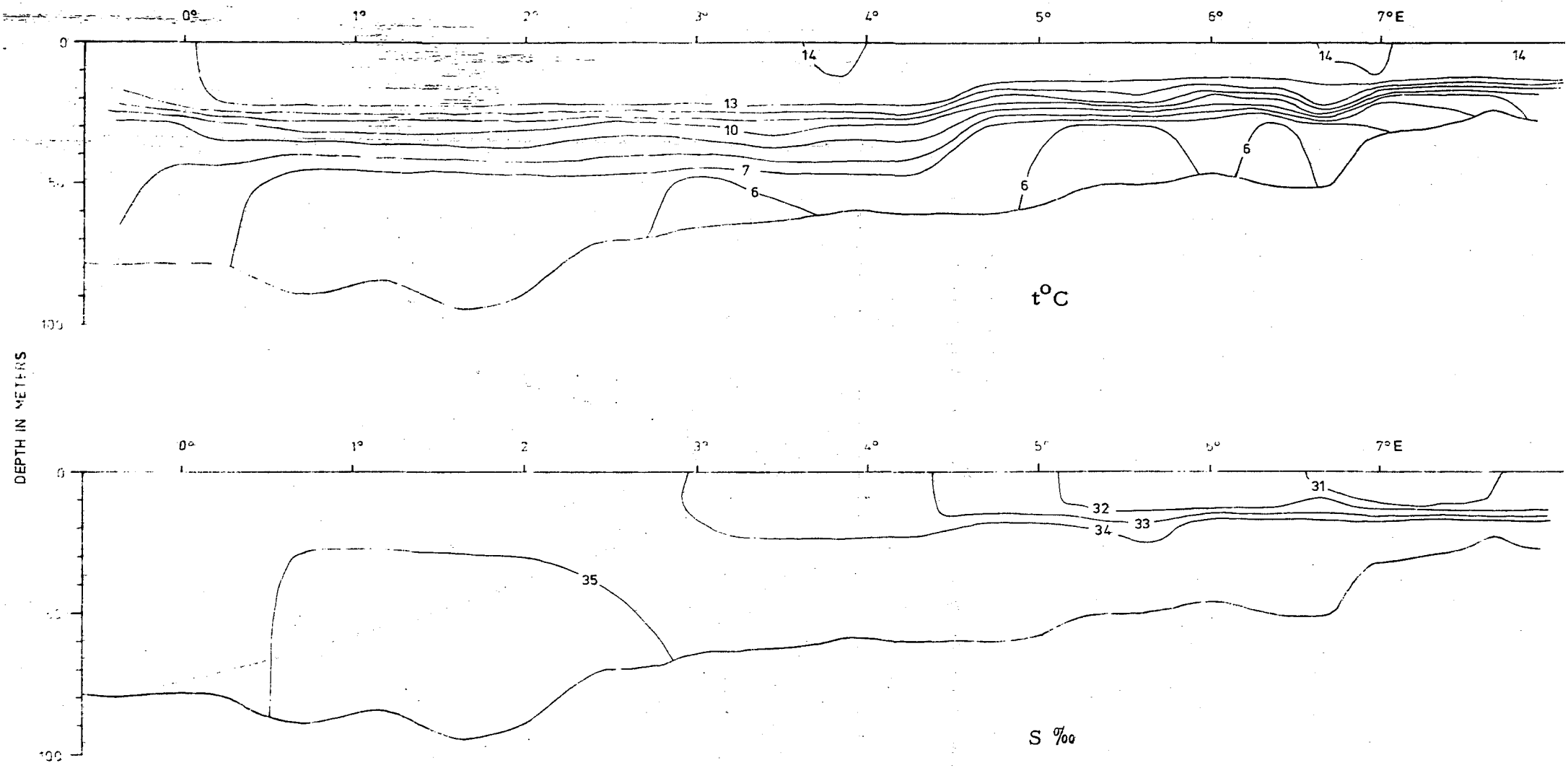


Fig. 2.13 Temperature, t°C, and salinity, S ‰, along the 57° N parallel, June 23 - 25.

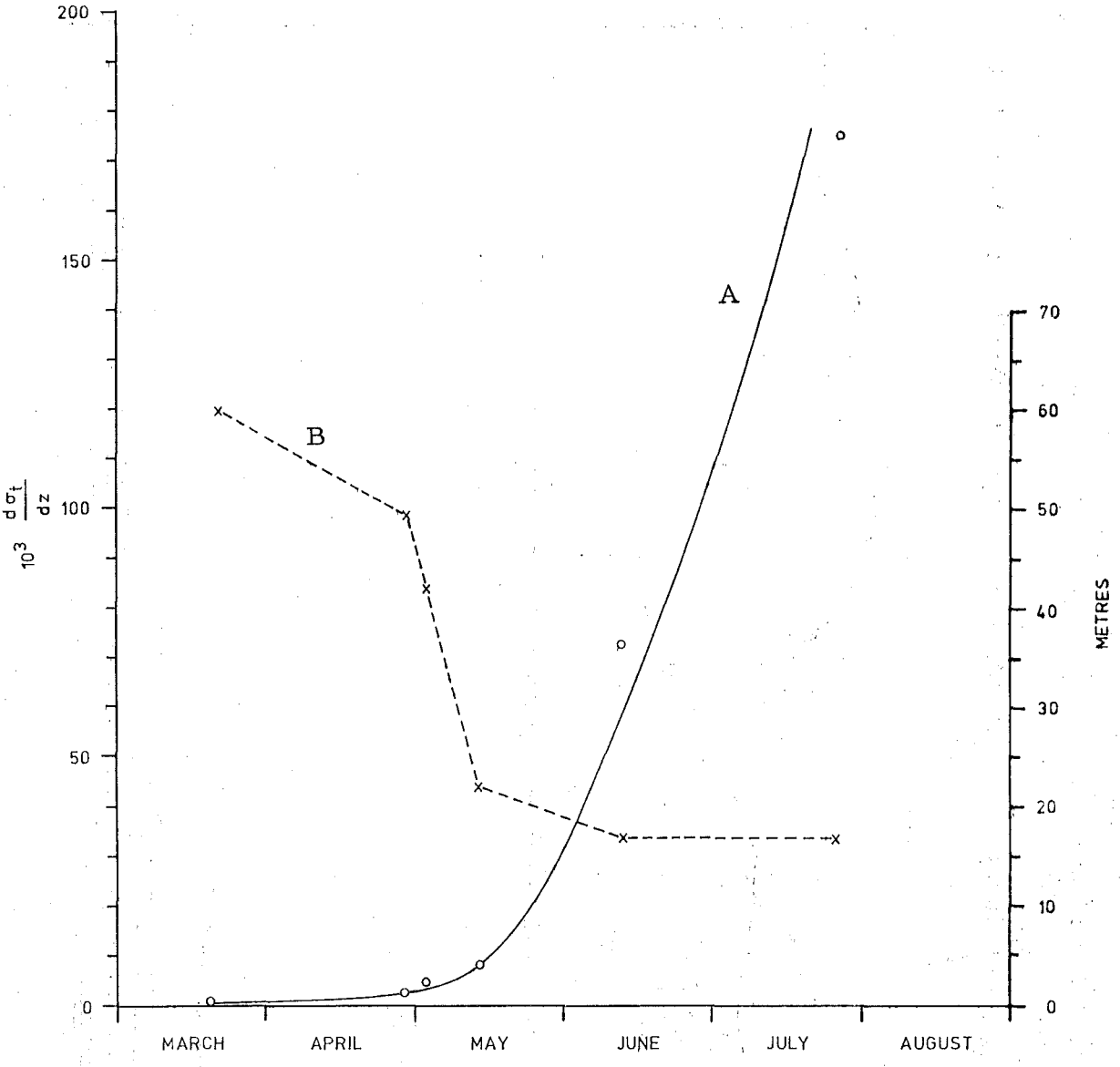


Fig. 2.14 A: stability, $10^3 \frac{d\sigma_t}{dz}$, and B: thickness of the upper mixed layer.

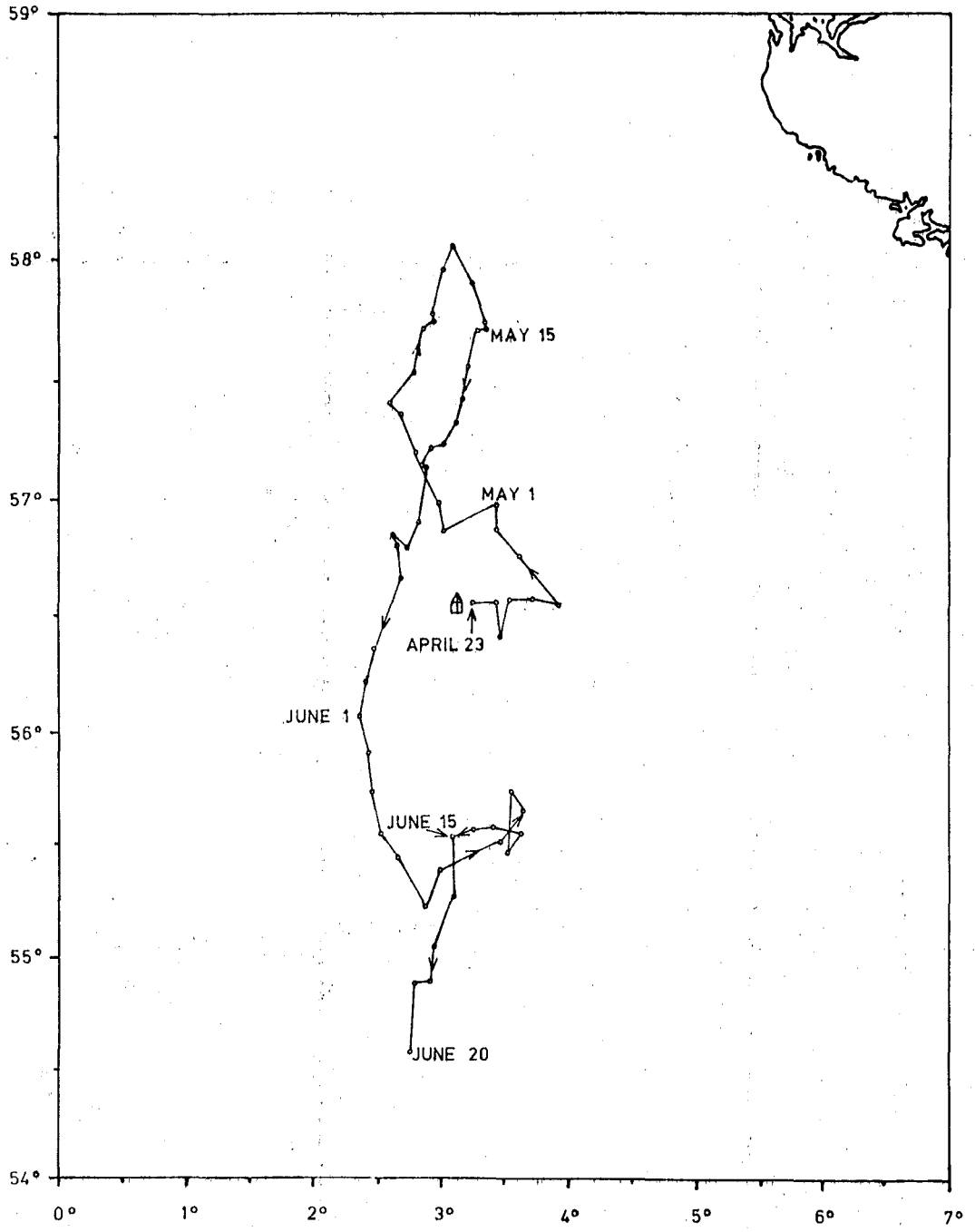


Fig. 2.15 Drift of oil, April 23 - June 20.

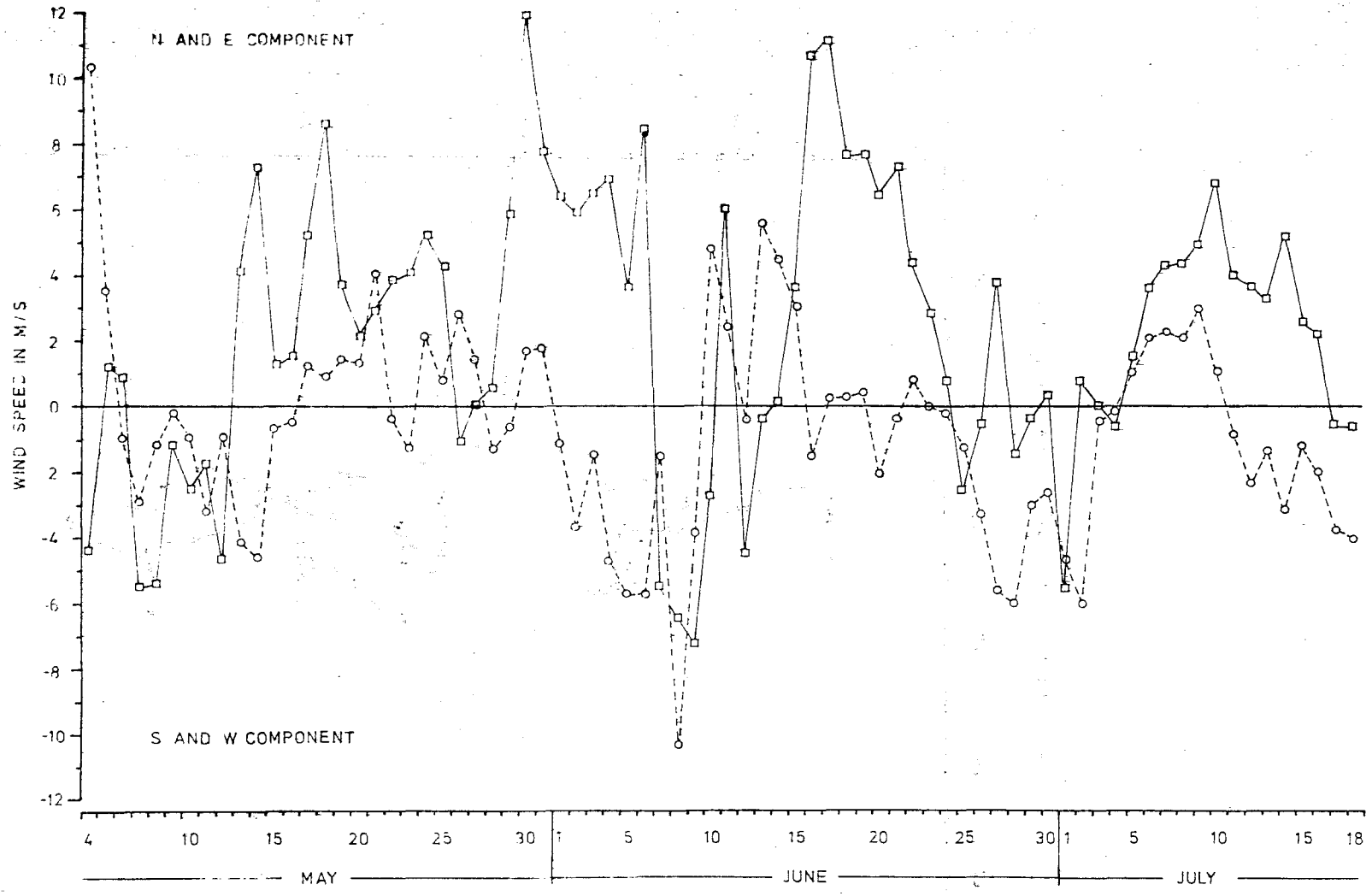


Fig. 2.16 —— north and south components . --- east and west components of wind, May 4 - July 18.

3. DETERMINATION OF PETROLEUM HYDROCARBONS IN THE WATER

by

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The blowout initiated a massive chemical investigation of the dynamics of the spilled oil in the environment. Of prime importance was the determination of the amount and type of petroleum hydrocarbons which entered the water column, and the distribution of the hydrocarbons both horizontally and vertically. This investigation was based on chemical analysis of water sampled at the majority of the stations on six different cruises.

EXPERIMENTAL

Water Sampling. Water was sampled with 2.8 l bottles mounted on a frame with lead weights at the bottom and suspended from a buoy. The bottle was stoppered when lowered and the stopper was removed by pulling a string. Great care was taken to avoid concentration from visible oil on the surface. As the main emphasis was placed on the horizontal distribution of petroleum hydrocarbons, samples from 1 m depth were taken at most stations. At certain selected stations samples were also collected from 5 and 10 m to investigate the vertical distribution. In these cases a half inch hose was used for support of the water sampler with the string for release of the stopper inside the hose. This rather primitive sampling method worked well down to 10 m. The bottles were retrieved open, and the upper 50 - 100 ml of water were immediately discharded.

Extraction. During the "Sleipner" and the two "G. O. Sars" cruises the water was extracted immediately. The samples from the other

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cruises had 30 ml column-distilled dichloromethane added to prevent biological activity, and they were then stored in the dark for subsequent extraction upon return to Bergen.

For extraction, the water sample was transferred to a 3 l separatory funnel with a teflon stopcock and stopper. The sample bottle was rinsed very carefully with 50 ml dichloromethane which was then thereafter also added to the separatory funnel for extraction. This was performed by thorough hand shaking for 1 minute. After separation of the dichloromethane the extraction was repeated twice with 25 ml each time. Both times the dichloromethane was first used for rinsing of the sample bottle. After these rinsings the sample bottle was ready for the next sampling. The combined extracts comprised 60 - 70 ml due to slight solubility of dichloromethane in seawater and to some evaporation from seawater. They were stored in the dark for analysis onshore. Controls were taken daily by going thorough the procedure three times with 25 ml dichloromethane as described, but without seawater. In this manner control of contamination during the extraction and analytical procedures as well as of the cleanliness of the sample bottles was obtained. A few controls of the efficiency of the extraction were made by repeated extraction was checked by addition of 1 ml methanol solution containing 31.9 µg Ekofisk crude oil to 2.8 l of uncontaminated seawater in a separatory funnel, resulting in a concentration of 11.36 µg/l. After thorough mixing with the water, extraction was carried out as described above.

Analysis. The extracts were dried with approximately 5 g sodium sulfate which had been freed from hydrocarbon contamination by soxhlet extraction with dichloromethane. Thereafter appropriate aliquots of the extracts were concentrated on a rotary evaporator at 15 - 20°C under reduced pressure from a water aspirator. The evaporation was stopped when approximately 0.5 ml solvent was left, and this was quantitatively transferred to a small vial with a conically shaped bottom. Further concentrating was achieved with a stream of dry nitrogen gas.

The final analysis was performed with gas chromatography in two different ways: with a flame ionisation detector for determination of total hydrocarbons, and with a mass spectrometer as detector of selected aromatics: naphthalenes, phenanthrenes and dibenzothiophenes.

For the determination of total hydrocarbons the extract aliquot was concentrated as described above to about 10 µg which were quantitatively transferred, by two rinsings with 15 µl each time, to a capsule of a Perkin-Elmer automatic sampler. The chromatography was performed in a Perkin-Elmer 900 gas chromatograph with a SP 2100 packed glass column, with nitrogen, 20 ml/min., being used as carrier gas. The total areas of the chromatograms were determined by planimetry and converted to concentration units by interpolation on a calibration curve. For this purpose a sample of Ekofisk crude oil from a test separator was distilled to about 200°C, when approximately 40% of the original weight had dissapeared. The calibration curve of chromatogram area versus injected amount was made from five different samples of this reference oil in dichloromethane.

For determination of selected aromatics, known amounts of fluorene and anthracene, which are present in Ekofisk crude in only trace amounts compared with phenanthrene and the other aromatics, were added to the aliquot which was withdrawn from the water extract. The dichloromethane was then evaporated just to dryness as described above, the residue dissolved in approximately 15 ul carbon disulfide, and 0.1 µl of this solution was chromatographed on a 20 m SE-54 glass capillary column, (from Jäeggi, Trogen, in Switzerland), with helium as carrier gas, at 2 ml/min. The oven was programmed to heat from 100 - 230°C, at 6°/min. The column was connected by a 30 cm platinum capillary tube without separator directly to the ion chamber of a Finnigan 3200 mass spectrometer. The mass fragmentographic analysis was achieved by tuning the quadropole analyser of the instrument to detect the ions with mass 128, 141 and 170 during the first 4.4 minutes after the temperature program of the gas chromatograph oven was started. Thereafter the ions with mass 141,

166 and 170 were detected during the next 6.8 minutes, followed by 3.2 minutes for 178, 184, 192 and 198 ions and finally 3.4 minutes for the ions 206, 212 and 226. These mass units represent the molecular ions of respectively: 128 - naphthalene, 141 - methylnaphthalene minus one mass unit and dimethylnaphthalene minus 15 mass units, 166 - fluorene, 170 - trimethylnaphthalene, 178 - phenanthrene and anthracene, 184 - dibenzothiophene, 192 - methylphenanthrene, 198 - methyldibenzothiophene, 206 - dimethylphenanthrene, 212 - dimethyldibenzothiophene and 226 - trimethyldibenzothiophene. The various peaks were integrated after subtraction of the background signal. Each area was corrected according to the percentage the molecular ions make out of the total ion current which results from fragmentation of each specific compound. The corrected areas were then converted to concentration units by comparison with the internal standards. The quantification is based on the assumption that all compounds give the samt total ion current per unit weight.

RESULTS AND DISCUSSION

The obtained values for total hydrocarbons had a lower limit of about 20 µg/l. The controls gave values of approximately 5 µg/l. The majority of the stations had amounts in the range from 20 to about 50 µg/l, while in a few instances on the "Sleipner" and the first "G.O.Sars" cruises amounts of more than 100 and up to an excess of 300 µg/l were found. From water samples taken well outside the contaminated area, and also from previous experience, it is known that the method used extracts a host of organic compounds from the water. They have similar gas chromatographic retention times as petroleum hydrocarbons. When the response factor of the Ekofisk referense oil was used, their concentrations were found to be in the order of 20 to 50 µg/l. the great variability, even on samples taken on the same station, must be due to patchiness. This means that the method alone cannot be used as indicator of pollution of petroleum hydrocarbons unless the detected amounts lie well above 50 µg/l. Even in these cases the quantification is uncertain because the amount of organic compounds other than petroelum hydrocarbons in the sample may be anything between 20 and 50 µg/l.

The few samples with significant contents of petroleum hydrocarbons were all taken in relatively close proximity to the Bravo platform during the blow-out and on the first day after it was stopped. Moreover, oil was present on the surface at these stations, either as blue sheen or as lumps and small slicks with blue sheen in-between. This suggests that the hydrocarbons in the water column in these cases were present as oil-in-water emulsion and not in true solution. The close resemblance of the chromatograms of these water extracts with the chromatograms of the oil on the surface substantiates this. The oil-in-water emulsion does not appear to be persistant in the water column since it was only found under relatively fresh oil on the surface.

It is apparent that dichloromethane extracts of water polluted by oil contain a large number of naturally occurring organic components in addition to the large number of petroleum hydrocarbons. No analytical method, not even gas chromatography, is able to give complete resolution into single components of such a complex mixture.

The non-selective flame ionisation detector is only applicable when the degree of pollution is substantial, i.e. in the order of 50 µg/l or more. For analysis of lower levels of pollution, a method which can detect petroleum hydrocarbons in the presence of an excess of other organic components has to be used. For this purpose a mass spectrometer was ideal, and combined with a gas chromatograph it was used as a selective detector of hydrocarbons which originated from the blow-out.

The aromatic hydrocarbons naphthalene, fenanthrene and dibenzothiophene and their alkyl derivatives, all components in mineral oil, do not appear to occur naturally in the marine environment. Their presence in a sample therefore indicates pollution by oil. Due to higher water solubility, a higher proportion of these hydrocarbons enter polluted water relative to the others in the polluting oil. They also belong to the hydrocarbons most resistant to microbial degradation.

Conclusive evidence of pollution of the water by the oil from the blow-out is therefore based on the mass fragmentographic analyses of the aromatic hydrocarbons.

The analysed aromatics must obviously have been accompanied by other polluting hydrocarbons in the water. However, the total amount of hydrocarbons could not be determined directry, for reasons given above. It was also impossible to determine the total amount indirectly from the concentration of aromatics since their percentage of the total was not known.

The best choice is therefore to use the results of the analyses of selected aromatics as such, and discuss the distribution of polluting hydrocarbons on this basis.

The control samples were not completely free of these aromatics, the amounts found were equivalent ot 0.01 µg/l. It is therefore anticipated that results in the order 0.02-0.04 µg/l indicate trace amounts of Bravo oil, and amounts in excess of 0.05 µg/l give a positive indication of Bravo oil in the water.

The waters in the near surroundings of the Bravo platform were subjected to a more thorough investigation than those of the more remote areas. Fig. 3.2 shows the results from the first three cruises. Conditions were quite different in these three instances: On April 24, the second day of the blow-out, the oil was spread out south-east of Bravo. The two samples taken north of Bravo showed virtually no pollution, while three samples taken a few hours later from a lifeboat between oilslicks in an area almost completely covered with oil, contained up to an excess of 300 µg/l of total extractable compounds. The aromatics accounted fro less than 2% of this. On April 29, when the blow-out had lasted a week, most of the area was covered with oil, while the main direction of the drift of the oil was north-north-east. Here also, the total amount of extractables exceeded 300 µg/l in some cases. The contribution to these values of naturally occurring compounds was in the range of

20 - 50 µg/l, as discussed above. When the average values of 35 µg/l is subtracted from the values given in the figure, it can be seen that the aromatics acount for 2 - 3% of the total.

On May 13, a fortnight after the well was capped, there was no visible oil in the nearby area. The analyses of total extractable organics did not give any indication of oil pollution: the amounts were within the range found for naturally occurring compounds, and the typical pattern of the normal alkanes was absent in the chromatograms, see Fig. 3.1. The analysis of the aromatics, however, showed significant amounts, leaving no doubt that the water was polluted.

On the "Sleipner" cruise, shown in Fig. 3.3, the samples were taken along the boundary of the distribution of visible oil on the surface. Only in two instances were significant amounts of total hydrocarbons found, while most of the stations, except the first two, had significant amounts of aromatics in the water.

The analytical results from the first "G. O. Sars" cruise, other than those from the vicinity of Bravo discussed above, are shown in Fig. 3.4. It can be seen that the total extractable analysis are not very helpful in detecting pollution: Only at three stations to the north-east of Bravo were values of above 50 µg/l detected. The aromatic content, however, indicated pollution in a wider area north and eastwards from Bravo. Of special interest is the transect north-eastwards from Bravo taken the day after the blow-out was stopped. A gradient was detected in the aromatic content, falling from about 4 µg/l close to Bravo, via 0.38 µg/l and 0.13 µg/l, down to pratically background values on the four stations of the transect.

The results of the analysis of the water sampled on the second "G. O. Sars" cruise, except the three stations shown in Fig. 3.2 and shown in Fig. 3.5. Again, analyses of the total extractables were of no help, but the findings of varying amounts, from trace to significant, of aromatics on the majority of the stations indicate that most of the area had been affected by pollution. The only two stations where oil in the form of small lumps was visible

on the surface, are indicated in the figure. The amounts of aromatics were surprisingly small, barely reaching the level of significance. Here the results are based on three parallel samples, from 1.5 and 10 m depth at one station, and on 5 parallels, 2 from 1 m, 2 from 5 m and 1 from 10 m depth at the other.

Only three samples from the first "Johan Hjort" cruise have been analysed to date. Two of the stations of this cruise corresponded with two of the stations on the transect taken north-eastwards from Bravo on the first "G. O. Sars" cruise. They were, however, taken a couple of days later. On the station closest to Bravo, the amount of aromatices was somewhat lower, and on the most remote the value was somewhat higher.

A series of water samples were also collected on the second "Johan Hjort" cruise. Of special interest was the section between Torungen in Norway and Hirtshals in Denmark, to see if any of the pollution from Bravo had been transported towards Skagerrak. Although traces of aromatics could be detected in some of the samples, the results showed no indication of a connection with the Ekofisk Bravo blow-out. Two samples collected on June 11 near Bravo show only traces of aromatics, 0.03 and 0.04 µg/l respectively, remaining in the water in this area.

On the other hand, four samples taken south of Bravo, between $55^{o}00'$ and $55^{o}30'$N, in an area with relatively large amounts of oil lumps on the surface, contained significant amounts of aromatics: 0.08, 0.15, 0.16 and 0.20 µg/l respectively. This was in contrast to the results from the samples taken under oil lumps on the second "G. O. Sars" cruise.

In order to investigate the vertical distribution of petroleum hydrocarbon in the water column, samples were retrieved from 1 and 5 m depths on a number of stations on the first "G. O. Sars" cruise, No gradient could be detected. The results indicate that the oil-in-water emulsion under visible oil on the surface is completely mixed in the uppermost 5 m. In the polluted waters dissolved aromatics appear to be evenly distributed in the uppermost 10 m.

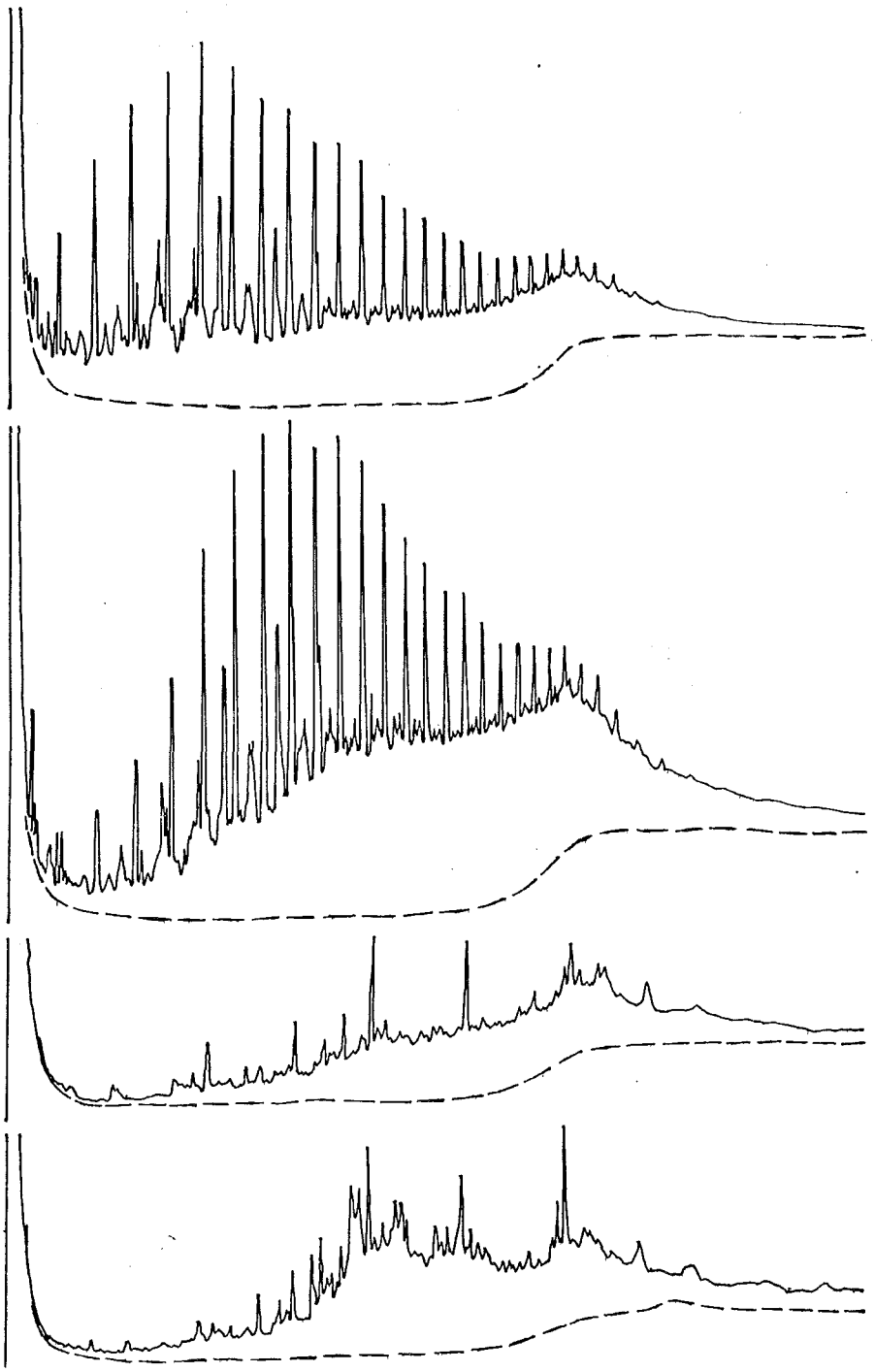

Fig.3.1 Gas chromatograms from a packed column with flame ionisation detector of, from the top: oil collected from a slick in the vicinity of Bravo on April 25, extract of water sampled at the station marked with B in Fig.3.2 north of Bravo on April 19, extract of water sampled at the station marked with A in Fig.3.2 north of Bravo on April 24, extract of water sampled at the station marked with C in Fig. north of Bravo on May 13.

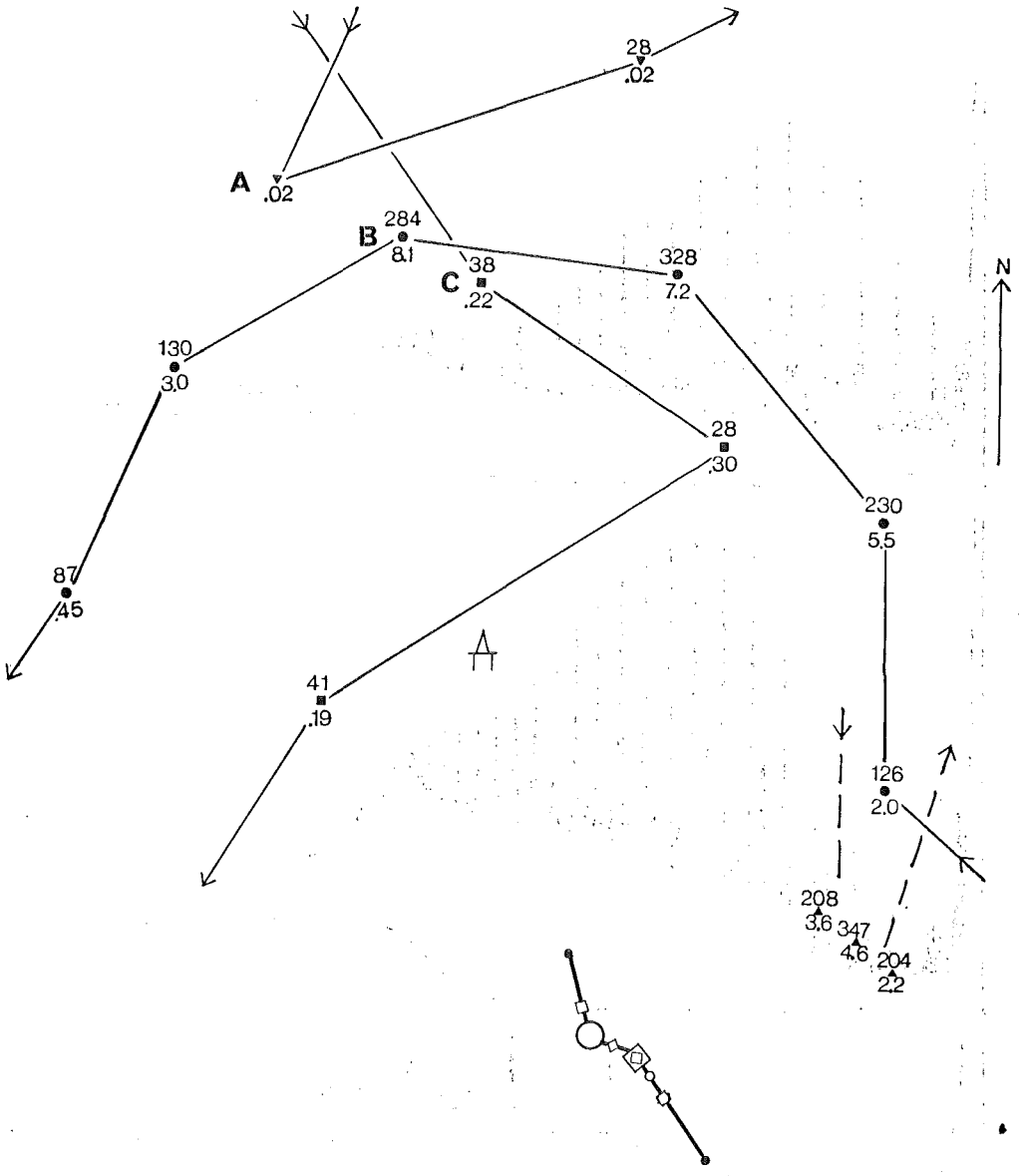

Fig. 3.2 Stations of three different cruises in the near surroundings of Bravo: —▼— "Sleipner" April 24, — — ▲ — — lifeboat from "Sleipner" April 24, —●— "G. O. Sars" April 29, —■— "G. O. Sars" May 13. The numbers above the symbols indicate the total amount of extractable organic compounds in micrograms per litre of water (µg/l), and the numbers below the symbols indicate the amount of selected aromatic hydrocarbons, also in µg/l. Gas chromatograms of extracts from water sampled stations marked with A, B and C are shown in Fig. 3.2.

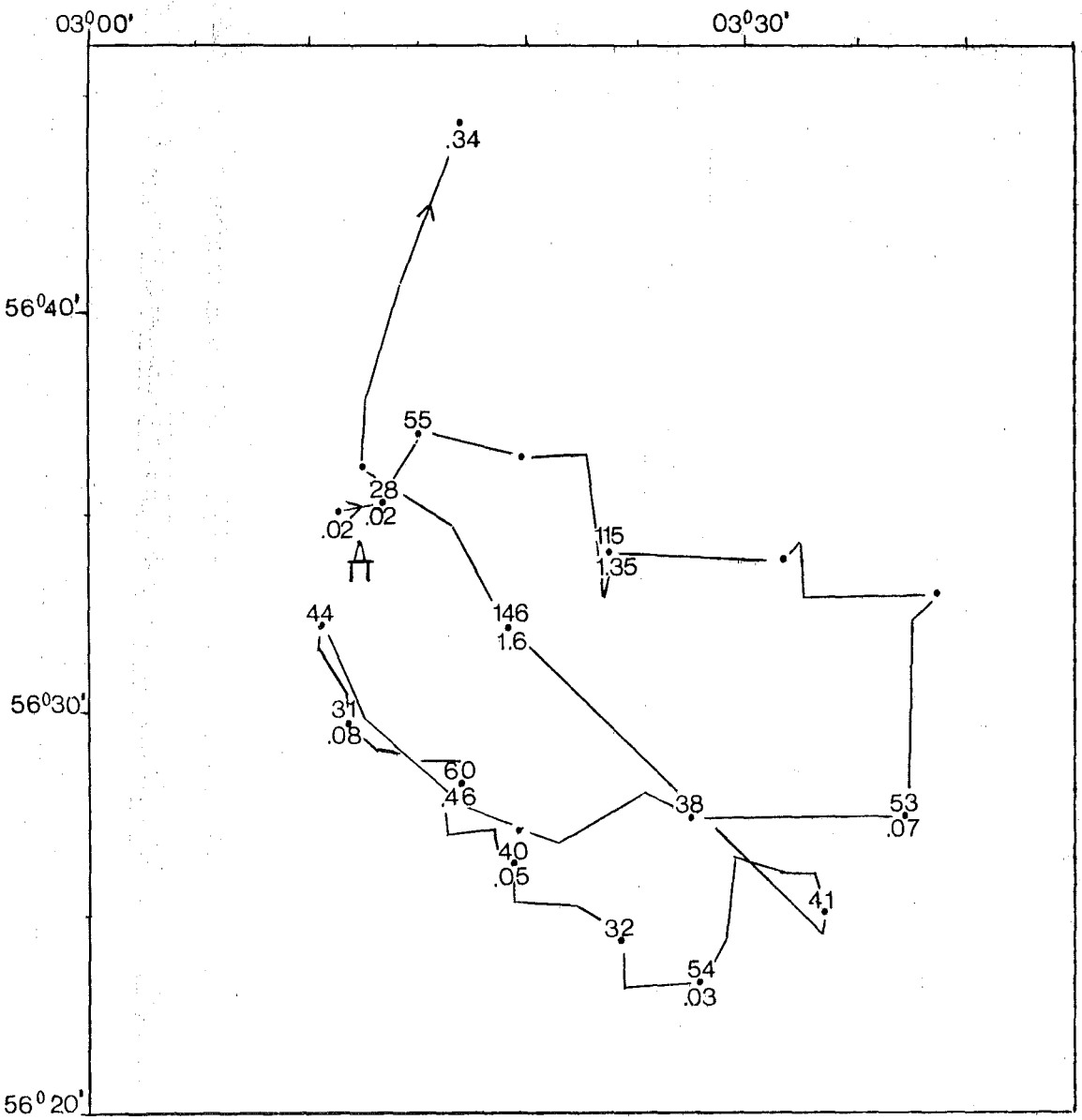

Fig. 3.3 Stations on the "Sleipner" cruise of 24. and 25 of April. Numbers above the symbols indicate µg/l of total extractable organisms, numbers below indicate µg/l of selected aromatics.

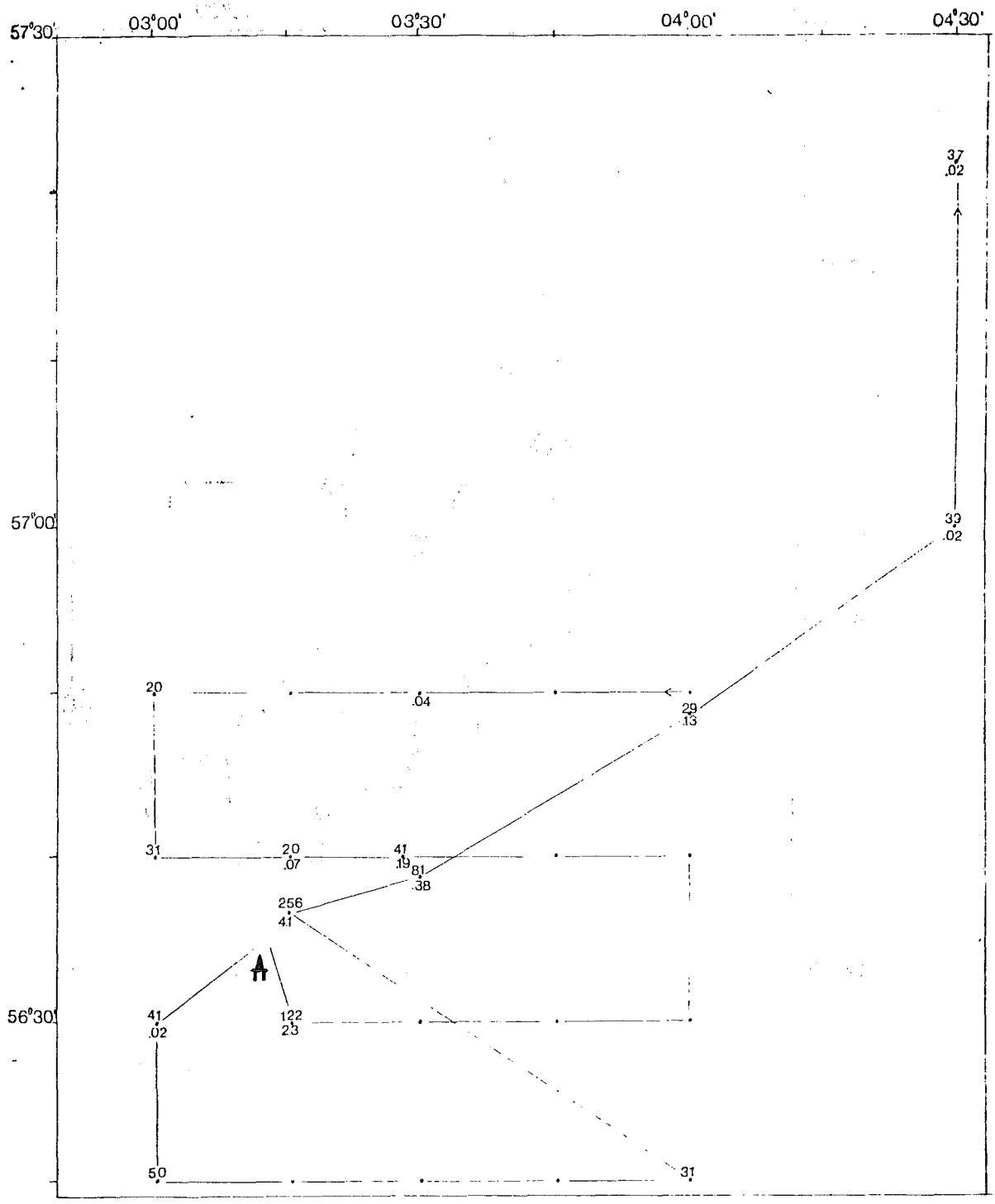

Fig. 3.4 Stations on the first "G. O. Sars" cruise between April 27 and May 1. Numbers above the symbols indicate µg/l of total extractable organics, numbers below indicate µg/l of selected aromatics.

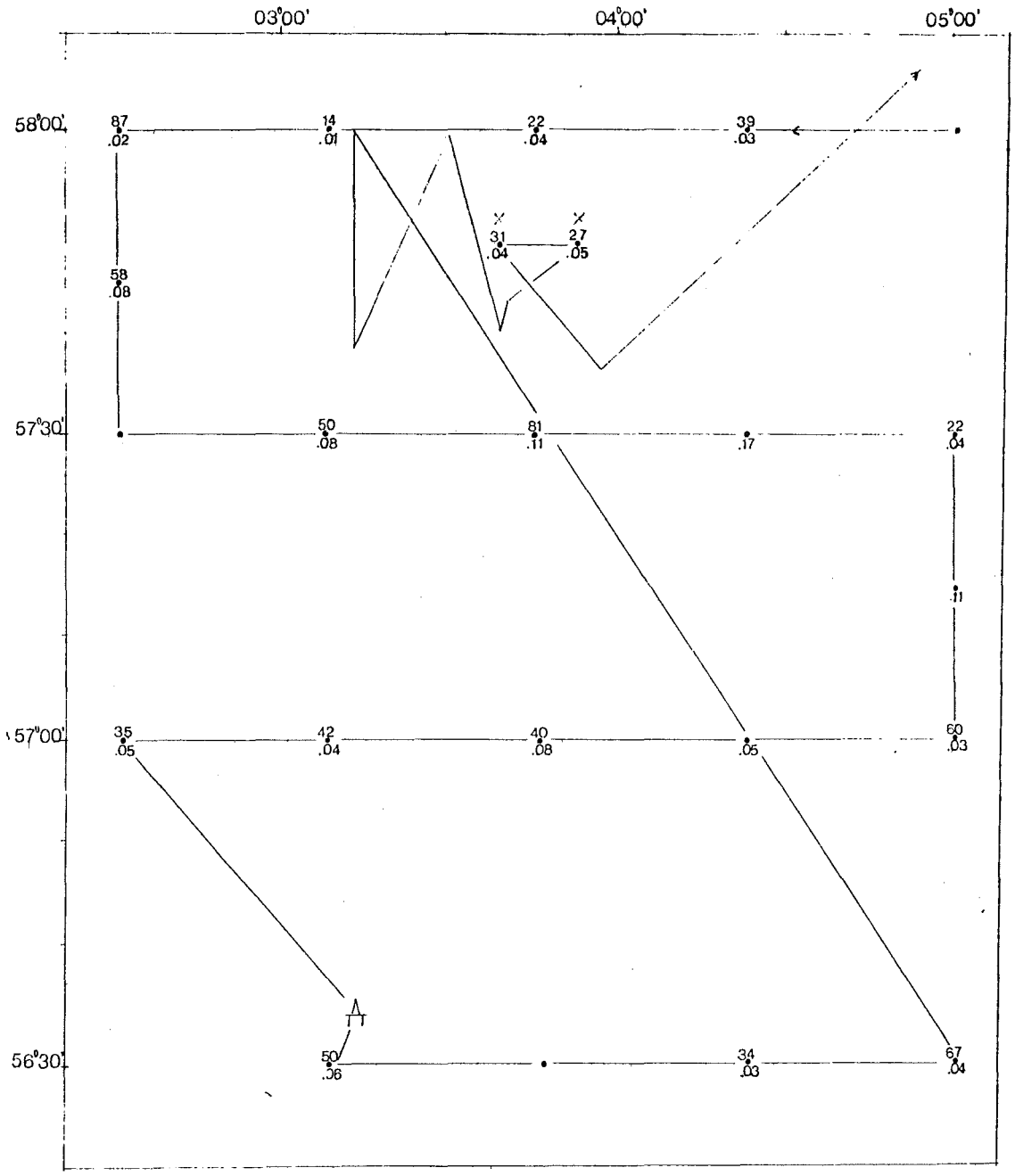

Fig. 3.5 Stations on the second "G. O. Sars" cruise between May 11 and May 15. Numbers above the symbols indicate µg/l of total extractable organics, numbers below indicate µg/l of selected aromatics. On the two stations marked with "x", oil lumps were visible on the surface.

4. FATE OF THE FLOATING OIL

by

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A chemical investigation of the oil on the surface was undertaken for several reasons. In order to obtain knowledge of the ability of the oil to form water-in-oil emulsion and of the stability of an emulsion, the amount of water in the oil has to be determined. A study of the relative loss of components from the oil will give further understanding of the various weathering processes: evaporation, dissolution, microbial degradation and photochemical degradation. Analysis of the relative composition of selected aromatics of low volatility was applied for the identification of the source of the floating oil.

EXPERIMENTAL

Sampling. Oil in the form of slicks or lumps was sampled from the surface either with a bucket (were the density allowed) or by an Otter trawl towed for 1 mile. In the cases where large amounts of oil were retrieved, small glass bottles were filled completely with the oil and closed with teflon-lined screw caps and kept at an ambient temperature. Samples of smaller size were frozen. A map of the sampling sites is shown in Fig. 4.1. As a reference oil, crude oil under pressure from a test separator on the Ekofisk field was supplied by Phillips Petroleum Company in a steel cylinder.

Analysis. Visible water on the surface of the oil samples was removed carefully by filterpaper, the sample was weighed and dissolved in an appropriate amount, usually a few ml of dichloromethane. The solution was carefully dried with pre-cleande sodium sulphate. The solution was filtered and the sodium sulfate washed with a small amount of dichloromethane. The combined filtrate and washings was evaporated carefully to near dryness under reduced pressure and then the last traces of dichloromethane were evaporated

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under a stream of dry nitrogen gas. The residue was then weighed. In this manner the content of water in the original oil sample was estimated.

The only residue was thereafter dissolved in carbon disulfide, a known amount of anthracene was added as internal standard, and approximately 0.1 ul of the solution was chromatographed on a glass capillary column. A mass spectrometer was used as selective detector for phenanthrene and dibenzothiophene and their alkylated derivatives, as described in the previous paper. The area of the peaks were integrated and by comparison with the area of the peak of the internal standard, the amounts of the various aromatic could be determined.

A weighed amount of the reference oil was taken from the steel cylinder. The volatile components which disappeared when the oil was depressurized accounted for 7% of the total weight. Two aliquots of the depressurized oil were artifically weathered by distillation in a nitrogen atmosphere (according to ASTM D - 3326 - 74T) until 40% and 55% respectively, had distilled off. Samples of the reference oil and the two distillation residues were chromatographed as described above.

The amount of dimethylphenanthrenes in the samples was used as the basis for calculation of the percentage of oil lost during weathering. This was achieved by comparison with the amounts of dimethylphenanthrene in the reference sample and in the artifically weathered samples. The results are given in Table 4.1.

In an attempt to distingnish the outside from the core of weathered oil lumps, one of the lumps sampled on May 15 and two lumps sampled on July 26 were carefully dissected. Specimens from the outside and from the core were subjected to gas chromatography on a packed column.

The heights of the 23 peaks in the mass fragmentograms were recorded for identification purposes, and the height of each peak was

expressed as percentage of the sum of all the heights. Based on these relative values, each sample was compared with the reference sample by summation of the squares of the differences of the vlaues for the corresponding peaks.

RESULTS

Water content. The oil appears to have taken up water rapidly, i.e. a sample (No. 1) collected from a lifeboat in close proximity to the Bravo platform 40 hours after the blow-out started, contained 30% water, while the sample collected the following day (No. 2) contained 60% water. These samples were very small lumps and had water contents of between 50 and 70%, the main reason for these differences being probably the primitive procedure for removal of surface water from the lumps.

Weathering. It can be seen from the following table that even the first oil samples had lost more than 30% of their components. This was due to relatively rapid evaporation of the most volatile components, since the hot oil was blown into the air from the open well. These two samples were probably not many hours old, as they were collected downwind and close to the Bravo platform. Within a few days the oil had lost more than half of its light ends. Sample No. 5 was an exception, but this sample was collected the last day of the blow-out, not far from Bravo. The time between escape from the well and collection of this sample from the surface must therefore have been relatively short.

The gas chromatograms of the inside and the core of the oil lump sampled on May 15 showed no significant differences. The weathreing of this 2-3 week-old sample seems therefore to have affected all parts of the lump. On the other hand, the oil lumps sampled by Otter trawl on July 26 had significant differences in the gas chromatograms of the surface and the core, showing that a greater portion of the lighter compounds had disappeared from the outside of the lumps. In case of sample 14 A, which could not be identified as Bravo oil, (see below), the ratios of the peaks of the C_{16} normal

alkane versus the C_{31} normal alkane were 0.78 for the surface and 0.93 for the core. For the 14 B sample, identified as being Bravo oil, the same ratios were 0.19 and 0.28, respectively. The relative difference between outside and inside was thus much larger for the Bravo oil lump than for the other, suggesting a heavier weathering of the Bravo oil.

The relative compositions of phenanthrene, methylphenanthrenes (four peaks in the fragmentogram), dimethylphenanthrenes (four peaks), dibenzothiophene, methyldibenzothiophenes (three peaks), dimethyldibenzothiophenes (four peaks) and trimethyldibenzothiophenes (six peaks) have proved to be a useful basis for identification of source of different oils. For oil spilled at sea and consequently exposed to weathering, this method is useful if samples can be obtained within a few days after the spill.

In the Bravo case, it turned out that weathering affected the parent compounds and also the methyl derivatives. Therefore, the identification was based on the dimethylphenanthrenes and the di- and trimethyldibenzothiophenes. There also appeared a very slight change in the relative concentrations of these compounds, manifested in a slight decrease of the dimethylphenanthrenes relative to the di- and trimethyldibenzothiophenes. This difference increased gradually with the age of the samples and could therefore be taken into account in the identification. Even in case of the last sample, collected on July 26, this difference relative to the reference oil was ten times less than the differences between the reference oil and the samples which could not be identified as Bravo oil.

Table 4.1. The content of water, effect of weathering and identification of samples of oil.

Sample no.	Date	Vessel	%Water	%Lost	Identification
1	24.4.	Sleipner	30	34	
2	25.4.	"	60	33	+
3	28.4.	G.O.Sars		44	
4	29.4.	"		48	+
5	30.4.	"		36	
6	1.5.	"		60	+
7	15.5.	G.O.Sars II			+
8	15.5.	"			+
9	14.6.	Johan Hjort II	54		+
10	14.6.	"	66		+
11	15.6.	"	67		+
12	25.7.	Johan Hjort III	67		-
13	25.7.	"	54		-
14 A	26.7.	"	68		-
14 B	26.7.	"	44		+

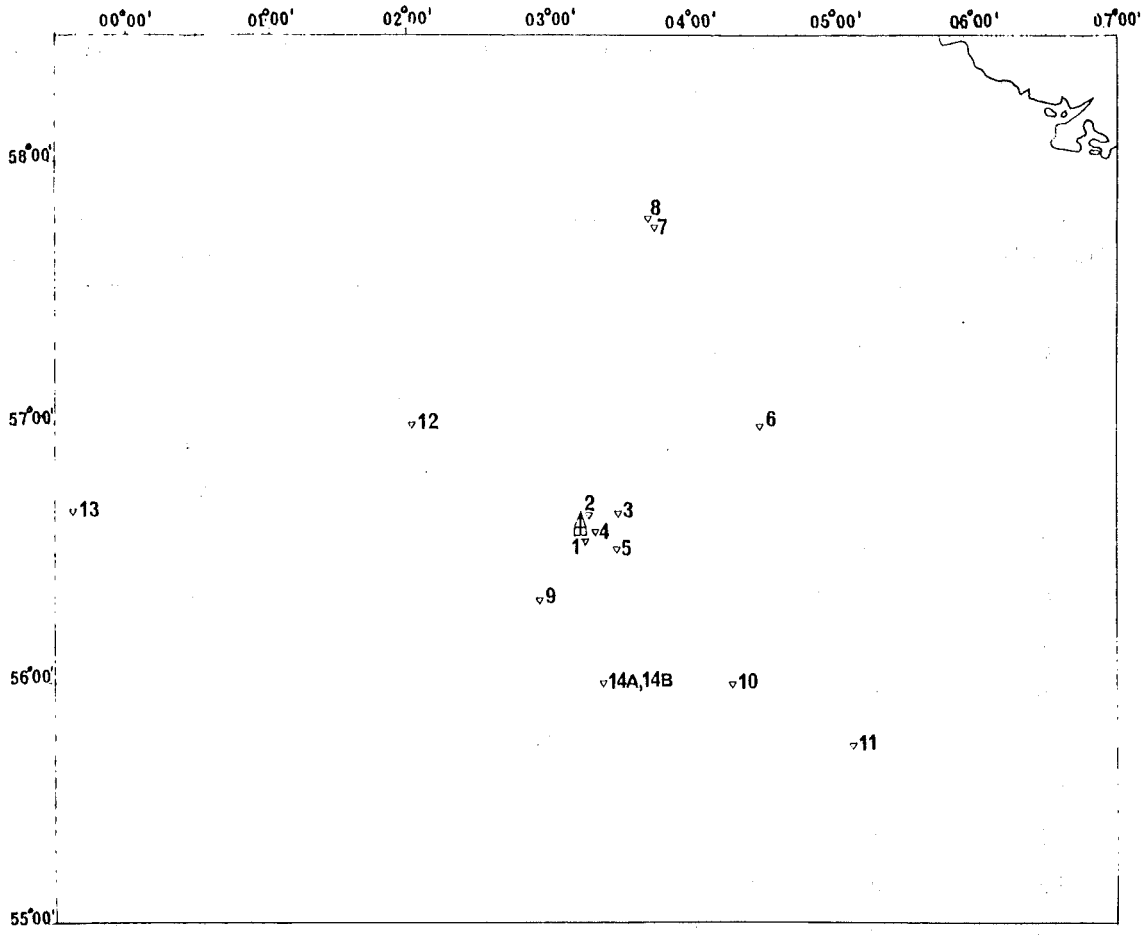

Fig. 4.1 Positions where samples of oil were collected from the surface. The numbers correspond with the numbers in the table.

5. Occurrence and distribution of particulate oil following the Bravo blow out

by

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Petroleum at sea will, in the course of time, undergo a whole series of processes such as evaporation, solution, oxydation and degradation. Eventually semi-solid globules of floating oil residues, also known as oil lumps, pelagic tar or tar balls, are formed.

Further degradation of these tar particles leads to the formation of smaller, denser forms that may eventually sink to the sea bottom (MORRIS and BUTLER 1973). Tar particles in the water column, although derived from the surface tar lumps, may exceed the quantity of lumps floating on the surface at any given time simply by being more resistant to degradation. They thus having a longer residence time in the water column than the residence time of the parent lumps on the surface (MORRIS, BUTLER, SLEETER and CADWALLADER 1975). The longevity of particulate oil in the sea may consequently be in the order of years.

Sampling of tar balls by neuston nets is an important part of the Marine Pollution (Petroleum) Monitoring Pilot Project of IOC's Integrated Global Ocean Station System (IGOSS), which is supported by several UN agencies and in which a number of member states are participating.

Several thousand samples have been taken in Norwegian waters from the Skagerrak, the North Sea and northward to the Barents Sea, since the initiation of the project in 1975. The sampling has been undertaken regularly as monitoring along fixed hydrographic sections as well as occasionally where given situations or opportunities have called for it.

The Bravo blow-out was naturally an incidence that called for monitoring of the spilled oil as it eventually formed lumps and tar balls which made the oil available to trawling by sampling nets.

MATERIALS AND METHODS

The oil lumps, and eventually tar balls were collected with a modified neuston net (SAMEOTO and JAROSZYNSKI 1969). This is a surface sampler with a square opening (40 x 40 cm) leading to a nylon plankton net (mesh size 243 um) which scoops along the sea surface. Towed over a distance of 1 nautical mile (using standard procedures, 5 knots for 12 minutes accordingly) about 740 m^2 of sea surface is filtered to a depth of approximately 20 cm. The sampler was towed to the side of the ship by an arrangement of a boom and otter boards, thus preventing pollution and disturbance of the surface water by the research vessel.

Immediately upon retrieval the total contents of the sampler were flushed into plastic bottles or jars and stored frozen until analysis in the laboratory. After thawing, the tarry particles were separated from the plankton under a binocular microscope and dried at a maximum of 40°C until evaporable water had dissipated and constant weight was obtained.

Particulate oil matter is, however, actually a water-in-oil emulsion, with a water content ranging from virtually nothing to more than half the total weight. No attempt has so far been made to determine the water content of the present material, but other investigators (C. D. McAULIFFE 1976) have corrected their data for 21% water content, which was the mean value measured by McGOWAN et al. (1974). The concentrations presented in this report have not, however, been corrected for any water content. Particulate matter attached to or mixed with the oil has been avoided as far as practically feasible and has not been accounted for.

The sampling as well as the analytical methods were in accordance with the procedures recommended for the IGOSS Marine Pollution (Petroleum) Monitoring Pilot Project (ANON. 1974).

The concentrations are expressed as mg particulate oil collected per m^2 sea surface sampled. For a description of the oil pollution expressed by these values the following denotations introduced by WONG, GREEN and CRETNEY (1976) may be used:

Trace	:	<	0.1	mg/m^2
Medium	:		0.1-1	"
Heavy	:		1 -5	"
Extra heavy:		>	5	"

Five surveys using the neuston sampler were made on four different cruises to the area thought, according to meteorological data, to be affected by the Bravo oil spill. The survey periods relevant to this report were April 27-30, May 1-4, May 11-15, June 7-16 and July 20-28. Some comments should be made to the different sampling conditions during these five periods:

April 27-30:

The Bravo oil had, at least in part, solidified enough to be available to sampling by the neuston net. But it was still too liquid for manual treatment and separation from planktonic material also taken in the sample. Consequently, positive findings are only presented as such, and are not given numerical values (Fig. 5.1).

Simultaneous measurements were made of tar balls of other origins on all but the last survey, and these results will be published in a separate report.

May 1-4:

The weather conditions were unfavorable and the seas too rough for a good sampling coverage of the area. The scanty material from this survey is, therefore, not presented, as the few samples taken are all in accordance with the survey of the previous period.

May 11-15:

The Bravo oil had by now solidified enough to allow proper handling by the techniques prescribed for these investigations. The oil was, however, still visibly distinguishable from other oil pollutants by its light brown color and loose or hardly cohesive consistence.

In some areas the oil appeared in such quantities as to be visible from the moving vessel through binoculars or even to the naked eye, and was to greater or lesser extent covering the whole sea surface.

In those areas such observations were just taken note of (Fig. 5.2) as sampling with the neuston net would serve no purpose because oil would clog and smear the equipment.

The oil lumps observed ranged in size from that of peas on down to the mesh size of the sampling net.

June 7-16:

The Bravo oil lumps had dispersed sufficiently for sampling with the neuston net at all pre-set and improvised stations (Fig. 5.3). One oil sample was lost before quantification.

July 20-28:

By now the Bravo oil had undergone substantial changes due to the various weathering and degradation processes, so much that the recently formed Bravo tar balls were no longer visibly distinguishable from oil pollutants from other sources. Chemical analysis must be carried out in order to recognize the Bravo oil and determine the remaining concentrations.

The total tar load of the surveyed area is discussed in this report as only a few gas chromatographic/mass spectrometric spot check analyses of the tar balls have so far been carried out.

However, since the "background" pollution of the area is fairly well documented, through simultaneous measurements on previous surveys, and is reported to be in the order of 0.1 mg or less, at least a general view of the distribution of Bravo tar balls may be obtained, assuming that samples containing more than 0.1 mg/m^2 are partly or completely of Bravo origin (Fig. 5.4). Seven samples were lost before quantitative measurements could be taken. There was no sampling south of N 56°00'.

Routine monitoring was carried out in June and July on the hydrographic sections along the N 60°45' (Bergen - Shetland) and N 59°17' (Utsira-W) parallels.

RESULTS AND DISCUSSION

The observations from the oil lump and tar ball sampling have been plotted on the maps for the four consecutive survey periods (Figs.5.1-4). Some data derived from these observations have been compiled in Table 5.1.

Table 5.1. Concentrations and quantities of oil lumps and tar balls following the Bravo blow-out.

Survey period	Extent of distribution (km^2)	Average concentration (mg/m^2)	Total weight (tons)	Per cent of the 13000 tons spilled
April 27-30	12000	-	-	-
May 11-15	20500	0.7[x]	14.4[x]	0.1[x]
June 7-16	55000	2.1	115.5	0.9
July 20-28	55000	2.7	148.5	1.1

[x] Oil slick not included.

By the end of April some of the Bravo oil had solidified sufficiently to become available to the neuston sampler, but the oil was still too incohesive for quantitative measurements. The oil had spread out over an area of at least 12000 km^2 to the east of the Ekofisk field (Fig. 5.1).

By the middle of May about 0.1 % of the spilled oil had conglomerated into lumps, in concentrations averaging 0.7 mg/m^2 outside the main slicks, partly covering an area of minimum 20500 km^2. The cil had drifted to the north of the Ekofisk field (Fig. 5.2).

By the middle of June all retrievable oil, or 0.9 % of the spill, had been transformed into oil lumps in concentrations that had increased to 2.1 mg/m^2. The lumps were scattered over an area of 55000 km^2 surrounding the Ekofisk field along a NW - SE axis (Fig. 5.3).

By the end of July the oil lumps had developed further into tar balls, amounting to 1.1 % of the spill, and were now in slightly increased concentrations (2.7 mg/m^2). The area covered was essentially the same, with the main occurrences being to the south of Ekofisk (Fig.5.4). Data is lacking to define the southward distribution of the tar balls and this may disguise the real amounts of oil still drifting and the actual area covered. The 150 tons referred to in Table 5.1 is clearly a minimum estimate.

The negative samples along the N 60°45' and N 59°17' parallels suggest no or at least insignificant drift of Bravo oil northward from the North Sea. But a substantial amount of tar balls may have escaped registration by being suspended in the water column by having sunk to the sea bottom.

Only follow-up research will reveal the endurance, or half life, of these tar balls in the North Sea, the possibility for their continued identification, and their impact, if any, on the marine environment.

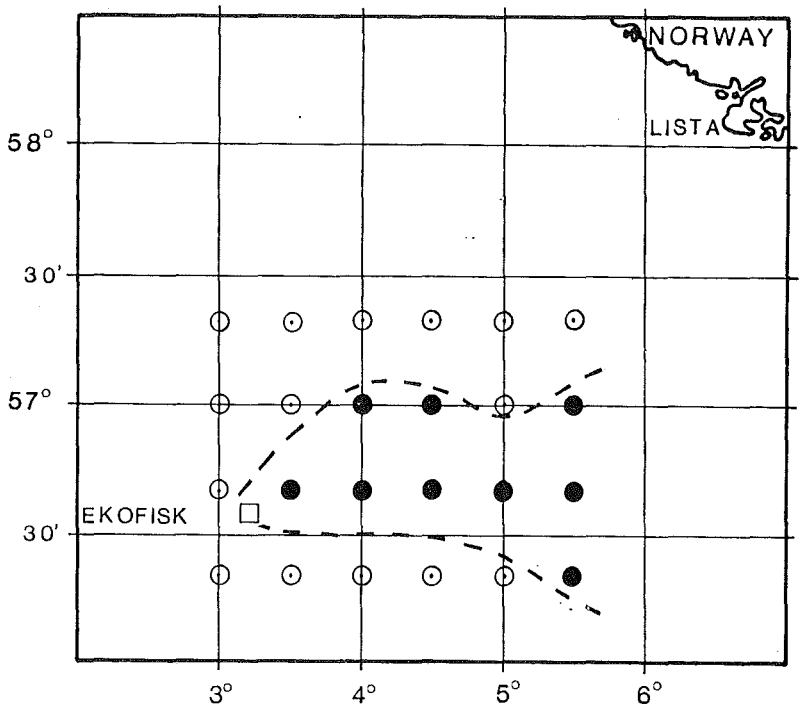

Fig. 5.1. The distribution of Bravo oil lumps, April 27-30. Circles: Sampling positions. Filled circles: Bravo oil in sample.

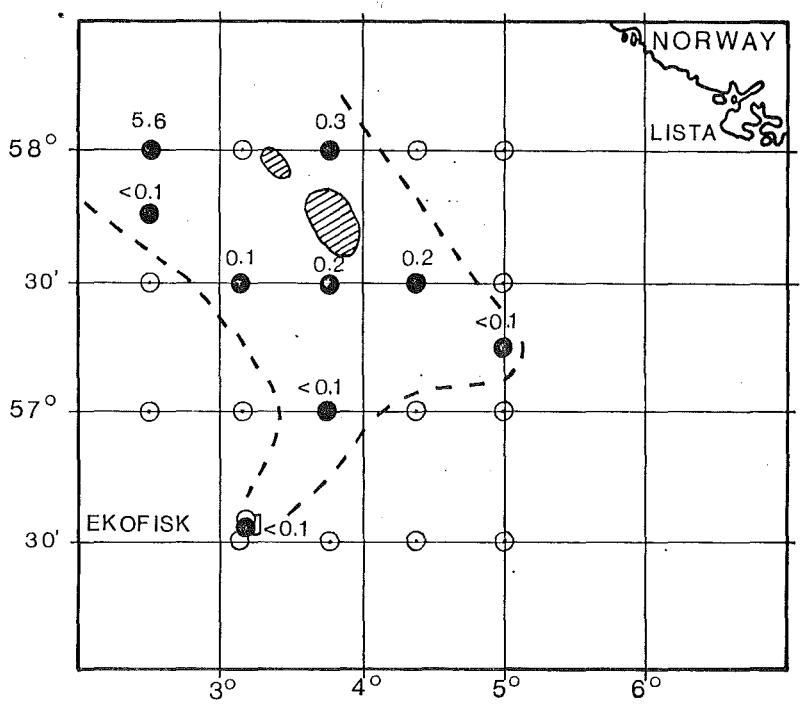

Fig. 5.2. The distribution of Bravo oil lumps, May 11-15. Circles: Sampling positions. Filled circles: Bravo oil in sample. Concentrations expressed as mg/m^2. Hachure: Concentrations too heavy for sampling with neuston net.

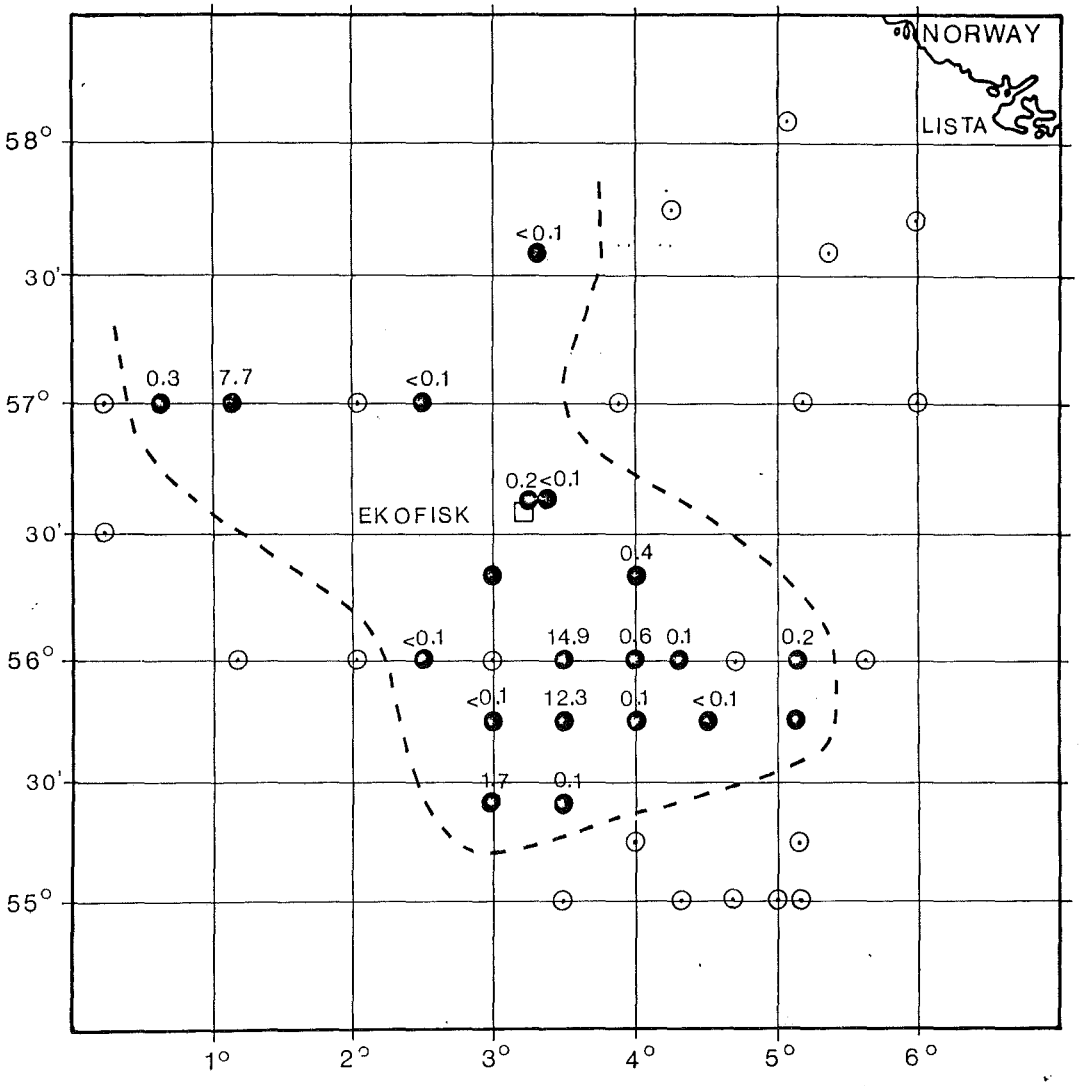

Fig. 5.3. The distribution of Bravo oil lumps, June 7-16. Circles: Sampling positions. Filled circles: Bravo oil in sample. Concentrations expressed as mg/m^2.

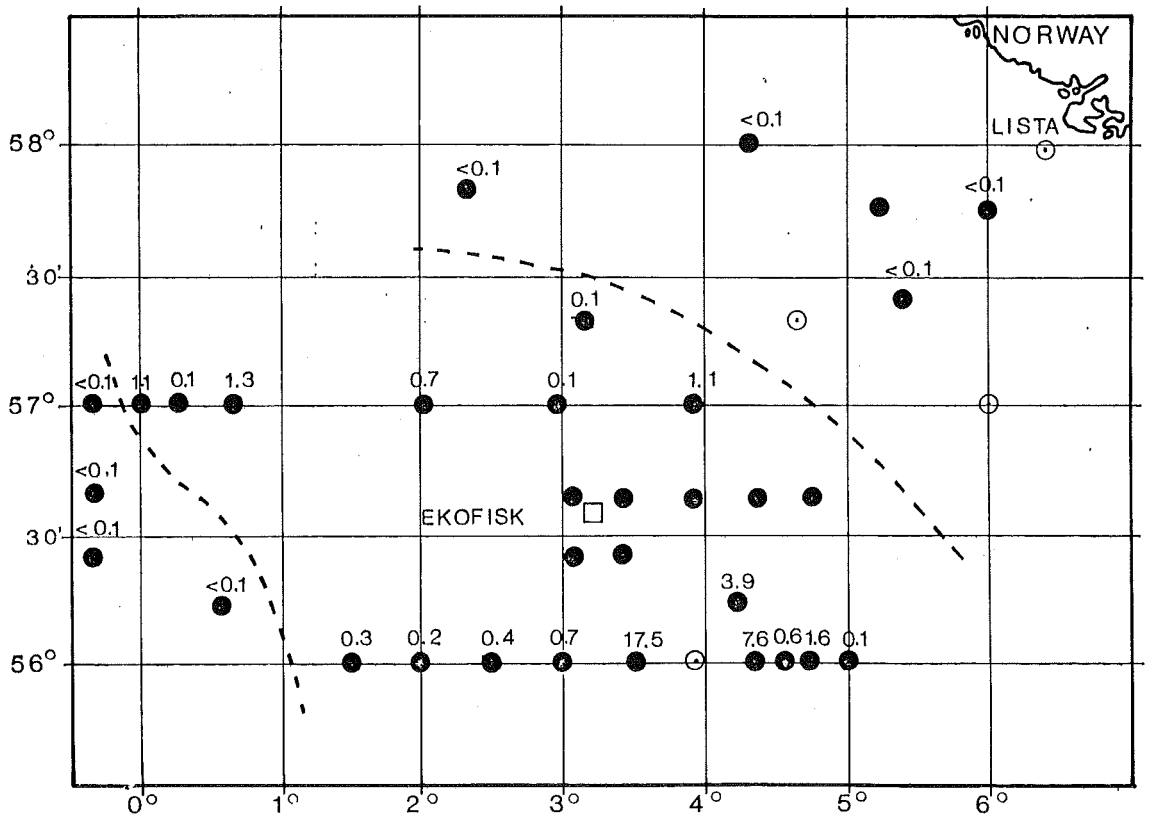

Fig. 5.4. The distribution of tar balls, July 20-28. Circles: Sampling positions. Filled circles: Tar balls in sample. Concentrations expressed as mg/m^2. Values higher than 0.1 are assumed to partly or completely represent Bravo oil (see text). Outside scope of map: Five negative samples in various positions east of E 07°00'and north of N 57°00'.

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6

OIL-DEGRADING BACTERIA AND FUNGI

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Introduction

Some bacteria and fungi have the capability to degrade and mineralise hydrocarbons, and these micro-organisms play an important part with respect to the purification of waters in which oil spills have occurred.

We are still lacking much of the basic knowledge concerning the self-cleaning capacity of the North Sea, where a fairly low average annual temperature may put limitations on oil biodegradation. The Bravo blow-out gave us an opportunity to study the effects of a heavy environmental oil load within a restricted area on the quantitative distribution and composition of oil-degrading micro-organisms, under otherwise normal field conditions. conditions.

The microbiological analyses to be reported on in this short paper were performed during the 27.4 - 2.5.77 cruise with R.V. "G.O. Sars".

Experimental

Water samples were collected from varying depths (Niskin sampler for 5 - 20 m, bucket for 0 m samples). Dilution series

(1/1 to $1/10^6$) from each sample were set up, and 20, 10 and 1 ml of the undiluted water sample and 1 ml of the remaining dilutions were filtered through membrane filters (0,45 µm pore diameter, Selectron).

The membrane filters were placed in Petri dishes on top of cellulose pads soaked with growth medium. This consisted of sea-water, strengthened with phosphate (0.002% w/v as K_2HPO_4) and ammonia (0.005% as NH_4Cl), and buffered with tris HCl (0.01%), pH 7.2. A mixture of different oil constituents ($n\text{-}C_{14}$, $n\text{-}C_{16}$ and $n\text{-}C_{18}$ alkanes plus weathered oil in equal amounts, (total 0.1% w/v) was used as a carbon and energy source. Media without hydrocarbons were also used in order to detect a possible background growth on the pure seawater/salts medium.

The Petri dishes were incubated at $10^{o}C$, and the number of oil degrading bacteria and fungi in the original water sample could be deduced from the number of bacterial colonies that developed on the surface of the membrane filter after an incubation period of 1 - 3 weeks.

Results

Table 6 gives the numbers of oil-degrading bacteria and fungi in the water samples at different locations in the Ekofisk-Bravo area.

The bacterial counts are also presented in figs. 6.1 - 6.3 where the relative amounts of bacteria are plotted as circles of varying diameter on the cruise grid for a more straightforward interpretation and comparison of the results.

Table 6.1 Total numbers of oil-degrading bacteria and fungi in water samples from the Ekofisk-Bravo area 5 - 8 days after the blow-out, (Values are given as numbers/l).

The station numbers refer to positions given in Fig. 6.1.

Station	0 m		5 m		10 m	
	Bacteria	Fungi	Bacteria	Fungi	Bacteria	Fungi
218	50	<50	$3.4 \cdot 10^4$	<50	$2.0 \cdot 10^3$	<50
220	50	<50	$7.8 \cdot 10^3$	<50	$1.4 \cdot 10^4$	<50
222	$1.4 \cdot 10^3$	<50	$2.0 \cdot 10^4$	$1.4 \cdot 10^3$	$8.0 \cdot 10^3$	50
223	50	<50	$1.0 \cdot 10^4$	<50	$1.4 \cdot 10^4$	<50
225	$6.0 \cdot 10^2$	$1.4\ 10^2$	$1.1 \cdot 10^4$	<50	$4.3 \cdot 10^3$	<50
227	$1.4 \cdot 10^2$	<50	$8.7 \cdot 10^3$	50	$1.4 \cdot 10^4$	<50
228	$2.0 \cdot 10^3$	<50	$5.9 \cdot 10^3$	<50	$1.1 \cdot 10^4$	50
230	50	<50	$5.9 \cdot 10^3$	<50	$1.1 \cdot 10^4$	<50
231	$5.4 \cdot 10^2$	50				
B 1	$2.0 \cdot 10^2$	<50	$1.1 \cdot 10^3$	50	$1.4 \cdot 10^2$	<50
B 2	50	<50				
B 3	50	<50	$2.0 \cdot 10^2$	$2.8 \cdot 10^2$	$4.0 \cdot 10^2$	<50
B 4	$6.0 \cdot 10^2$	<50				
B 5	50	<50	$6.7 \cdot 10^2$	$6.7 \cdot 10^2$	50	<50
232	$7.4 \cdot 10^2$	$1.6\ 10^3$	$4.9 \cdot 10^3$	<50	$3.8 \cdot 10^3$	<50
233	$1.4 \cdot 10^2$	<50	$2.7 \cdot 10^4$	$1.6 \cdot 10^3$	$3.0 \cdot 10^3$	50
235	$6.0 \cdot 10^3$	50	$5.3 \cdot 10^3$	<50	$3.0 \cdot 10^3$	<50
237	$1.4 \cdot 10^2$	<50	$4.0 \cdot 10^2$	<50	<50	<50

Fig. 6.1 Relative populations and distribution of oil-degrading bacteria in water samples from the Ekofisk-Bravo area 5 - 8 days after the blow-out.

Surface samples.

Areas of circles are approximately proportional to the total numbers of bacteria. Commonly used station numbers are assigned to each sampling position. Numerical values for population densities are given in Table 6.1.

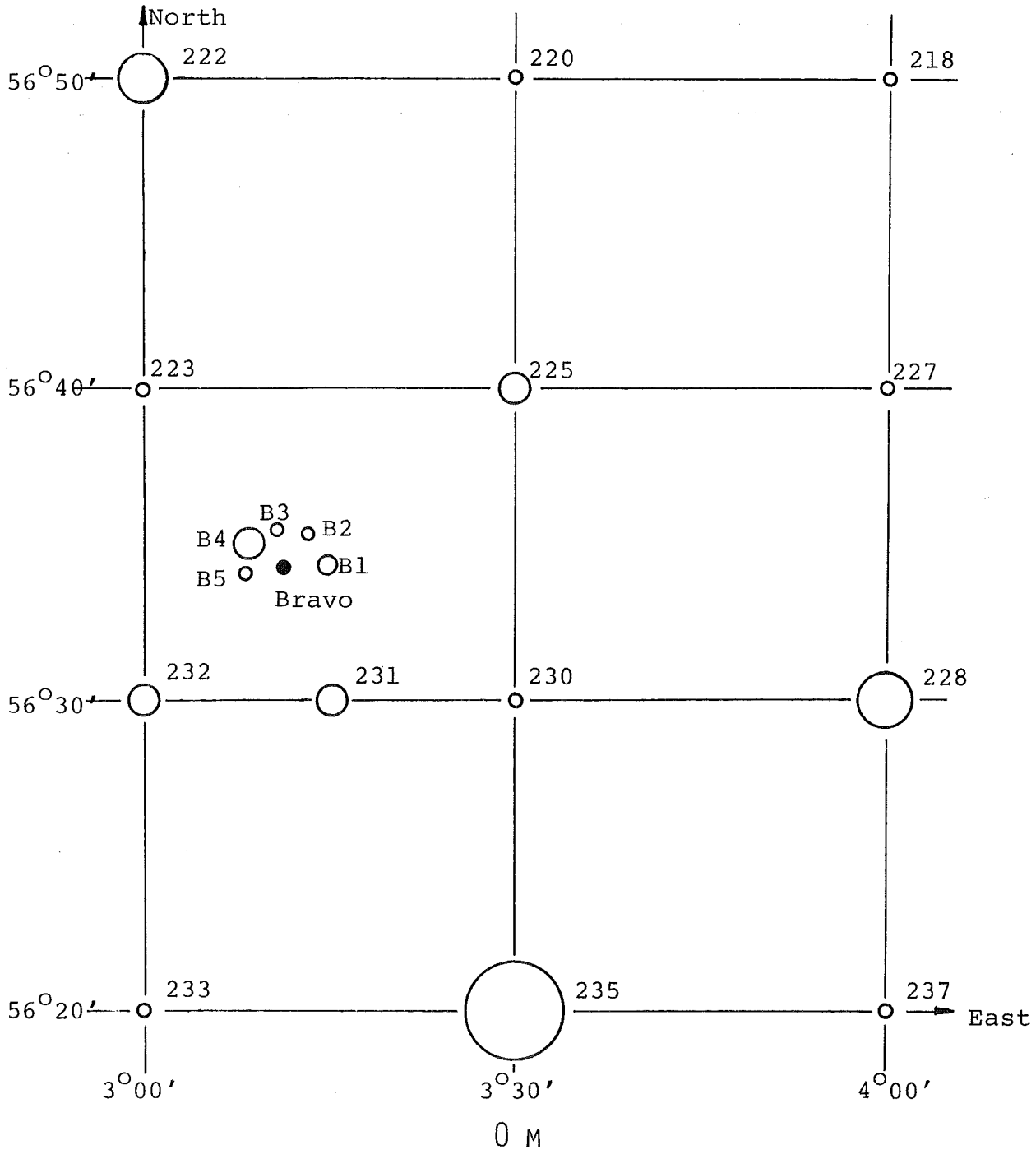


Fig. 6.2 Relative populations and distribution of oil-degrading bacteria in water samples from the Ekofisk-Bravo area 5 - 8 days after the blow-out.
Samples from 5m.
(See Fig. 6.1)

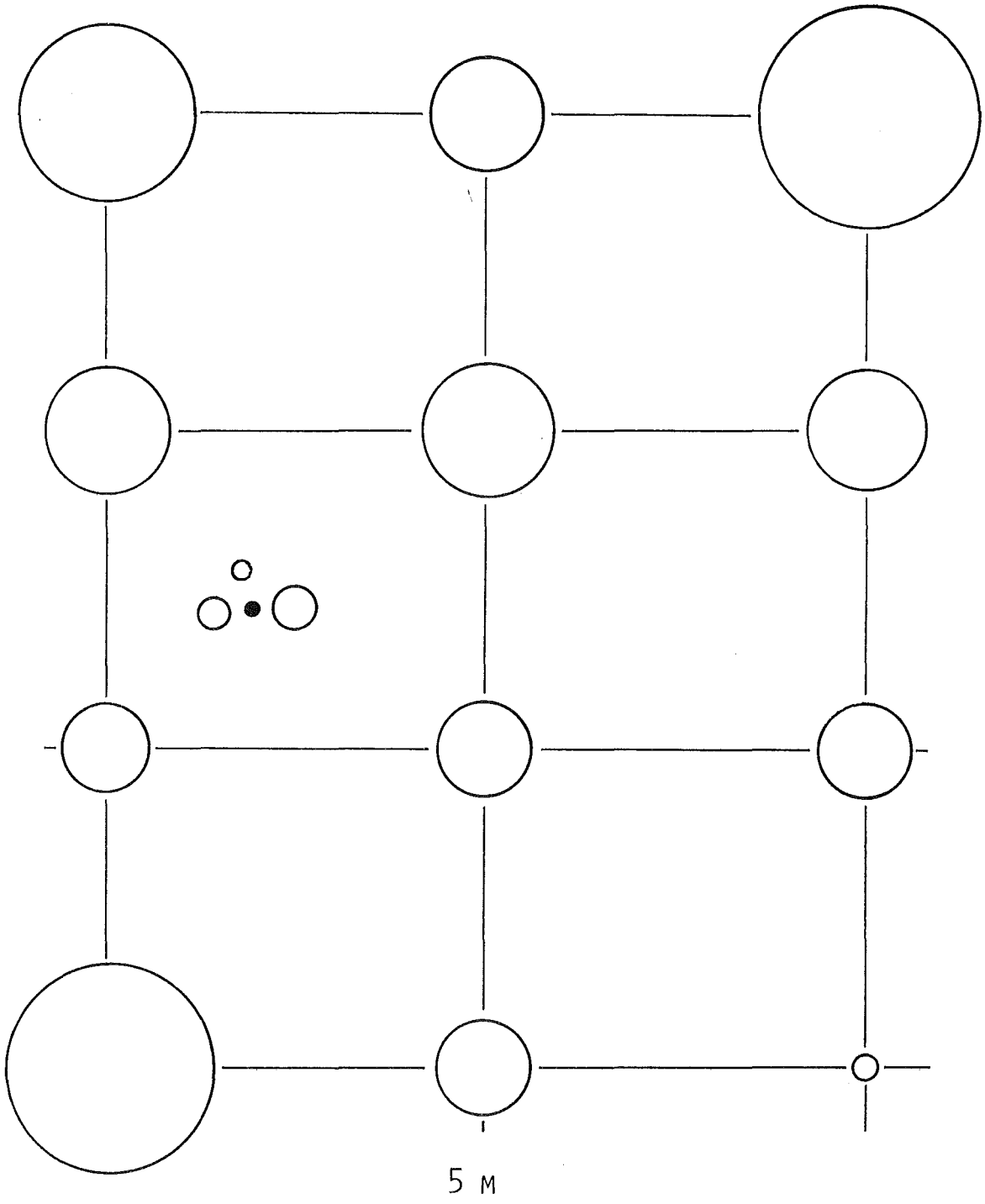
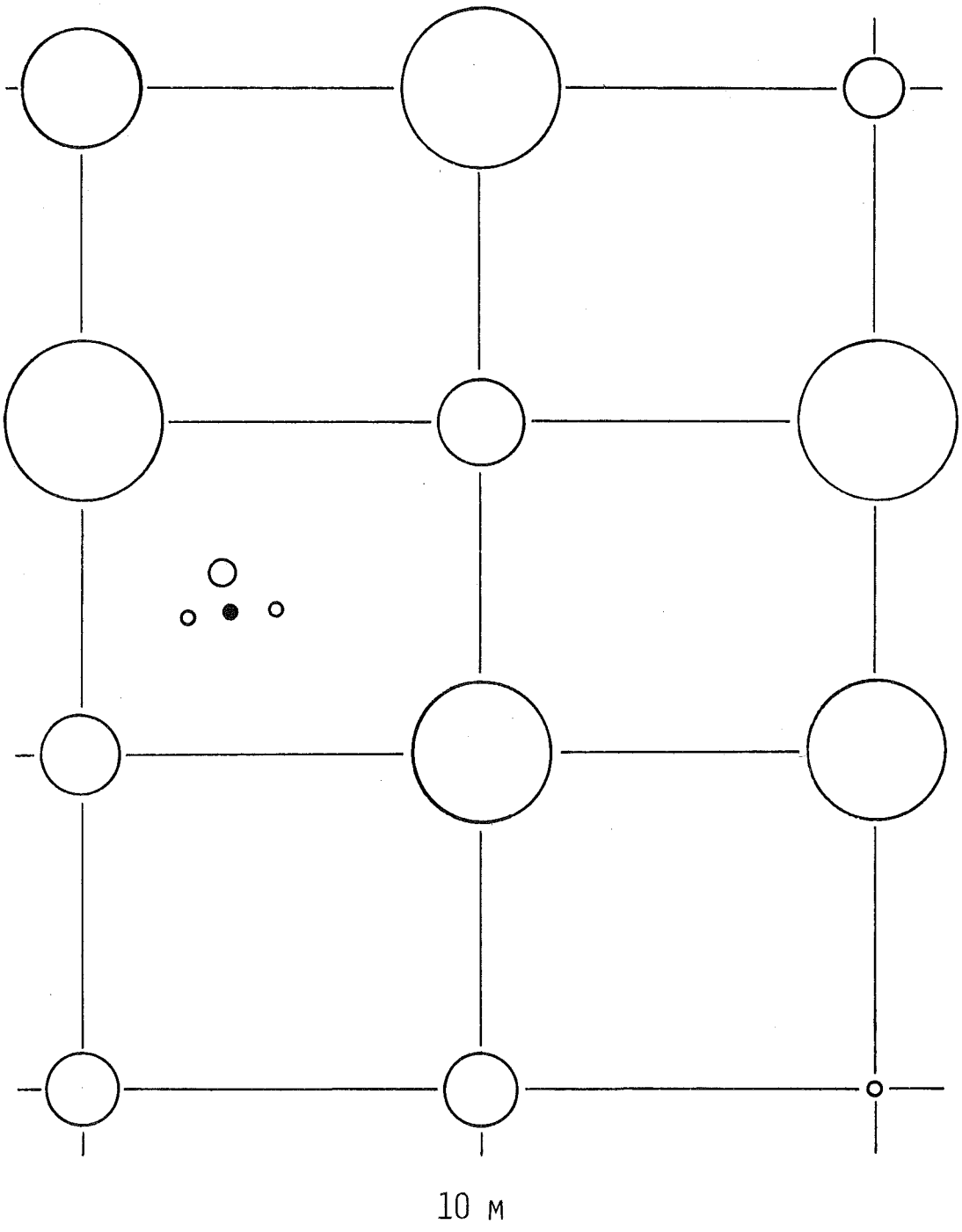


Fig. 6.3 Relative populations and distribution of oil-degrading bacteria in water samples from the Ekofisk-Bravo area 5 - 8 days after the blow-out.
Samples from 10m.
(See Fig. 6.1)



Discussion

The expedition was organised at short notice, and there was no time to make provisions for proper microbiological sampling, especially for the surface samples. However, both the results and various control experiments have shown that the improvised experimental scheme worked out very satisfactorily.

The numbers of oil degrading bacteria in the surface layer (0 - 20 cm) at different locations in the Ekofisk - Bravo area are presented in ig. 6.1. The observed populations were generally much smaller than one would have expected as normal for that time of the year. Earlier investigations in 1975 and 1976 by Gunkel, Oppenheimer, Pedersen and others (not yet published) have shown that a total of 10^3 - 10^4/l is a more common population level of oil-degrading bacteria at the surface in this area. Only exeptionally have as few as loo/l been recorded.

Figs. 6.2. and 6.3 give the bacterial counts at 5 and 10, respectively. The numbers of oil-degrading bacteria at these depths were observed to be much higher that at the surface. This observation was quite contrary to what we had observed during earlier investigations (Gunkel et al.), when our results showed the the bacterial count at 10 meters was roughly one order of magnitude lower that at the surface.

It is tempting to conclude that the oil film at the surface had had an inhibitory effect upon the microflora during the initial stages of the blow-out. This was possibly due to the high concentration of oil in the uppermost layers of the water nd/or a high concentration of especially toxic oil components. It is a common observation that crude oil has to be modified by exposure to sun and winds (that is "weathered") before it becomes susceptible microbial attack. In this process a major part of the volatile compounds dissappears, water soluble compounds may get lost, and the oil is possibly subjected to

photochemical modifications.

As these investigations were made in the close vicinity of the crude oil source, and furthermore were made just a few days after the blow-out, the weathering process may not have progressed very far. The oil may therefore have retained much of its original toxicity towards micro-organisms, even though extensive evaportation due to the high oil temperature was reported.

It should be noted that the low microbial counts observed during the present investigation may have been due to the temperature beeing lower than that under which higher counts were observed by Gunkel et al 12^{o}-14^{o}). It is evident from the results however that the conditions for microbial growth in the water masses were far more favorable at depth. This seems to indicate that the concentration of oil, or rather its specific components, was more suitable for microbial growth at 5 and 10.

It appears to the author to be of minor value to discuss the details regarding the horizontal population pattern without having a detailed knowledge of water currents and other important physicals and chemical parameters. One can, however, state that although there was a tendency towards a decreasing population level with increasing depth, there were no major quantitative differences between the populations of oildegrading micro-organisms at 5 and 10. As the chemical analyses have shown (Grahl-Nielsen), the vertical gradient of oil components from 1 to 10 in the same area was not especially pronounced either.

The present results, showing a markedly reduced population at the surface compared to the levels at 5 and 10, could be explained by assuming that most of the oil had been confined to the surface and the uppermost 10 to 20 cm water layer. This was probably due to the unusually calm weather during the investigation period, when no extensive vertical oil transport took place.

One can, however, put forward other possible explanations for the low surface population of oildegrades. One of these would be that other heterotrophic organisms were predominant in the surface layers, and that these had exhausted the scarce quantities of phoshporus and/or nitrogen, and thereby made growth conditions unfavorable for oil-degrading bacteria.

Another possibility is related to the prevailing water currents. A fast exchange of water at the surface compared to the lower water layers may have given the oil degrades at a certain depth ample time for extensive growth compared to the bacteria in the upper layers. Here, the only recent addition of carbon and energy (crude oil) may have caused bacterial degradation to be still in its initial phase.

At the moment it seems at bit far fetched to relate possible gradients of oxygen, temperature, nutrients etc. to these simple observations, and on the basic of these parameters try to construct plausible explanations for the results reported.

However, ad Figs. 6.1 - 6.3 clearly show, there was an extremely low population of oil degraders in the close vicinity of the Bravo platform at all depths soon after the blow-out. This observation seems to support the statement that the crude oil had had an immediate inhibitory or growth limiting effects upon oil-degrading micro-organisms present in the surrounding waters.

We also know that some quantities of dispersal agents were used close to the platform. This was done during the first days after the blow-out in order to minimize the explosion danger. Most of these chemicals were potent bacteriocides. The use of such agents may thus have had a general negative effect upon life in the affected water masses, and this could be an alternative explanation for the low level of oil-degrading bacteria in water near the platform.

The oil-degrading fungi showed a far less consistent propagation pattern than the bacteria (Table 6.1). It is the belief of the author that this was due to the short interval between the accident and the time of the investigations; fungi generally require more time for proper growth than bacteria.

7. Microbial counts in the EKOFISK area of the North Sea.

Geir Indrebø, Ian Dundas
Department of General Microbiology
University of Bergen

After the BRAVO blow-out two Norwegian microbiologists were invited by Dr. W. Gunkel from Biologische Anstalt Helgoland to participate in a cruise with the research vessel "Friedrich Heincke". Their participation was funded by the Norwegian Program for Research on Marine Pollution and their project was to assess microbial numbers by direct fluorescence microscopy of acridine orange stained and filtered water samples. Samples of the surface water were taken with a skimming device designed by C. Oppenheimer. Sub-surface samples were taken with sterile modified ZoBell samplers. The samples were also analyzed by other members of the expedition in relation to other microbiological and chemical parameters. The results thus obtained are to be compared with data obtained in 1975 and 1976 from the same sampling stations. The results will be published by the Biologische Anstalt Helgoland. The microbial counts obtained are given in Table 7.1.

The observed microbial counts were fairly normal. It may be that the lower counts correlated with hydrocarbon pollution (visible amounts of "granulated oil mousse" floating on surface at station 18/77), but the observed variations could easily have been due to other factors. A more detailed analysis of these results is impossible until correlating analytical data from the same water samples becomes available.

Table 7.1.

Date	Station position		Station number	Sample depth	Microbial counts as cells /ml seawater
12/5 -77	55°12'N	05°00'E	3/77	surface	$2,5 \times 10^6$
"	"	"	"	10	$2,3 \times 10^6$
"	55°48'N	04°00'E	6/77	surface	$1,0 \times 10^6$
"	"	"	"	2	$1,2 \times 10^6$
"	"	"	"	10	$8,3 \times 10^5$
13/5 -77	57°00'N	05°30'E	9/77	surface	$2,2 \times 10^6$
"	"	"	"	2	$1,9 \times 10^6$
"	"	"	"	10	$1,2 \times 10^6$
"	57°00'N	04°00'E	11/77	surface	$9,7 \times 10^5$
"	"	"	"	2	$9,2 \times 10^5$
"	"	"	"	10	$9,5 \times 10^5$
14/5 -77	57°20'N	03°25'E	18/77	surface	$4,2 \times 10^5$
"	"	"	"	2	$4,2 \times 10^5$
"	"	"	"	10	$3,7 \times 10^5$
"	57°00'N	02°51'E	19/77	surface	$7,8 \times 10^5$
"	"	"	"	2	$5,4 \times 10^5$
"	"	"	"	10	$1,0 \times 10^6$
15/5 -77	56°46'N	02°00'E	21/77	surface	$4,6 \times 10^5$
"	"	"	"	2	$6,5 \times 10^5$
"	"	"	"	10	$5,4 \times 10^5$
"	56°00'N	02°00'E	23/77	surface	$1,3 \times 10^6$
"	"	"	"	2	$9,2 \times 10^5$
"	"	"	"	10	$8,7 \times 10^5$

8. Phytoplankton and primary production investigations

by

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The present report is based on a series of observations made in the Ekofisk area before, during and after the Bravo blow-out (Figs. 1.1 - 1.6). A summary of the sampled material has already been given (Institute of Marine Research, 1977).

The main purposes of these investigations were to describe the distribution of phytoplankton and its primary production and to follow its development over time, together with an attempt to detect and evaluate possible effects of oil on the phytoplankton community.

Methods.

Samples for determination of phytoplankton standing stock, primary production and nutrients were obtained from 0, 5, 10, 20 and 30 m depth levels with Niskin water samplers.

Surface water was sampled at every station for determination of particle size frequency distribution and for phytoplankton species composition.

Secchi depth was determined at every day station. Underwater irradiance measurements were made with a Lambda quantameter at a few stations.

Continuous recordings of chlorophyll in vivo fluorescence were made with a Turner 111 fluorometer.

Aboard, 290 ml samples for pigments determination were filtered through 0,45 um membrane filters in the presence of $MgCO_3$. After filtration the filters were dried and frozen at -10°C until analysis. Samples for primary production had 1 ml $NaH^{14}CO_3$ solution with an activity of 4 uC added and were then incubated for about 4 hours under fluorescent light (Philips TL 40 W/57, 60 10^{14} quanta $cm^{-2} sec^{-1}$) at in situ temperature. After incubation the samples were filtered through 0.45 um membrane filters and dried until analysis.

Ashore, chlorophyll a and phaeopigments were extracted in 90% acetone and measured in a fluorometer. The radioactivity of the primary production filters was measured by liquid scintillation. Nutrients were measured in an auto-analyzer.

The situation before the blow-out (15 - 26 March 1977).

Surface phytoplankton biomass along a transect at 57°N was very low and typical of the winter season with chlorophyll a values lower than 0,3 $mg \cdot m^{-3}$. North-east from the Ekofisk area towards the Norwegian coast, chlorophyll a concentrations were of the same magnitude ($< 0,3$ $mg \cdot m^{-3}$) until about 40 - 50 nautical miles from the coast, where a strong gradient of chlorophyll a was observed, reaching its highest values close the coast ($> 4,0$ $mg \cdot m^{-3}$). This pattern of chlorophyll a distribution agreed very well with the observed hydrography of the region (see page). The low chlorophyll a values were found in areas of strong vertical convection, characterized by high nutrient concentrations. In contrast, the high chlorophyll a concentrations near the Norwegian coast were related to the less saline water masses dominating the surface layers of the Norwegian Coastal Current in this period, causing a very strong pycnocline and thus allowing an early development of the spring phytoplankton bloom. Surface nutrient concentrations in this area were very low.

The situation during the blow-out (24 - 30 April 1977).

Immediately after the start of the blow-out a rapid survey of surface chlorophyll a close to the Bravo platform showed a patch of high concentration a few miles to the south of the platform (Fig.8.1). During the following days this patch moved slowly towards the east, along 56°30'N (Fig.8.2). The relatively high concentrations of chlorophyll a, together with the already present dominance of diatoms in the phytoplankton community, suggest that this patch originated before the start of the blow-out.

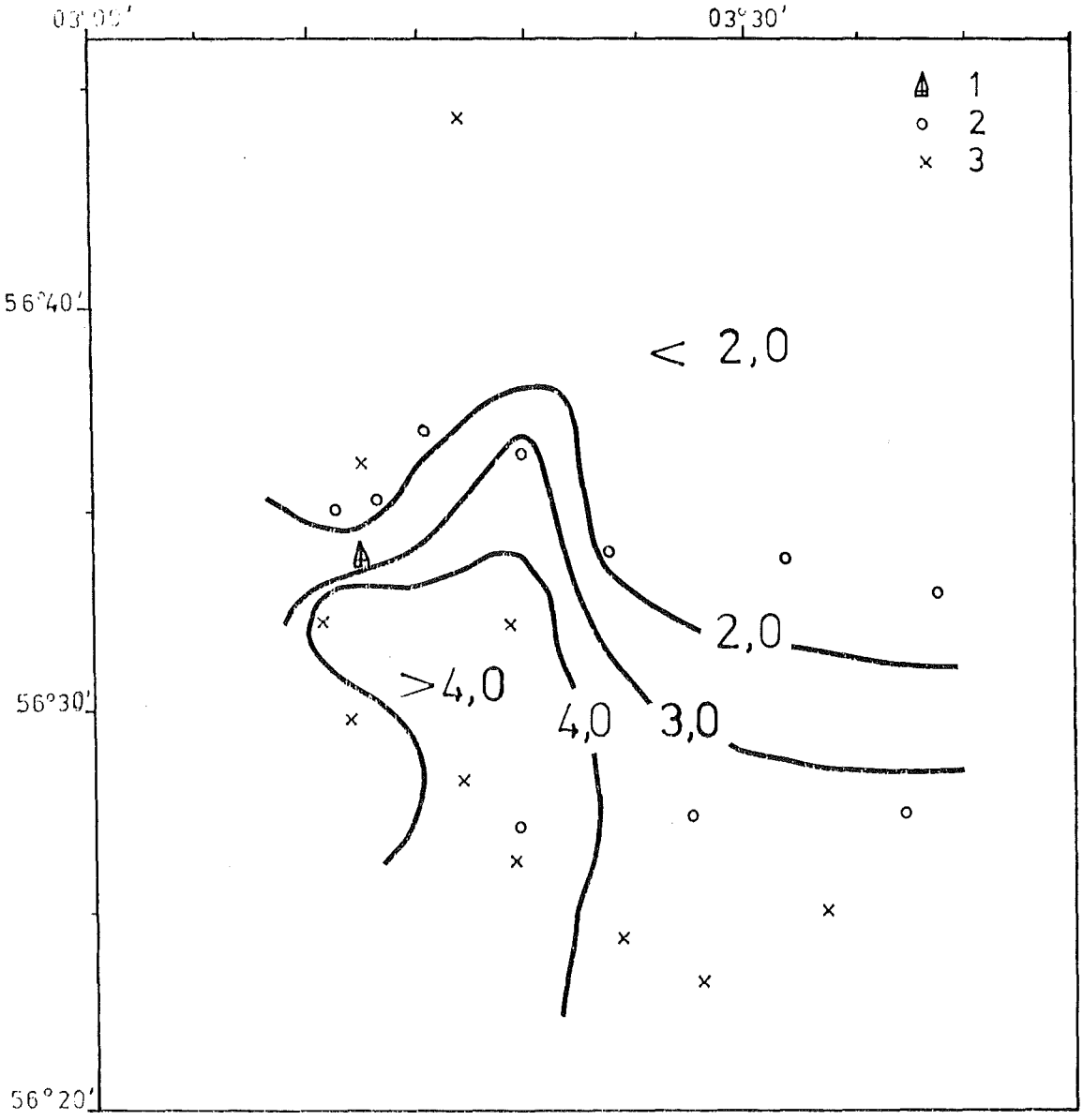

Fig. 8.1 Surface distribution of chlorophyll a . 24 -25 April. ($mg\ m^{-3}$). 1 : Bravo platform. 2: 24 April. 3: 25 April .

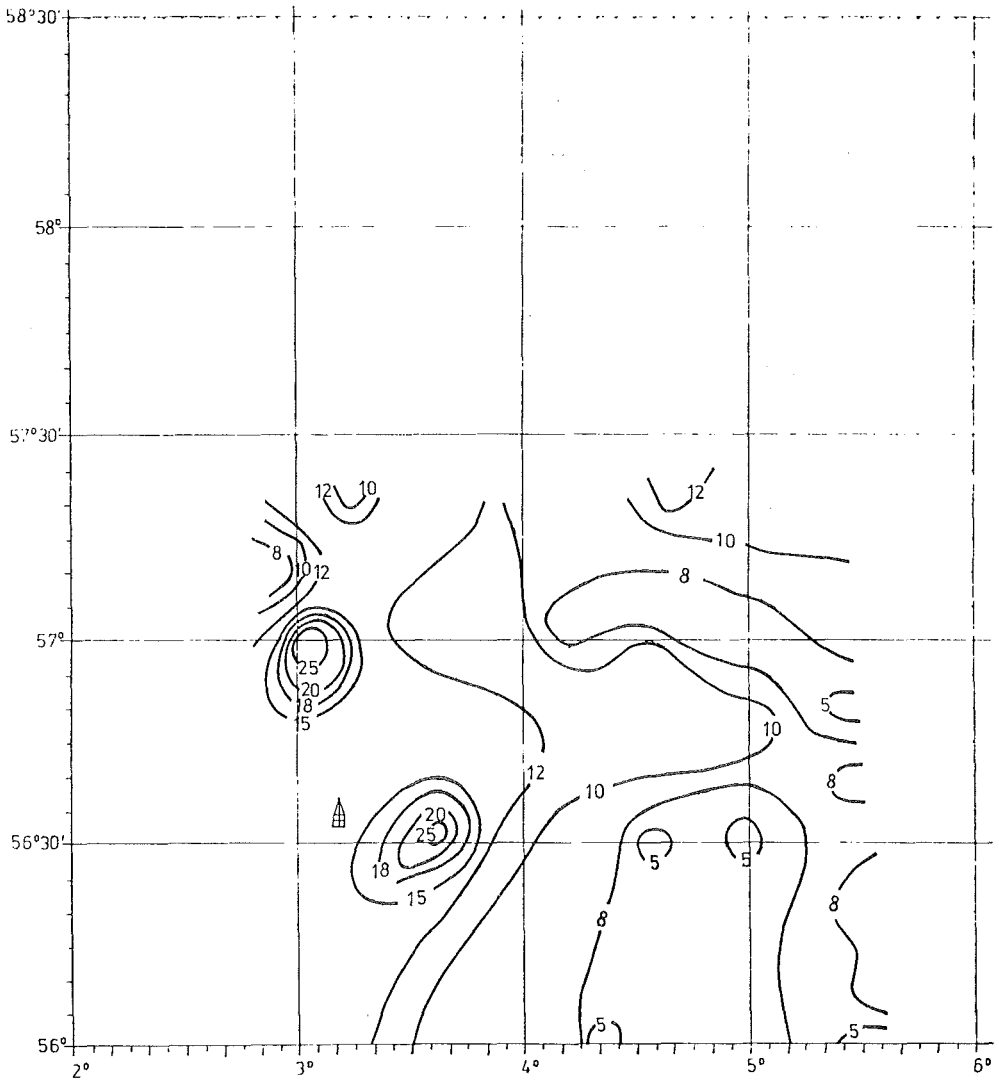

Fig. 8.2 Horizontal distribution at 5 m of relative chlorophyll in vivo fluorescence. 27 April - 1 May.

In the rest of the investigated area the standing stock was relatively low (from 0,55 to 3,78 mg chlorophyll a m^{-3}). The phytoplankton was rather uniformly distributed with some patches of higher concentrations changing locations in the subsequent surveys, obviously caused by physical transport of the water masses.

The vertical distribution of the phytoplankton standing stock was also uniform from surface to about 20 m depth, and from there on decreasing rapidly to 30 m.

Large diatoms were dominant especially Rhizosolenia hebetata var. semispina, Chaetoceros convolutus and Thalassiosira sp. Dinoflagellates was the second dominant group, while flagellates occurred in very low concentrations.

Primary production rates per unit of light followed roughly the same pattern as the phytoplankton standing stock and were generally medium high and somewhat delayed in relation to what is normal for that time of the year (from 6.0 to 42 µgC x m^{-3} x 10^{17} quanta x cm^{-2} x hr^{-1}).

Normally during the spring bloom in the North Sea phytoplankton standing stock can easily exceed 5 mg chlorophyll a m^{-3} and, production rates can be higher than 20 - 25 ugC m^{-3} 10^{17} quanta cm^{-2} hr^{-1}.

Nutrient concentrations (nitrate, phosphate and silicate) were generally medium low. A tongue-like distribution with a center of high concentrations was observed in the western region of the investigated area, just north of Ekofisk (Figs. 8.3.-8.5). This distribution agreed very

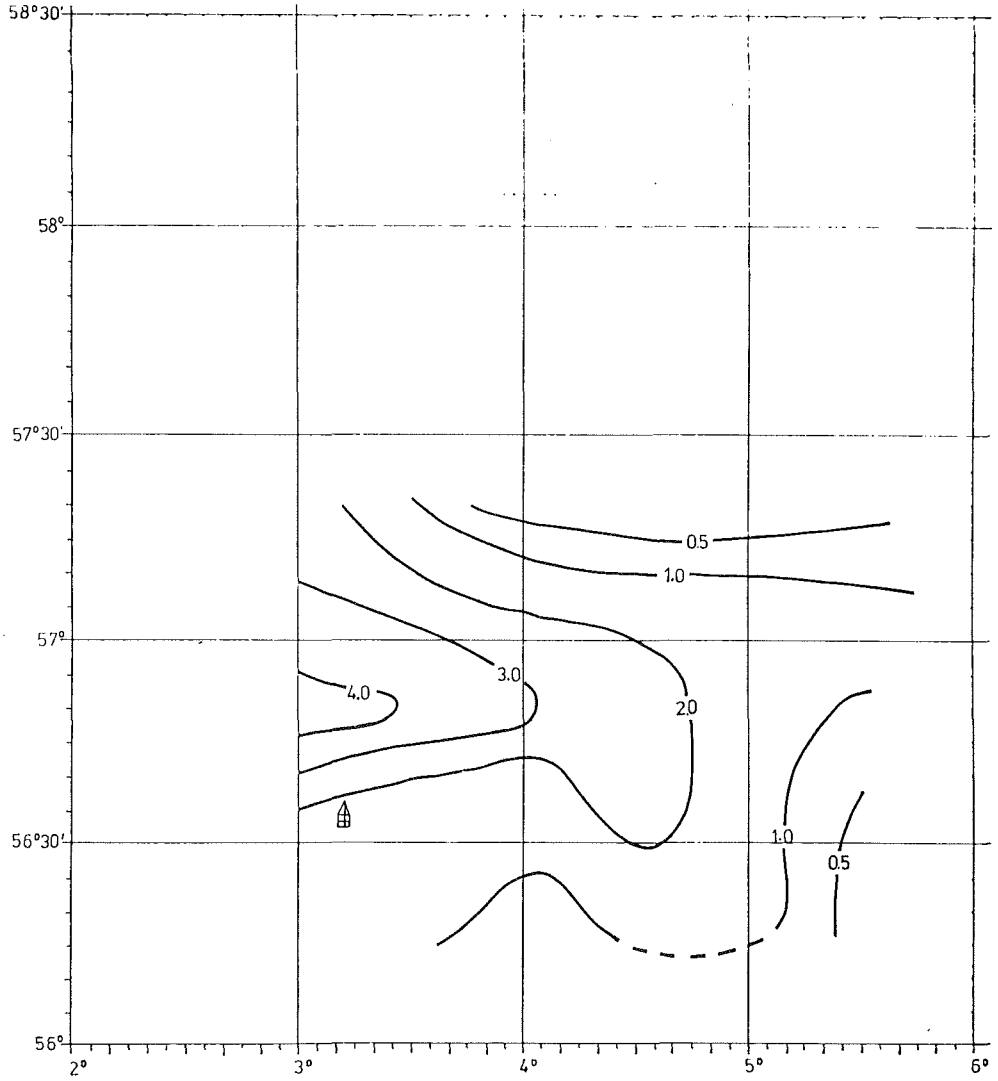

Fig.8.3. Surface distribution of nitrate. 27 April - 1 May. (in µg - at · l^{-1})

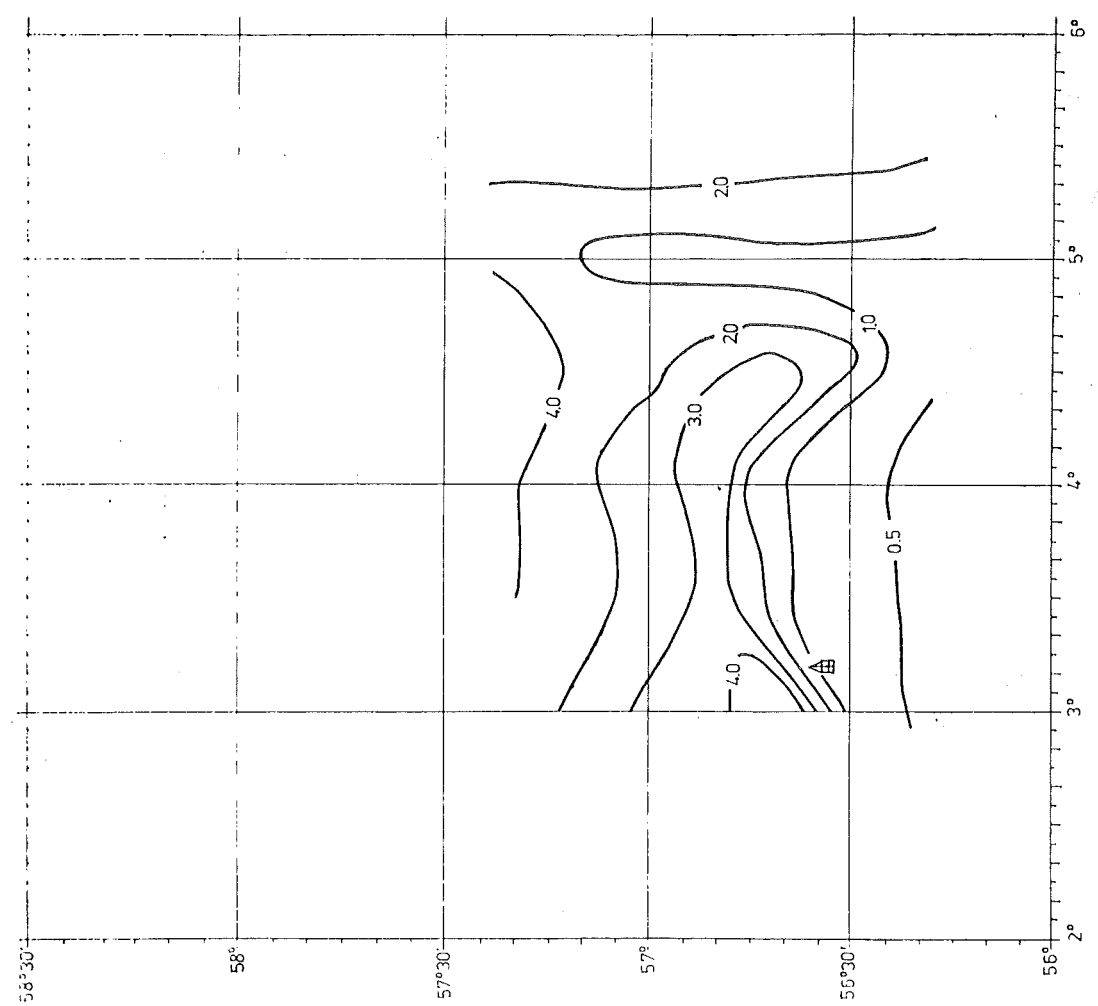

Fig. 8.5. Surface distribution of silicate. 27 April - 1 May. (in μg-at $\cdot$ l^{-1}).

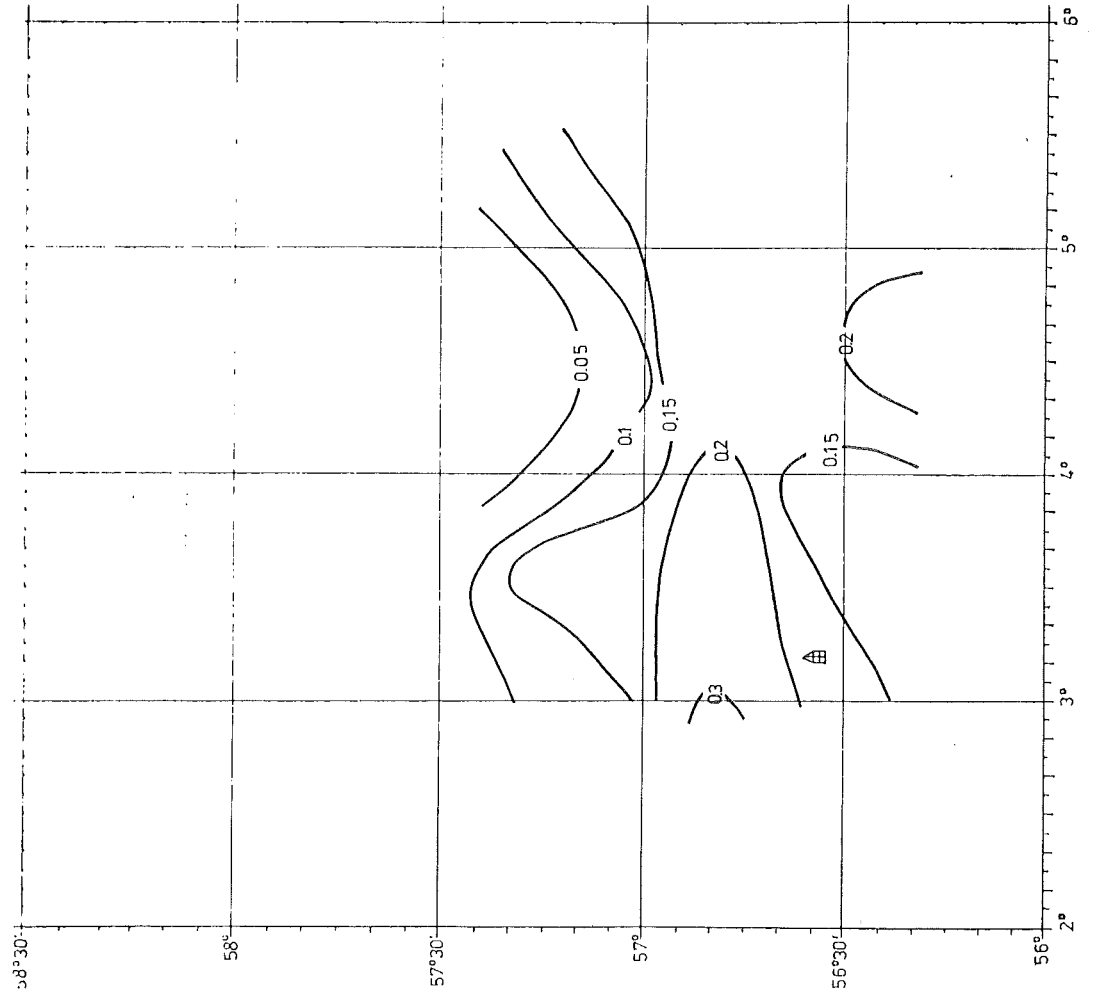

Fig. 8.4. Surface distribution of phosphate. 27 April - 1 May. (in μg-at $\cdot$ l^{-1}).

well with the existence of a core of cold water probably locally formed in winter, which indicated an eddy. Vertical stability was very low and nutrients were evenly distributed with depth. To the north-east of the core surface nutrients decreased quite rapidly as a different water mass became dominant in this area. This water mass of lower salinity and relatively high temperature was typical of the coastal water mass where the spring bloom of phytoplankton had already taken place.

These results indicate that the spring bloom of phytoplankton around Ekofisk had started, before the blow-out but with a rather medium growth rate. presence of an eddy and the low stability of the water masses resulted in convections from surface to bottom and this situation explains why the standing stock of phytoplankton was kept rather low. The horizontal distribution of phytoplankton was closely related to the hydrographic conditions. On the whole, the situation indicates an early stage in the typical spring development of phytoplankton.

The situation immediately after the blow-out. (1-4 May 1977).

The phytoplankton standing stock was still relatively low, although a slight increase was generally observed. The patchy horizontal distribution was the same, but with a displacement towards the east especially north of Ekofisk (Fig. 8.6.). Vertical distribution of the phytoplankton was again uniform down to about 20 m and decreasing rapidly from there to 30 m.

Diatoms were on the whole still dominating the species composition of the phytoplankton.

Primary production rates per unit of light were slightly higher than during the previous period.

Low vertical stability of the water masses forming the eddy, caused a relatively uniform vertical distribution of nutrients, but surface concentrations were much lower than before, especially in the western part of the area, and the tongue-like distribution tended to disappear (Figs 8.7 - 8.9).

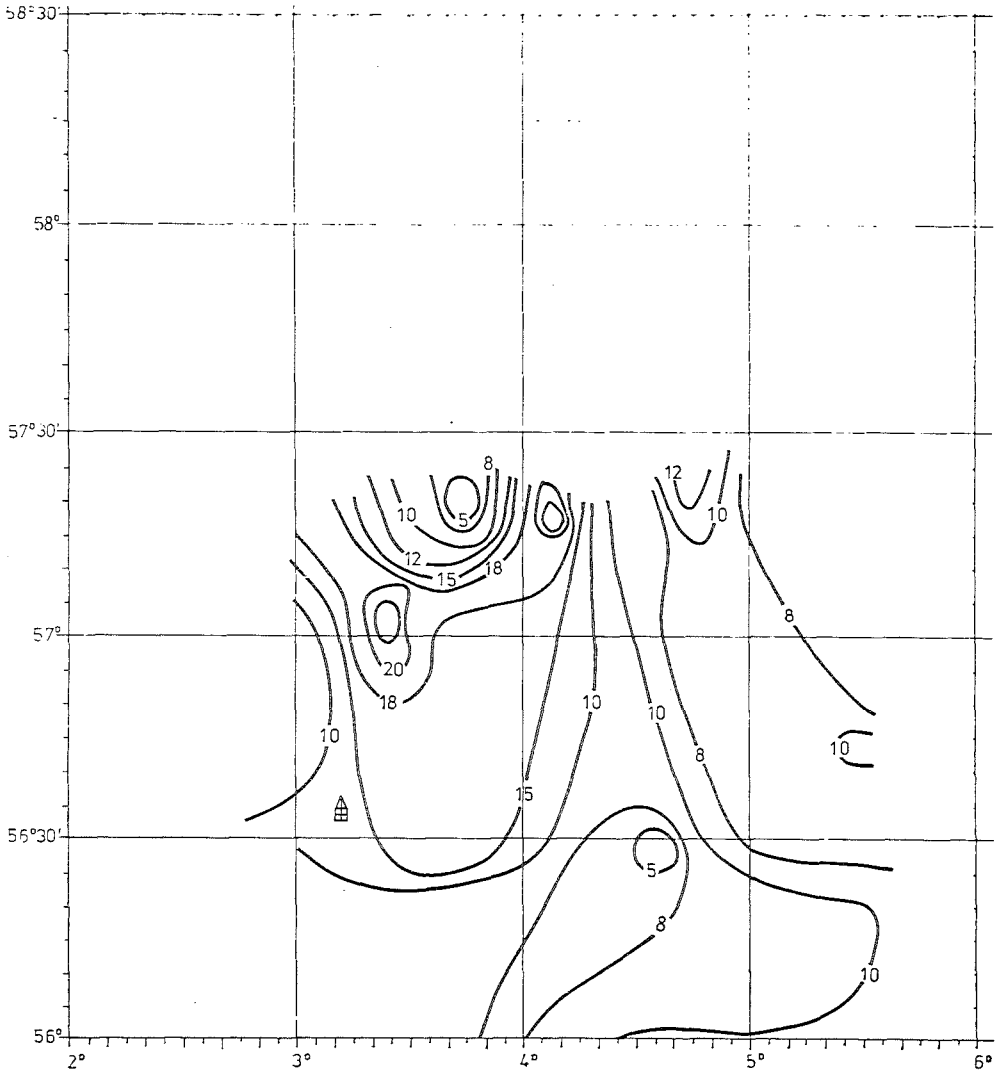

Fig. 8. 6 Horizontal distribution at 5 m of relative chlorophyll in vivo fluorescence. 1 - 4 May.

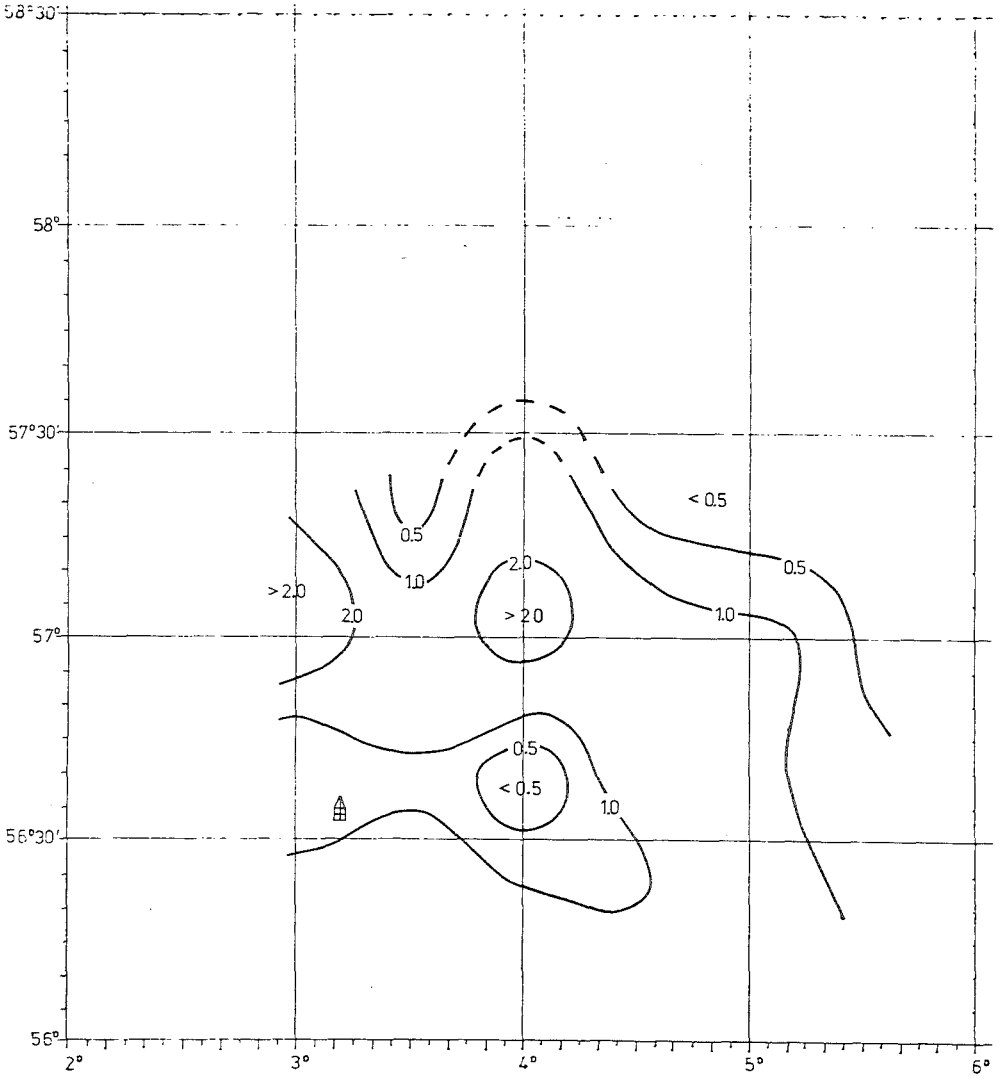

Fig. 8. 7. Surface distribution of nitrate. 1 - 4 May. (in $\mu g\text{-at} \cdot l^{-1}$).

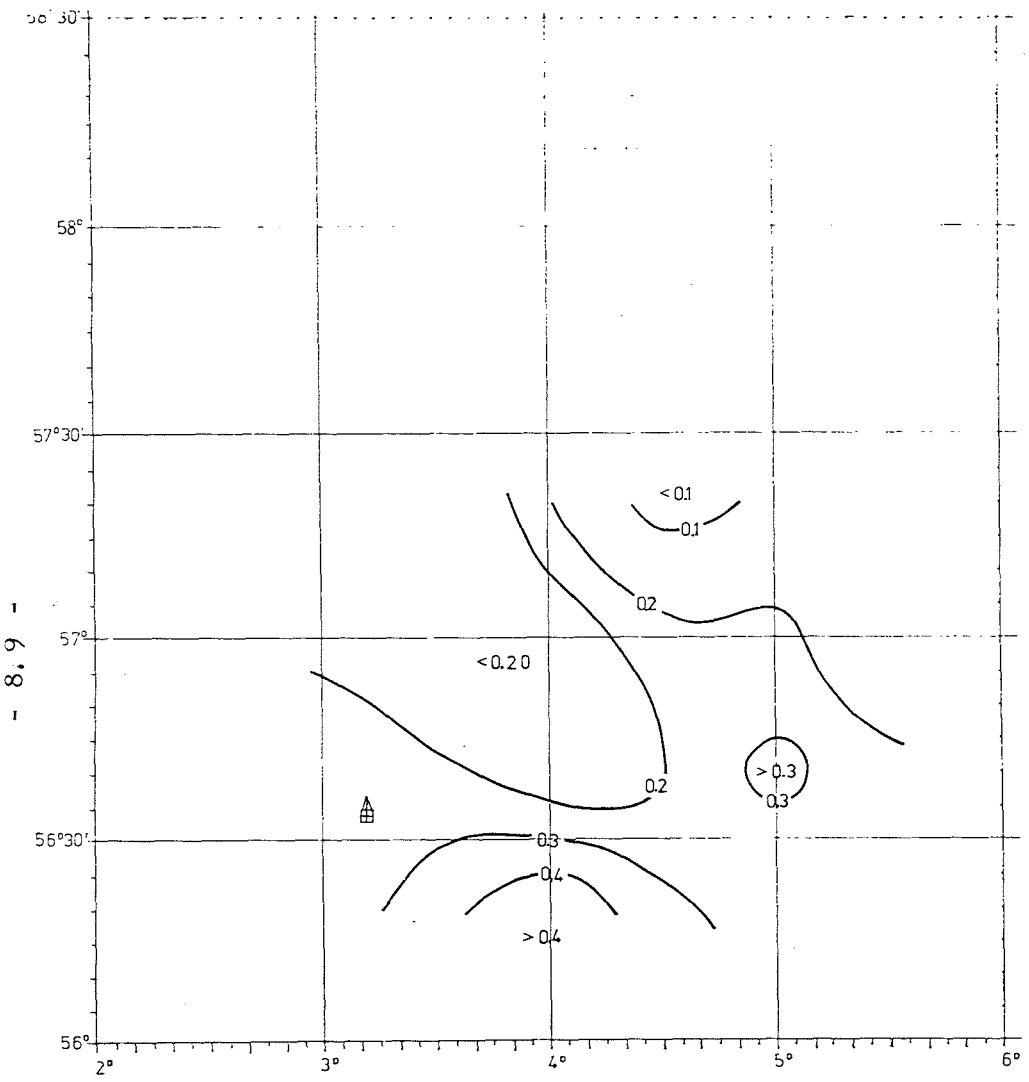

Fig. 8.8. Surface distribution of phosphate. 1 - 4 May. (in μg-at·l^{-1}).

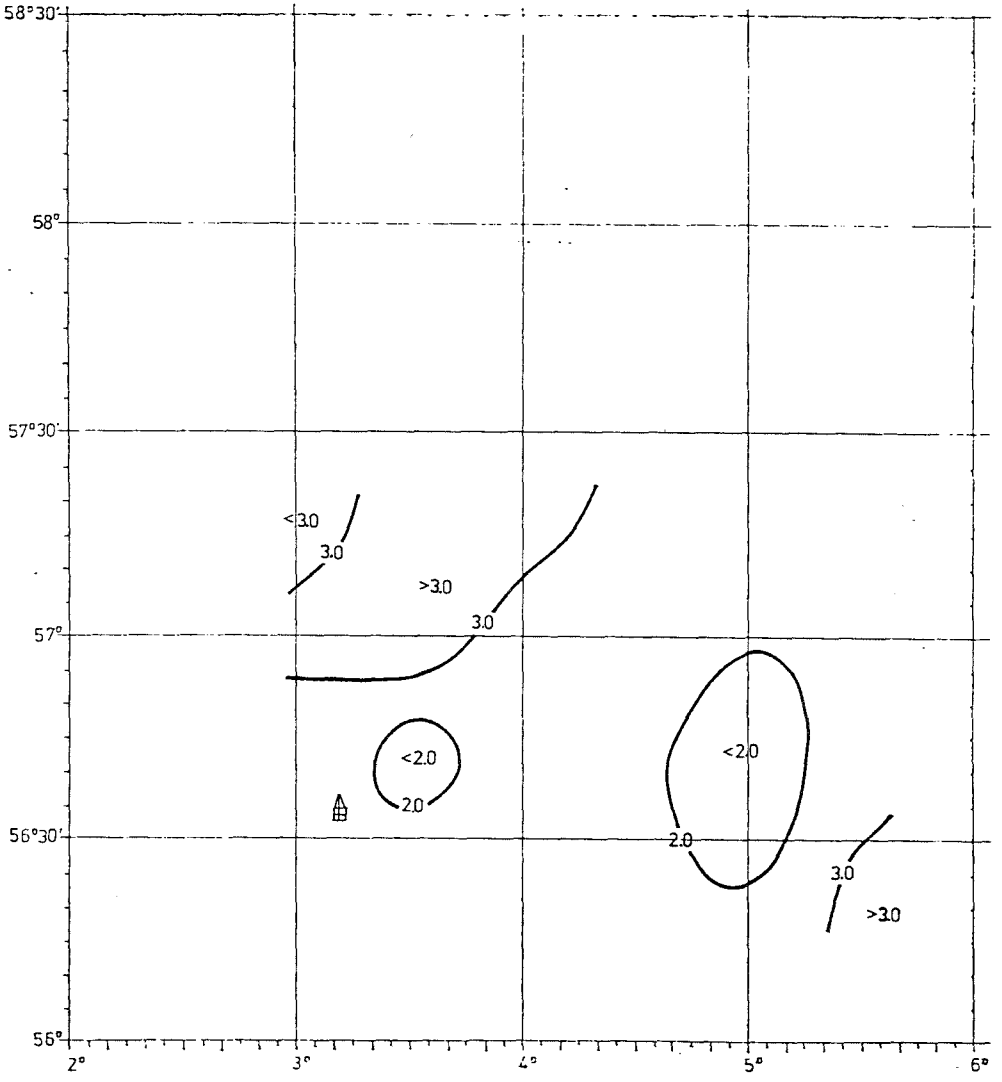

Fig. 8.9. Surface distribution of silicate. 1 - 4 May. (in μg-at·l^{-1}).

As a whole the situation can be described as a continuation in the development of the spring phytoplankton bloom with a rapid uptake of nutrients by phytoplankton but without this being reflected in an explosive growth. Loss of energy due to the large vertical convection still remains the main explanation for the observations. An eastward drift of the phytoplankton communities was evident and was obviously connected with the surface water movements.

The situation two weeks after the blow-out 10 - 15 May 1977.

The horizontal distribution of phytoplankton was more or less similar to that of the previous cruise as regards the slow eastwards drift and the levels of chlorophyll a concentrations. However, the patches now had a wider distribution, suggesting that the spring bloom of phytoplankton was reaching its climax (Fig. 8.10.). A new patch of high chlorophyll detected in the northwest corner of the investigated area was possibly a local and limited bloom.

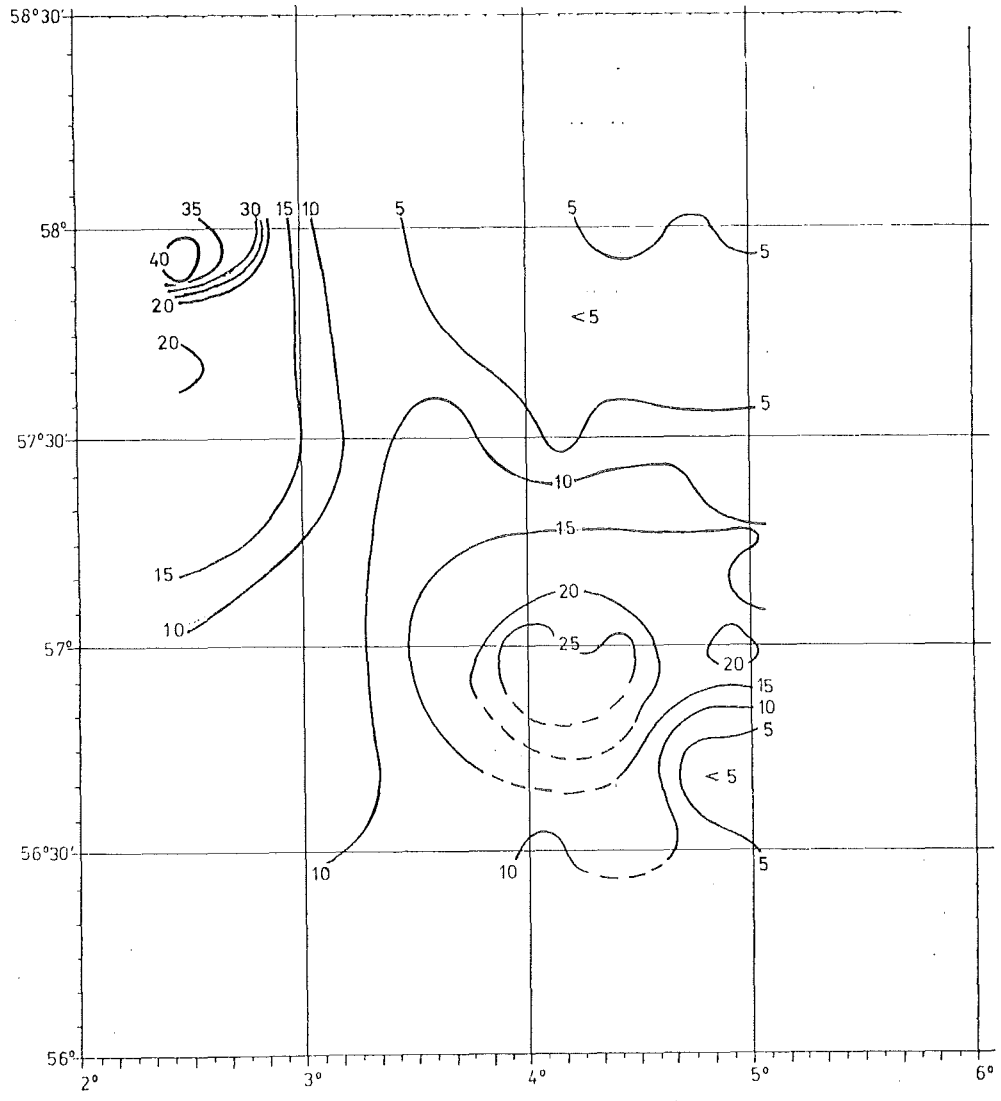

Fig. 8.10. Horizontal distribution at 5 m of relative chlorophyll in vivo fluoroscence. 10 - 15 May.

Vertical distribution of chlorophyll remained quite uniform with depth, and at several stations high chlorophyll concentrations were found as deep as 30 m.

Primary production rates were of the same order of magnitude as on the previous cruises, with exception of a patch in the north-west corner of the investigated area where very high rates were observed (as high as 40 $\mu g\ C \cdot m^{-3} \cdot 10^{17}$ quanta $\cdot cm^{-2} \cdot hr^{-1}$).

Nutrient concentrations were very low, reaching levels where phytoplankton growth limitation is possible (Figs. 8.11 - 8.12).

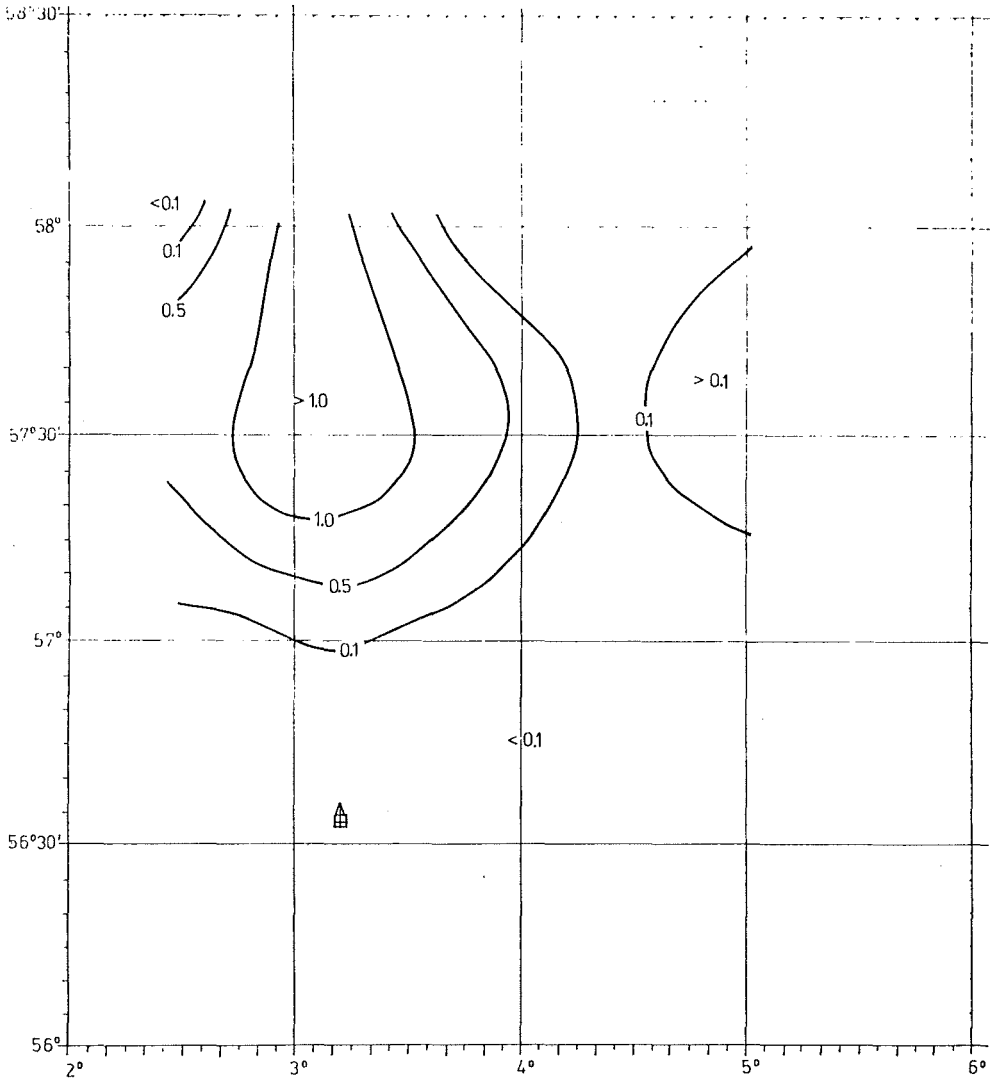

Fig. 8.11. Surface distribution of nitrate. 10 - 15 May (in μg - at $\cdot l^{-1}$).

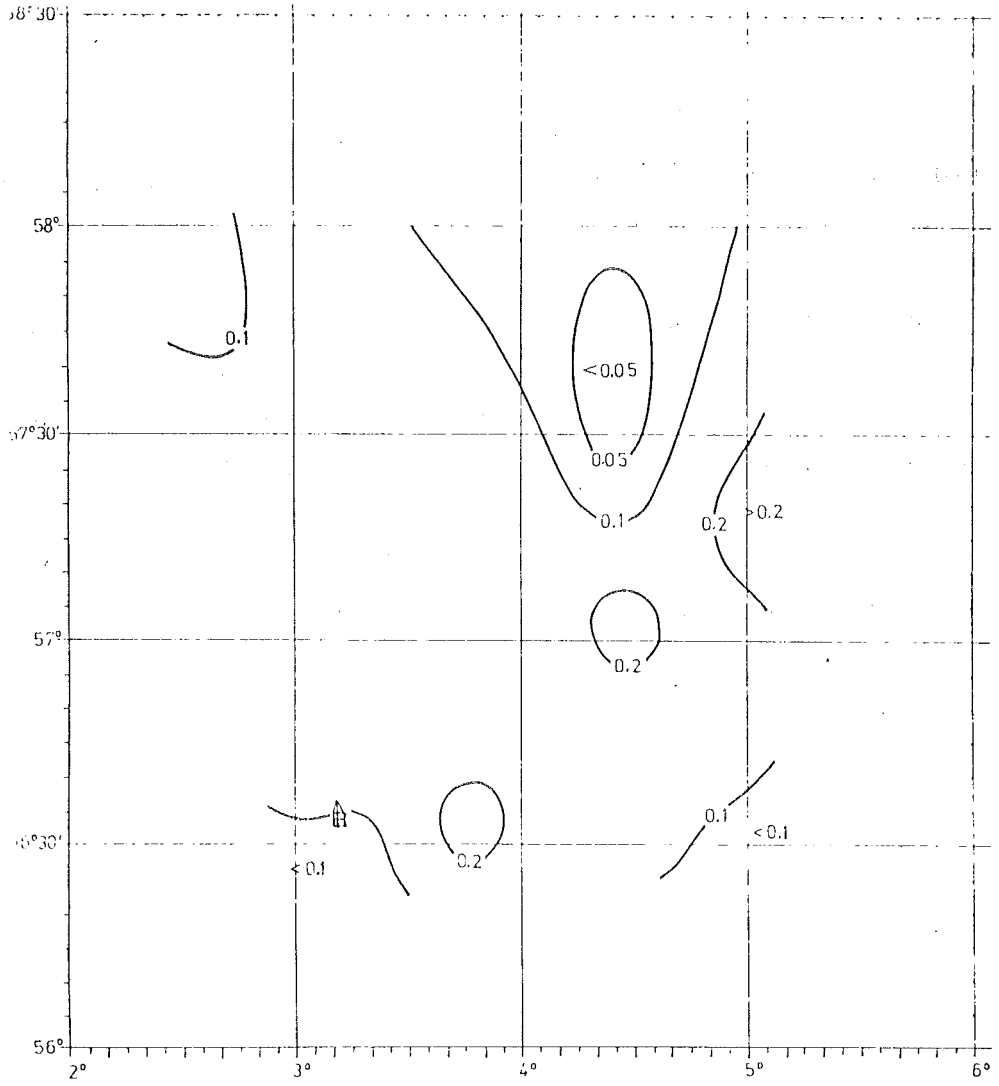

Fig. 8.12. Surface distribution of phosphate. 10 - 15 May (in ug - at l^{-1}) .

The formation of a thermocline between 20 and 30 meters depth was observed over a major part of the investigated area, thus creating better conditions for phytoplankton growth. However, the already low nutrient concentrations apparently did not permit the explosive growth that could otherwise have been expected.

Samples for species composition of the phytoplankton have not yet been fully analysed, but selected observations indicate that diatoms still dominated the phytoplankton communities during this part of the investigation period. In the southern part of the area, Phaeocystis was observed at some stations.

The situations one and two months after the blow-out (June and July 1977.)

Point sampling at different areas in the North Sea in June and July showed that the overall phytoplankton standing stock had reached its typical summer levels, with chlorophyll a concentrations lower than 0,5 $mg \cdot m^{-3}$. Only at a few locations close to the Norwegian coast was it possible to observe higher concentrations.

Samples for analysis of species composition of the phytoplankton were also taken, but have not yet been analysed.

The sequential observations from March 1977 to July 1977 demonstrate that the accident occurred in a period when the characteristic spring bloom of phytoplankton was just in its initial stages. A core of cold water around the Ekofisk field, combined with very low stability of the water masses and strong vertical convections created conditions for delayed development of the spring diatom bloom. The loss of energy produced at the surface by the diatoms to depths below the photic zone (about 20 - 25 m) together with the relatively lower growth rate of the large diatoms, explains the rather moderate development of the spring bloom in the subsequent investigion periods. Usually, the spring bloom in this area rises in March, peaks in April, and then dies away in June (CUSHING, 1973). In 1977 the spring bloom was considerably delayed and lasted a month, starting just before the blow-out and reaching its maximum during the second - third week of May. The chlorophyll concentrations and the primary production rates reached only moderate levels, significantly lower than what has been observed in previous years. However, the long duration of the spring bloom may have compensated for the moderate production in the annual production budget.

Production indices in the oil polluted area.

The production index (P.I.), as used in the present report, is computed as primary production rates per unit of biomass and light intensity, and it is considered as a factor independent of the phytoplankton biomass and variations in light energy. It will, in general, reflect the environmental conditions of a given area. This factor can be invluenced by several other natural parameters such as zooplankton grazing, nutrient availability and species composition, but in a given situation it can be used as an indicator of the physiological stage of the phytoplankton community.

During the Bravo blow-out, production indices were computed at several depths at almost every station during each of the three cruises from 27 April to 15 May. In an attempt to detect any variation in the production indices in areas where oil in form of a slick or thin film has or has not been sighted, an elementary statistical processing of the data was carried out. The results are listed in Table 8.1. On application of statistical tests no significant differences were found between P.I. values at the same depth from the two areas ($P < 0,05$). This indicates that average P.I. values from supposedly polluted waters were not statistically different from those of non-polluted areas. Neither were there significant differences between P.I. values from 0, 5, 10 and 20 m during all cruises ($P < 0,05$). However, slight differences between P.I. values from 20 m and 30 m ($0,1 < P < 0,05$) indicated the relatively poorer conditions of phytoplankton in the deeper parts of the photic zone.

Table 8.1. Production indices (P.I.) during the different cruises in areas where oil was and was not sighted.

Period	Depth m	All stations				Stations in the area where oil was sighted				Stations in the area where oil was not sighted.			
		$\bar{P.I.}$ x)	n	s	c.v. %	$\bar{P.I.}$ x)	n	s	c.v. %	$\bar{P.I.}$ x)	n	s	c.v. %
27 April-1 May	0	7,83	26	2,25	28,7	7,64	19	2,37	31,0	8,37	7	1,91	22,8
	5	8,91	25	2,80	31,4	9,07	18	3,03	33,4	8,55	7	2,31	27,0
	10	8,86	26	3,39	38,3	8,23	19	2,58	31,4	10,50	7	4,83	46,0
	20	8,02	26	2,66	33,2	7,67	19	2,47	32,2	8,95	7	3,12	34,9
	30	6,50	24	3,00	46,2	6,28	17	2,69	42,8	7,04	7	3,85	54,7
1 - 4 May	0	9,4	12	2,62	27,9	9,72	5	1,94	20,0	9,17	7	3,16	34,5
	5	10,0	10	2,27	22,7	10,62	5	1,45	13,7	9,50	5	2,83	29,8
	10	8,88	11	2,45	27,6	8,98	4	1,48	16,5	8,82	7	2,99	33,9
	20	8,75	11	2,51	28,7	7,90	5	1,80	22,8	9,46	6	2,95	31,2
	30	8,69	12	2,81	32,3	9,14	5	2,55	27,9	8,37	7	3,14	37,5
11 - 15 May	0	8,80	19	3,55	40,4								
	5	8,64	20	3,16	36,6								
	10	8,61	18	3,03	35,2								
	20	8,61	19	2,70	31,4								
	30	7,70	19	3,27	42,4								

x) For explanation of symbols see Table 8.2.

When the production indices values were arranged according to three different levels of hydrocarbon concentration, (Table 8.2) no significant differences were found between the intermediate and the lowest levels. ($P < 0,05$). However, the production indices corresponding to the highest concentrations, which were not significantly different when plotted against total hydrocarbons, ($P < 0,05$) were shown to be slightly different when computed against aromatic hydrocarbon levels ($0,1 < P < 0,05$).

Table 8.2. Production indices at different ranges of hydrocarbon concentrations

Production index (P.I.)
(10^{-3} mg C x mg Chl. a x 10^{17} cuanta x cm^{-2} x hr^{-1})

	Concentration range	$\bar{P.I.}$	n	s	c.v. %
Total hydrocarbons	100 µg/l	6,40	3	0,83	13,0
	50-100 µg/l	9,12	4	2,93	32,7
	50 µg/l	8,21	21	2,02	24,6
Aromatic hydrocarbons	1 µg/l	6,40	3	0,83	13,0
	0,1-1 µg/l	9,12	15	3,27	35,9
	0,1 µg/l	8,55	23	2,86	33,5

x)

x) $\bar{P.I.}$ average production index
n number of measurements
s standard deviation
c.v. % coeficient of variation in percentage.

Since the water samples for hydrocarbon analysis were obtained from a depth of 1 m in order to avoid contamination by surface oil, it has been assumed that concentrations at the surface were equal or higher to those actually measured. These results indicate that at the highest aromatic hydrocarbon concentrations there was a slight detrimental effect on the production index and this was restricted to a very small area around the platform during the first days of the blow-out. A slight trend towards higher P. I. values was observed at a total hydrocarbon concentration range of 50 - 100 ug/l (light polluted water), but since there was no significant difference compared with P. I. values at the lowest concentration range (non polluted waters), it is impossible to attribute this enhancement in production to oil effects.

Several field and laboratory investigations have shown that oil effects on phytoplankton photosynthesis vary with different oil components and concentrations, and also vary according to the species of algae present. Our results show that in the Bravo blow-out slight negative effects on photosynthesis were observed when relatively high aromatic hydrocarbon concentrations were present (> 7 µg/l). In most of the samples hydrocarbon concentrations were below 100 µg/l (total hydrocarbons) and 0,5 µg/l (aromatic hydrocarbons) and no detrimental effects were observed.

Large changes in species composition of phytoplankton as one could have expected according to the observations by PARSONS, LI and WATERS (1976) and LEE et al. (1977), were not detectable until at least two weeks after the capping of the blow-out.

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9. Net- and nanoplankton: Effects of the Bravo oil spill.

by

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This study deals with the size distribution of the phytoplankton biomass and its primary production, and was performed on board R/V "G. O. Sars" during the cruise April 26 to May 1, and the analytical part was carried out at the Institute of Marine Research, Bergen.

It has been experimentally demonstrated that the presence of low concentrations of petroleum hydrocarbons in seawater may cause a shift from a phytoplankton community dominated by diatoms to one dominated by nanoflagellates (PARSONS et al., 1976). By affecting the composition of zooplankton, such a shift may have consequences for the higher trophic levels.

In laboratory experiments oil has been shown to suppress phytoplankton photosynthesis and cell division (e.g. BAKER, 1971). At low hydrocarbon concentrations (< 50 ppb) a stimulatory effect has also been observed (GORDON & PROUSE, 1973). The sensitivity to oil varies with the species as well as with the origin of the oil (PULICH et al., 1974). Field investigations following oil spills, however, have revealed few effects. The Santa Barbara blow-out caused no gross effects (OGURI & KANTES, 1971), and the cause of the mortality observed after the Torrey Canyon spill (SMITH, 1970) is uncertain, as large amounts of dispersants were used.

Between 4 and 9 days after the start of the blow-out surface samples were collected at 24 stations (Fig. 9.1.) ranging from unpolluted to heavily polluted sites, for determination of phytoplankton biomass and its primary production.

Primary production was determined in samples of 118 ml to which was added 1 ml of $NaH^{14}CO_3$ solution (4.6 μCi ml^{-1}). They were incubated for 3.5 - 5 hrs in fluorescent light (Philips TL 40 W/57, 100 $\mu E\ m^{-2}\ sec^{-1}$) and at in situ temperature. After incubation 35 ml were filtered directly onto a .45 μm membrane filter, 35 ml were pre-filtered through a 5 μm plankton net, and 35 ml through a 30 μm plankton net. The radioactivity was measured by liquid scintillation.

Chlorophyll a and phaeopigments were analysed in 250 ml samples, fractionated as described above, and collected on Whatman GF/C filters covered with $MgCO_3$. The pigments were extracted in 90% acetone and analysed with a fluorometer.

Due to low temperatures and late development of the thermocline the spring bloom was delayed in 1977. The blow-out occurred at the beginning of the bloom. The levels of phosphate, nitrate, and silicate were high throughout the water column, and the diatom population was dominated by two large species, Chaetoceros convolutus and Thizosolenia hebetata f. semispina (REY, pers. com.)

Total values and percentages of chlorophyll a and carbon assimilation in the fractions >30 μm, and 5 um are given in Table 9.1. together with averages calculated for all stations and for the four stations close to Bravo (238, B1, B3 and B5). The values indicate no relationship between the presence of oil and the size distribution of the algae. Table 9.2, which gives chlorophyll a/phaeopigment ratios and assimilation numbers, also indicates no relationship between oil and the physiological state of the algae.

In Fig. 9.2 the stations have been separated into three groups: those with a total hydrocarbon content below 60 ppb, those with a content between 60 and 200 ppb, and those with a content above 200 ppb. Only stations 238 and B3 belonged to the last group. There was a slight tendency towards higher relative biomass and production of the larger algae as the hydrocarbon content increased, and an opposite tendency for the algae <5 μm. The figure do not conclusively indicate an effect of the oil, as the results were influenced by patchiness, different times of sampling, and possibly, by different water masses.

However, the same tendency was found for the four last stations (238 - 241), which were situated along an oil concentration gradient. The ship was on these stations more than eight days after the leakage had started, during which time the algae, had as expected, adapted to the presence of oil. Chlorophyll a and carbon assimilation were both highest at Stn 238, closest to Bravo, with a total hydrocarbon content of 256 ppb, and they decreased with decreasing hydrocarbon concentrations (Fig. 9.3a). The variations in the chlorophyll content were almost entirely due to the fraction > 30 µm (Fig. 9.3b). As before, low concentrations were found in the fraction 5 - 30 µm (not shown in the figure), and the algae < 5 µm contributed about the same amount at all four stations.

Nevertheless, the conclusion that those observations were caused by the presence of hydrocarbons is not supported by the assimilation numbers, which did not vary consistently alon the gradient. Only one day after the beginning of the leakage a patch of high chlorophyll concentrations was found in the neighbourhood of Bravo (cf. p.). Therefore the distribution of chlorophyll may have been a phenomenon not connected with the oil spill. On the other hand, the results do not support the findings by PARSONS et al. (1976), that oil stimulates growth of nanoalgae, or those by GORDON et al. (1973), and others, that phytoplankton growth is suppressed by hydrocarbon concentrations of the magnitude 200 ppb.

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I thank the Institute of Marine Research, Bergen, for allowing me to participate in the cruise, and for placing laboratory facilities at my disposal.

Table 9.1. Total values and average percentages, with standard deviations, of chlorophyll a and carbon assimilation for three size fractions of phytoplankton. Calculated for all stations and for four stations (238, B1, B3 and B5) close to Bravo.

	All stations		Stations close to Bravo	
Chl a (mg/m^3)	2.2 ± 0.8		2.7 ± 0.9	
	%	SD	%	SD
> 30 µm:	58.0	11.0	52,0	22,7
5 - 30 µm:	11,4	6,5	15,0	12,6
< 5 µm:	30,5	8,4	32,8	13,8
C ass($mg/m^3/h$)	$4,5 \pm 2,1$		$6,0 \pm 1,0$	
	%	SD	%	SD
> 30 µm:	49,8	15,0	53,5	6,8
5 - 30 µm:	9,8	7,8	9,8	5,3
< 5 µm:	40,4	9,3	36,5	1,7

Table 9.2. Averages and standard deviations of chlorophyll a/ phaeopigment ratios and assimilation numbers (mg C mg Chl a $^{-1}$ h^{-1}) for three size fractions of phytoplankton. Calculated for the same stations as in Table 1.

	All stations		Stations close to Bravo	
		SD		SD
> 30 µm:	6,4	2,2	7,1	1,7
5 - 30 µm:	3,2	0,8	3,8	1,3
< 5 µm:	3,0	0,7	3,5	0,9
> 30 µm:	2,1	0,9	3,6	3,7
5 - 30 µm:	2,0	1,5	1,9	0,9
< 5 µm:	3,0	1,4	3,0	1,8

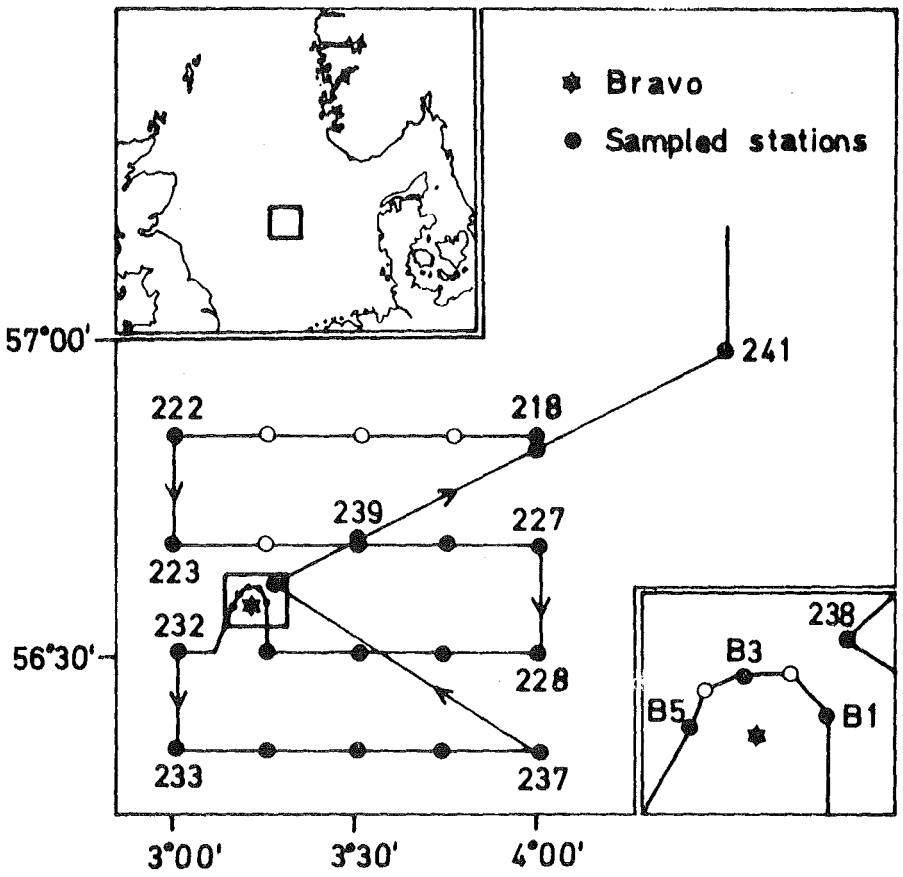

Fig. 9.1 Map of the area, with station grid and sampled stations.

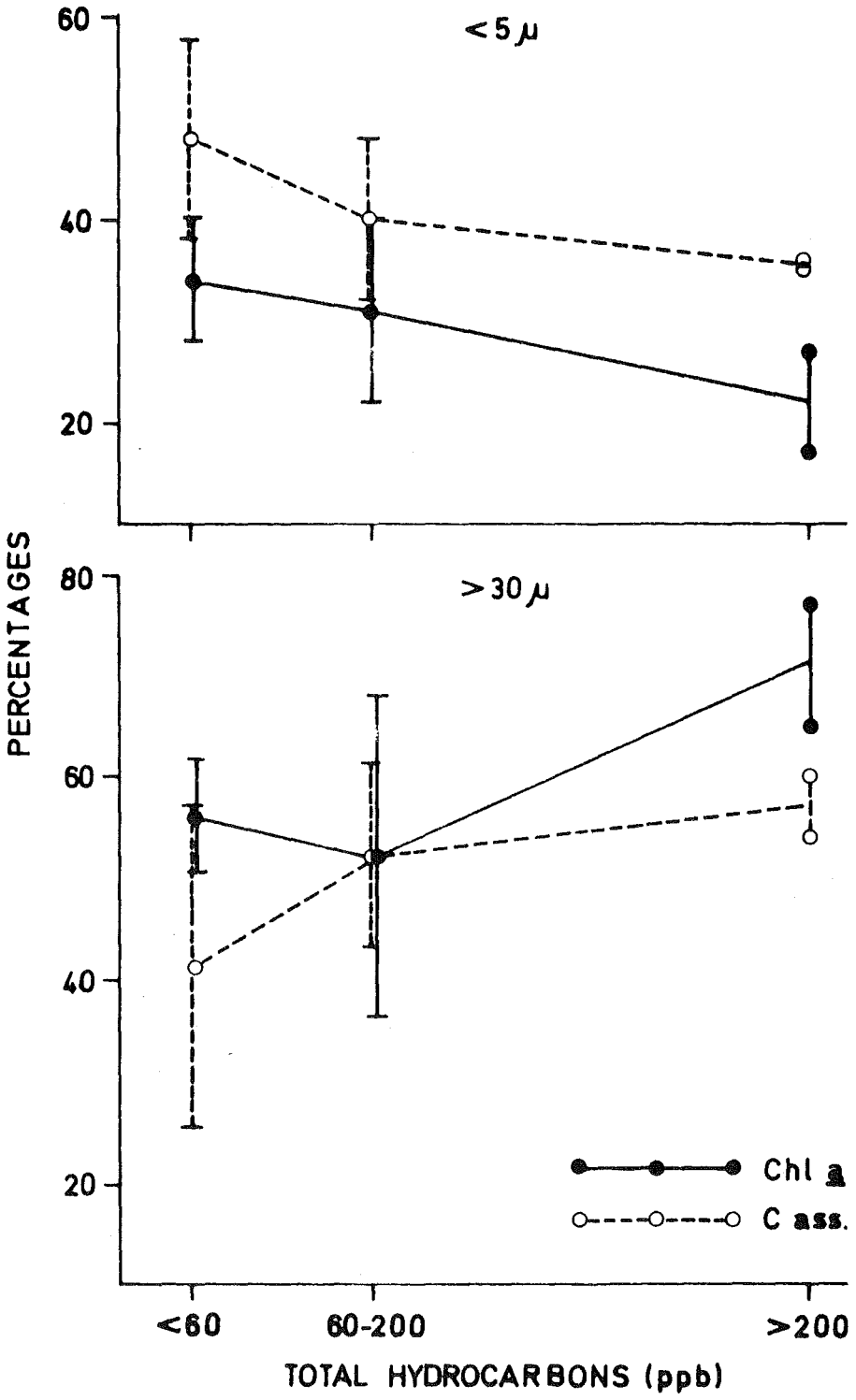

Fig. 9.2 The relationships between total hydrocarbon content in the water and percentages of chlorophyll a and carbon assimilation in the fractions > 30 μm and < 5 μm. Standard deviations are indicated.

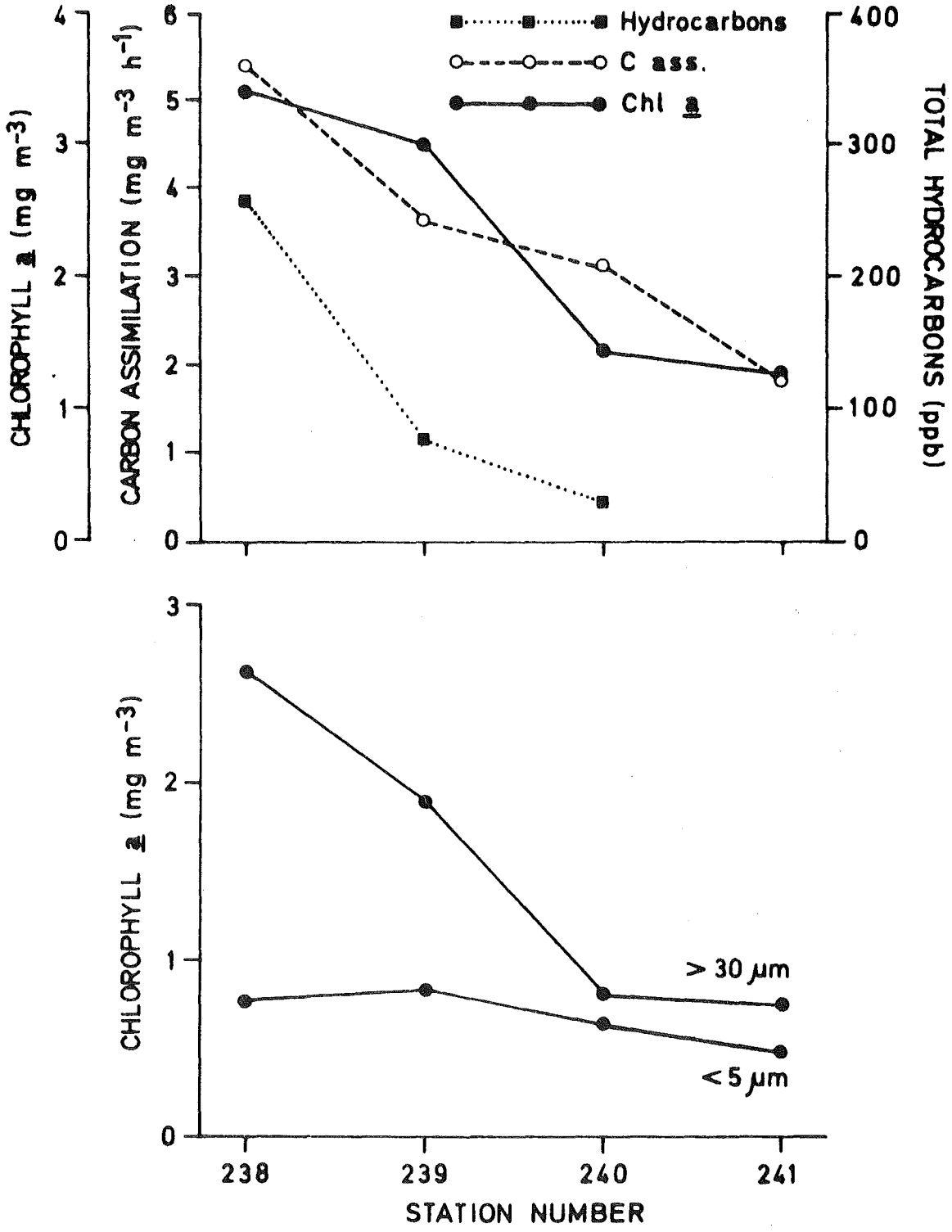

Fig. 9.3 a Total hydrocarbon content, chlorophyll a concentrations, and carbon assimilation rates along the gradient from Stn. 238 to Stn. 241.

Fig. 9.3b Chlorophyll a concentrations in the fractions >30 µm and < 5 µm at the same stations as in Fig. 3 a.

10. Zooplankton, fish eggs and larvae

by

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METHODS

The sampling methods used are indicated in Table 10.1. The Juday net samples were taken as vertical hauls from 50 - 0 m; the net opening was 36 cm in diameter and the mesh size was 0.18 mm. Only during coverage no. 6 were 80 cm diameter Juday nets used; these had a mesh size of 0.5 mm. The Otter Surface Sampler, mesh size 0.243 mm (SAMEOTO and JAROZYNSKI 1969) was towed for one nautical mile at a speed of 5 knots. The A.G.D. III (ZIJLSTRA 1970) was lowered and raised at the rate of 0.5 m/sec. to a depth of 50 m, the ships' speed being 5 knots. The Clarke-Bumpus Plankton Sampler (mesh size 0.5 mm) was used in two ways: During coverages 2-4 it was towed in single oblique hauls from 40 m to the surface, remaining 4 minutes at each 10 m level. However, during coverages 6 and 7, four samplers were towed at depths of 0, 5, 10 and 15 m for 10 minutes. This change in sampling technique was carried out to be able to compare the results with those from previous investigations on mackerel spawning in the same area.

Table 10.1. Sampling methods used during the different cruises.

Ship	Date	Juday 50-0 m	Otter Surface Sampler	Clarke-Bumpus 40-0 m	Clarke-Bumpus 0-5-10-15 m	A.D.G.III 50-0 m	Coverage no.
Sleipner	24-25/4		x				1
G.O. Sars	27/4-1/5	x	x	x			2
J. Hjort	27/4-1/5	x	x	x			3
	1-4/5	x	x	x			4
G.O. Sars	10-16/5	x	x			x	5
J. Hjort	31/5-17/6	x	x		x		6
J. Hjort	11-30/7		x		x		7

All the samples were superficially examined under low magnification while at sea. This involved noting the occurrence of oil droplets and any physical effects of oil upon the zooplankton in the sample. Zooplankton concentrations were determined by the displacement volume method. More detailed analysis has so far not been carried out.

RESULTS AND DISCUSSION

Large concentrations of krill were observed by echo sounder and verified by trawling in April-May. The dominant copepods in the samples were Calanus spp. During the initial cruises (April - early May) the zooplankton volumes could not be estimated due to the fact that the Juday nets were repeatedly clogged by phytoplankton, and the Clarke-Bumpus samplers, when used at night, caught large volumes of krill organisms in relation to copepods.

Figs. 10.1 and 10.2 show the zooplankton volumes measured during two subsequent cruises, coverage nos. 5 and 6 in the Ekofisk area. The results appear to be more or less the same as those recorded in the same area from 1967-1975, (IVERSEN 1977).

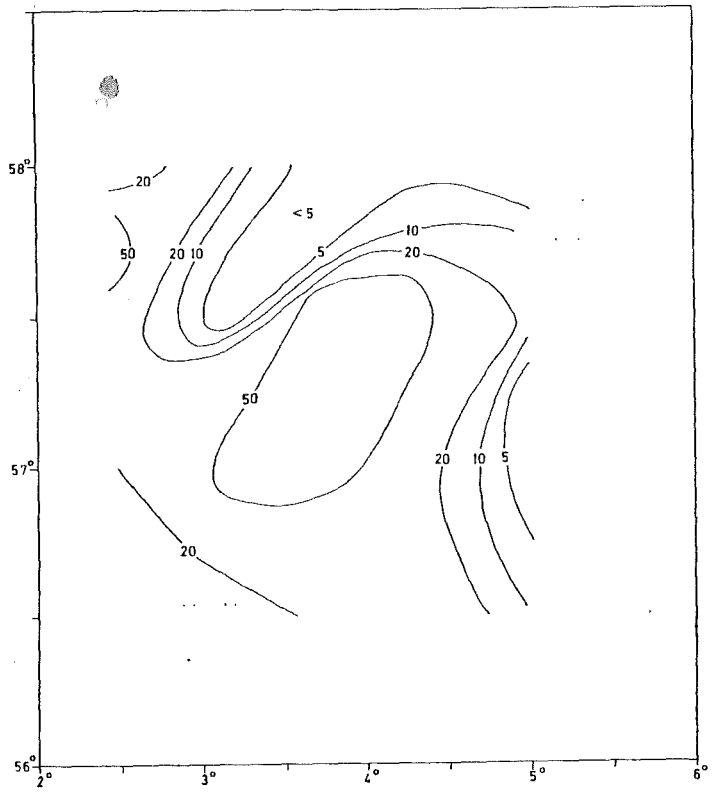

Fig. 10.1 Zooplankton volumes in ml/m^2 surface area, Juday net. May 10 - 16, 1977.

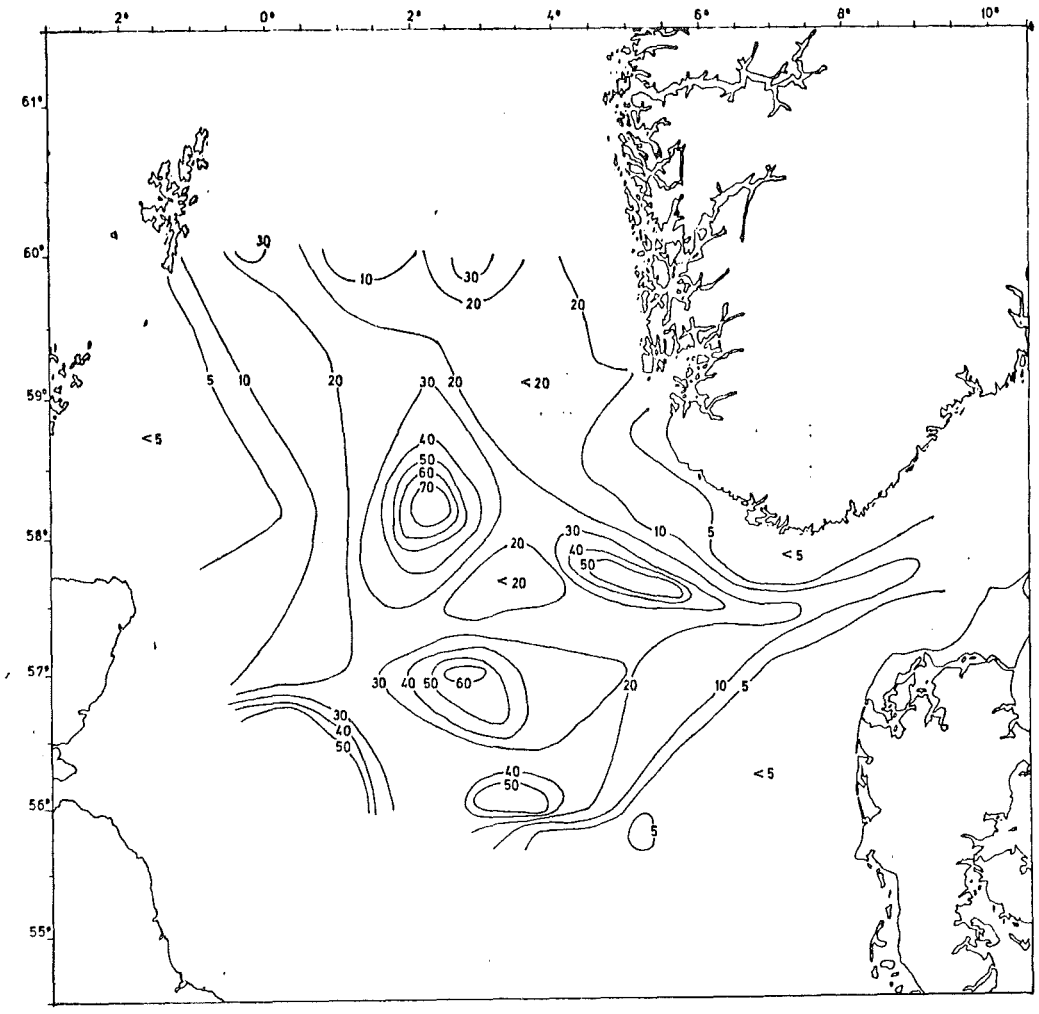

Fig. 10.2 Zooplankton volumes in ml/m^2 surface area, Juday net. May 31 - June 17, 1977.

At some stations copepods were observed to be covered with oil. However, the samples concerned contained fresh oil and it is likely that the copepods became covered during the haul. Samples containing fresh oil were mainly taken by the Otter Surface Sampler.

A few dead copepods (Calanus spp.) were observed during coverages 2-5, in an area south-east of the Bravo platform, 56°20'-56°30' N and 3°10'-3°30' E .

During the April - early May coverages fish eggs were thinly scattered, except for a more dense concentration north to north-east of the Bravo platform (Figs.10.3 and 10.4). The eggs were identified as those of long rough dab and gadoids, probably whiting, haddock and cod. Eggs of dab and plaice were also found in some of the samples. In the middle of May (Fig.10.5), egg densities were minimal, being composed of species mentioned above and a few mackerel.

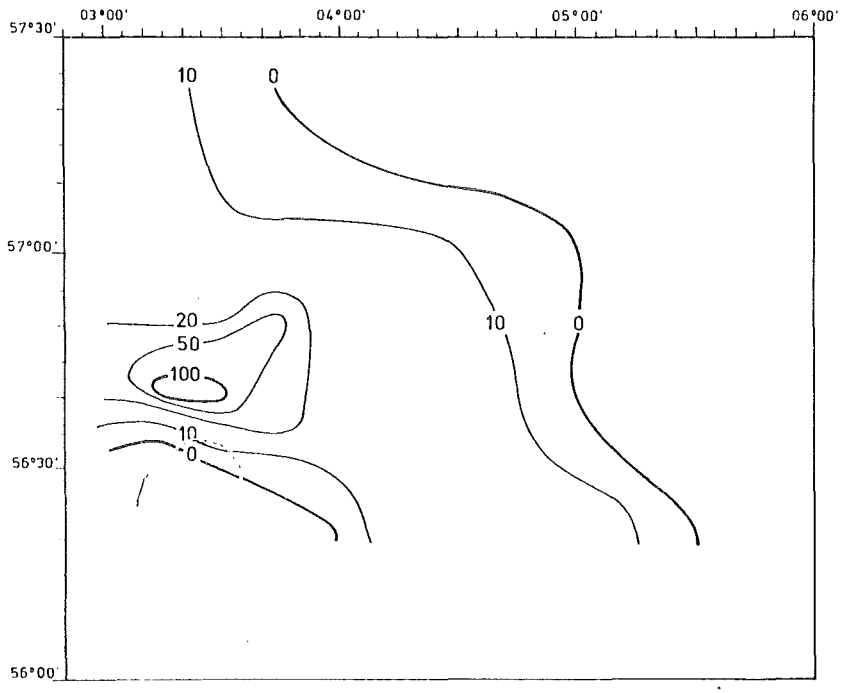

Fig. 10.3 Fish eggs in mumbers/m^2 surface area, Juday net. April 27 - May 1, 1977.

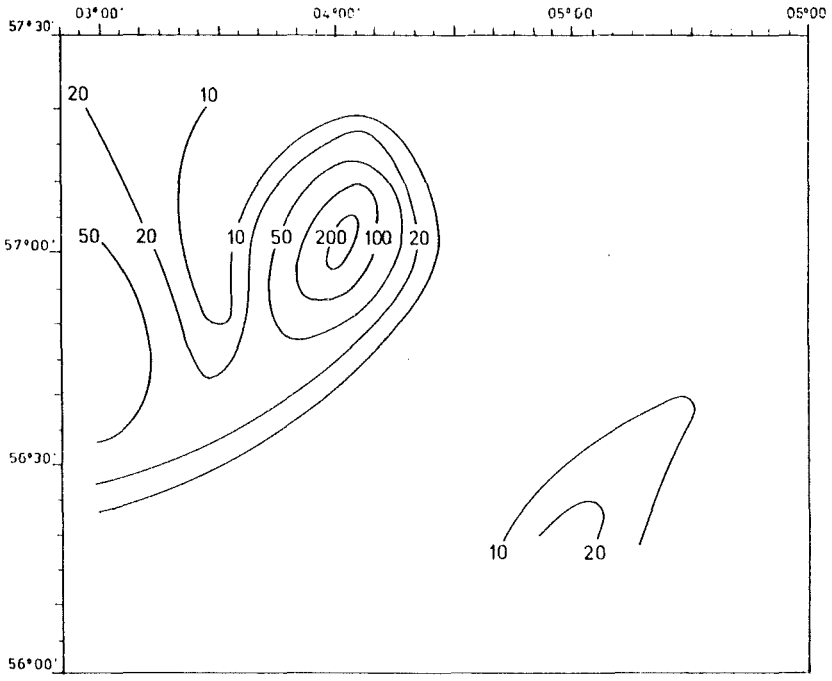

Fig. 10.4 Fish eggs in numbers/m^2 surface area, Juday net. May 1 - 5, 1977.

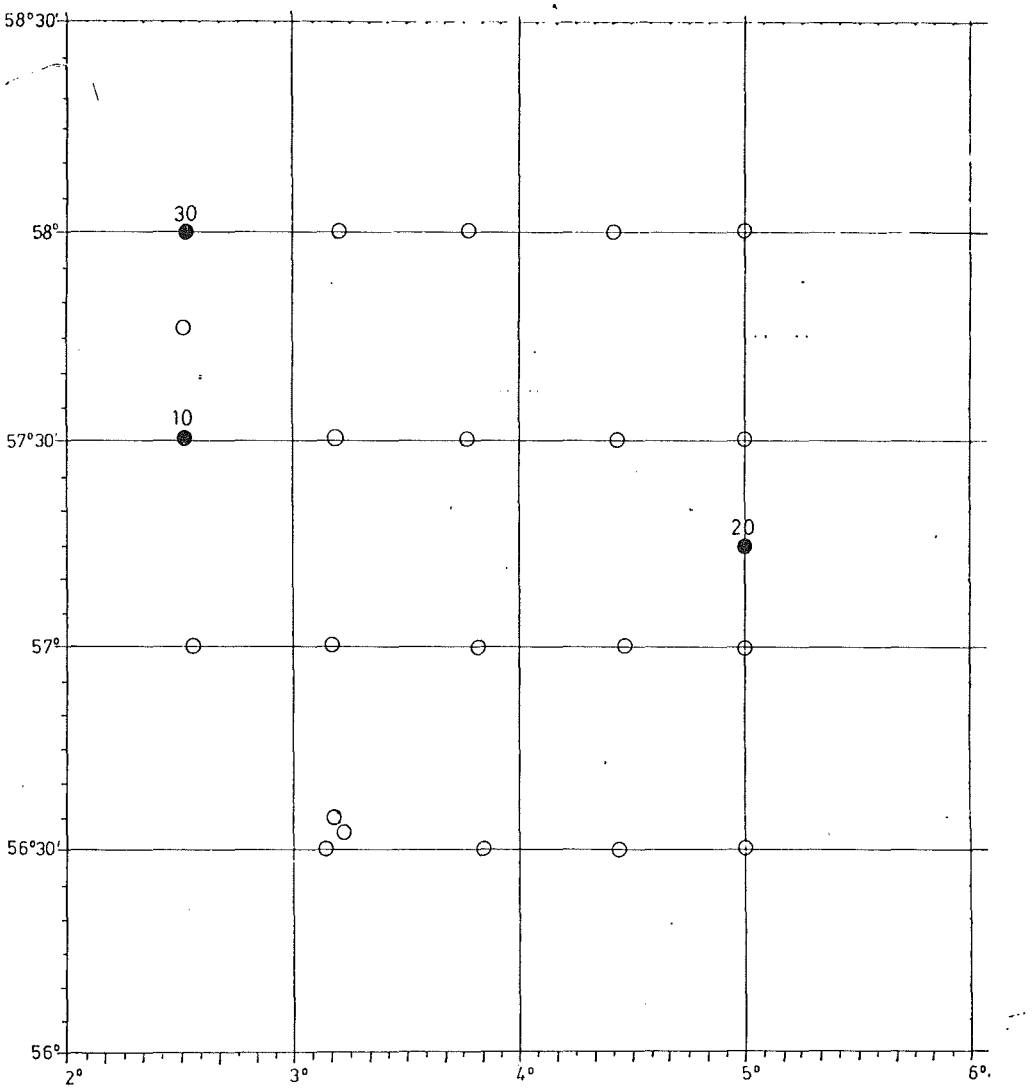

Fig. 10.5 Fish eggs in number/m^2 surface area, Juday net. May 10 - 16, 1977.

The egg catches taken in June were considerably larger due to the mackerel spawning, Fig. 10.6. During this months' coverage some dead mackerel eggs were found 60 to 70 nautical miles south-east of the Bravo platform. However, it should be noted that it is not an unusual phenomenon to find dead eggs in a fish spawning area. During July the numbers of eggs were much less, indicating the end of the mackerel spawning season, Fig. 10.7. The isolines in these two diagrams are based on total numbers of eggs per station and should be reduced by roughly 40-60% to give eggs/m^2 surface area. During June-July eggs densities of other species were very low.

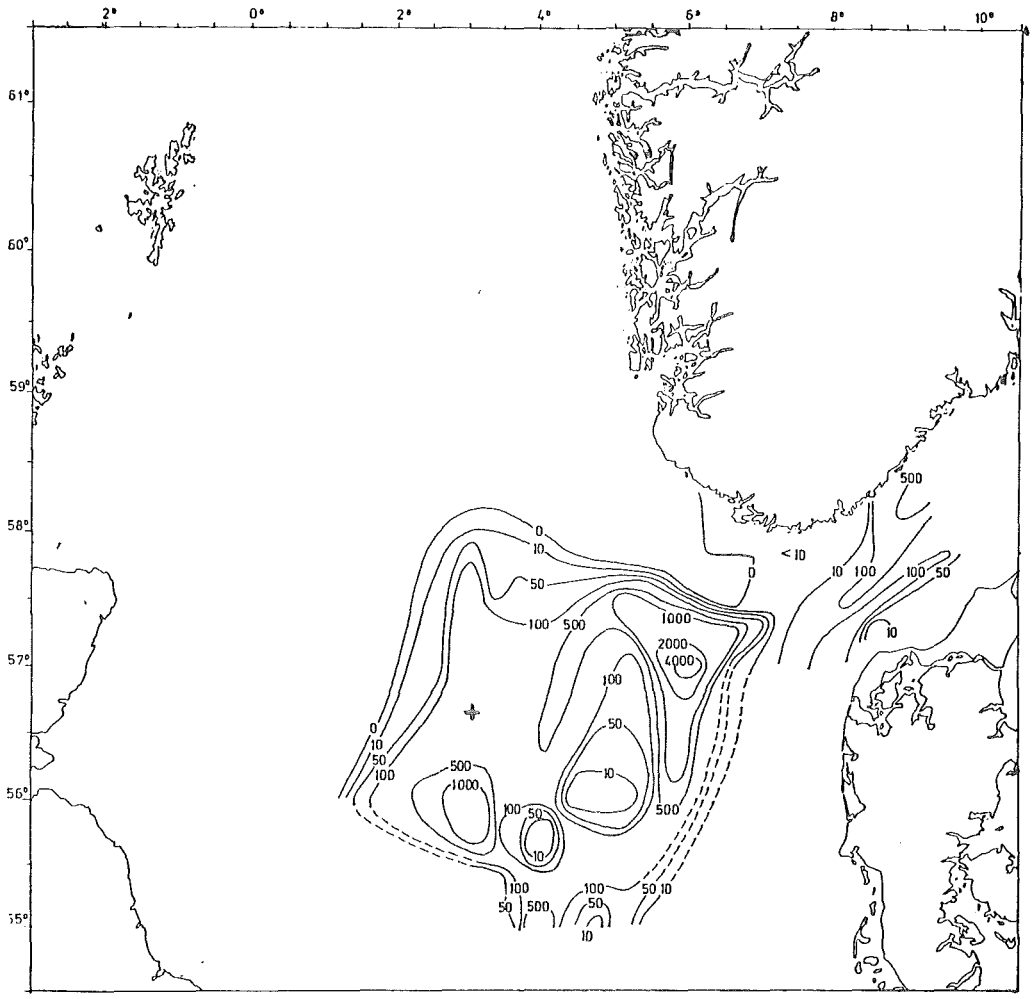

Fig. 10.6 Total numbers of mackerel eggs per station, Clarke - Bumpus sampler. May 31 - June 17, 1977 (+Bravo platform).

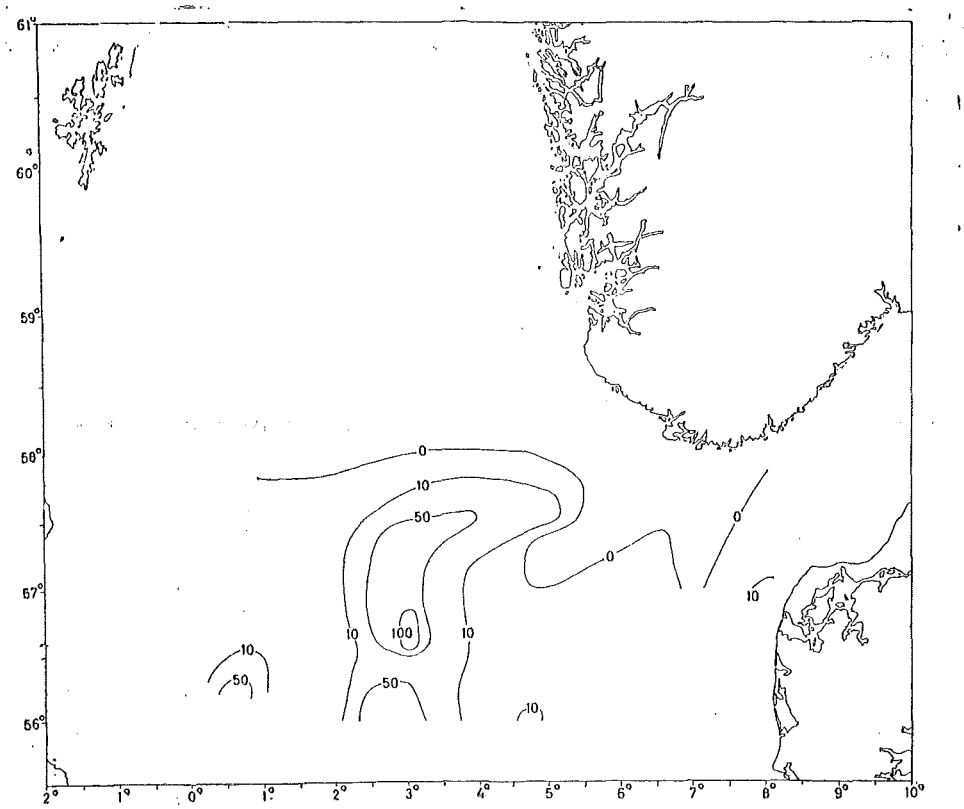

Fig. 10.7 Total numbers of mackerel eggs per station, Clarke - Bumpus sampler. July 11 - 29, 1977.

On average, few larvae were caught during all coverages, this possibly being due to avoidance of the plankton gear. During April - May larvae were mainly those of sand eel and catfish, and later on, mackerel. Pelagic trawling just below the surface showed that 0-group herring were scattered more or less all over the surveyed area.

CONCLUSION

Due to lack of readily available data, it is difficult to make comparisons of results on zooplankton, fish eggs and larvae, and thereby draw conclusions as to any effects of the blow-out. The general zooplankton situation was in the early spring condition of low biomass during the blow-out. This could be the reason why no obvious effects of the mishap were observed. It cannot be ruled out that presence of some dead copepods in the vicinity of the Bravo platform could have been caused by oil or detergents.

In relation to mackerel, however, earlier data are available (IVERSEN 1973, 1977) and the only irregularity in the present results is that spawning occurred further south than in previous years. This was most probably due to the fact that the water temperatures were too low for spawning in the northern areas. Two patches of egg minima were observed in areas local to the Bravo platform. However, it is not unusual to observe such minima within the mackerel spawning area.

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11. Notes on observations of fish in the area of Ekofisk Bravo

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INTRODUCTION

Species composition, distribution and abundance of fish in localized areas of the North Sea will vary greatly with time. Possible changes in such parameters, caused by effects of oil pollution, cannot be separated from the observed total variability by standard field methods. For this reason, the investigations carried out during and after the Ekofisk Bravo blow-out were intended to characterize the situation rather than to detect possible biological effects on the fish.

Data on the commercial important fish species are presented in these notes.

MATERIAL AND METHODS

The observations were based on catches by pelagic and bottom trawls and on echo integration in a limited area of about 70 x 70 nautical miles near the Ekofisk oil installation.

The pelagic trawl had an opening of 1 600 mesh (20 cm) circumference and the bottom trawl had a horizontal width of about 20 m and a height of 6 m.

The echo integrator was connected to a 50 kHz sounder, and the readings were related to pelagic or demersal fish from the paper recordings and the trawl catches.

The investigations covered the periods: 27 April - 5 May (Research vessels "Johan Hjort" and "G. O. Sars") and 10-16 May 1977 ("G. O. Sars"), and are assumed to reflect the situation at the time of the blow-out (22 April) and shortly after. During the first period eight hauls were made with a bottom trawl and 13 with a pelagic trawl, while 5 and 11 hauls respectively, were made in the second period.

RESULTS

Table 11.1 lists catches of fish taken in the bottom trawl, and Table 11.2 the catches in the pelagic trawl during the first period. The fishing localities are indicated in Fig. 11.1. Table 11.1 shows that the dominant demersal fish species in the area were dab, haddock, whiting and long rough dab, which were taken on nearly all fishing stations. The catches were rather light, about 50 kg/hr on average.

The pelagic trawl (Table 11.2) was towed at 0-30 m depths and no adult fish were caught; but O-group herring, catfish and sand eel occured on most stations. The O-group herring had a modal length of about 40 mm.

The distribution and relative abundance of demersal fish were determined by echo integrator onboard both "Johan Hjort" and "G. O. Sars" during the first period, as shown in Figs. 11.2 and 11.3. There were no significant recordings of pelagic fish. The echo integration demonstrated that very few demersal fish were present in the vicinity of Ekofisk Bravo (Fig. 11.3) and in the surrounding area. The abundance was below recording threshold level, except in the north-eastern part (Figs. 11.2 A and B). This was also the only place where fishing vessels operated at the time. The echo integrator observations correlated closely to the trawl catches (Table 11.1 and 11.2).

The second period of investigation, 10-16 May, covered the area 56°30' - 58°00'N and 2°30' - 5°00'E, extending more to the north than in the first period due to the distribution of oil on the surface.

The trawl catches taken during the second period are given in Tables 11.3 and 11.4. As in the previous period, the catches of demersal fish were small, with the same average of about 50 kg/ trawl hour. Very few adult pelagic fish were caught, except for some garfish and sand eel, and also 98 mackerel in a tow near Ekofisk.

The plots of echo integrator readings have been made from the data obtained by "G. O. Sars". It should be noted that the recording threshold level on "G. O. Sars" is lower than on "Johan Hjort", and the recording gain twice as high. Fig. 11.4 shows the relative abundance of demersal fish in the area. The figure shows that the abundance of demersal fish was again very low, being highest in the north-eastern part of the area. After corrections have been made for vessel differences, the overall abundance was the same for both the investigated period, i.e. about 1 mm deflection per nautical mile ("Johan Hjort" values). This corresponds to an abundance of the dominant demersal fish species of approximately 2 tons/nauticle mile^2 (0.5 tons/km^2).

Fig. 11.5 shows the integrator readings of pelagic fish, and indicates a low abundance of them in the area. In an area north of 57°30'N the occurrence of sand eels was also recorded.

CONCLUSIONS

The data presented here show that the abundance of fish in the Ekofisk area was rather low at the time of the blow-out and shortly after. Very few pelagic fish were present, but herring larvae were found in the upper water layers. The demersal fish occurred in quantities estimated to be approximately 0.5 tons/km^2 on average, with the highest abundance to the north-east of Ekofisk.

Preliminary results from research cruises covering the Ekofisk area in June and July have shown that the fish abundance and distribution generally changed little in the months after the reported investigations. However, pelagic fish, especially mackerel, occurred more frequently.

Table 11.1 Bottom trawl catches 27 April - 5 May 1977.
Numbers/trawl hour.

Species	Trawl st.no. 79	81	84	85	88	91	95	97
Cod	4		2	2	2		18	
Haddock		52	18	2		286	16	46
Whiting	4	12	6	14	2	124	8	50
Dab	72	20	58	50	96		2	62
Long rough dab	12	12	12	16	30	2	2	8
Plaice	2				2			4
Sandeel	5 192	290						
Catfish	2	2	4	2		2	2	
Thornback ray		2					2	
Others			10	10	8	8	2	
Kg /hr	110	32	35	13	7	151	25	19

Table 11.2 Pelagic trawl catches 27 April - 5 May 1977.
Number of O-group fish per trawl hour.

	Trawl st. no.												
Species	78	80	82	83	86	87	89	90	92	93	94	96	98
Herring	800	80	15	50	22	200	112	3000		2		106	4
Sandeel	2				2		84	2					
Catfish				28	8	12	2	2		2	2		2
Gadoids							2						
Others	2				10	30	30	20		20	6	66	2

Table 11.3 Bottom trawl catches 10-16 May 1977.
Numbers per trawl hour.

Species	Position N, E			
	56°30' 3°16'	56°48' 4°38'	57°16' 4°03'	57°43' 3°30'
Cod	4	8	1	7
Haddock	55	22	7	205
Whiting	2	26	27	187
Dab	45	52	107	1308
Long rough dab	68	17	21	95
Plaice	3		10	3
Sandeel				6
Catfish			1	
Thornback ray	1	1		
Others	4	5	4	2
Kg/hr	28	18	17	136

Table 11.4 Pelagic trawl catches 10-16 May 1977.
Numbers of O-group fish per trawl hour.

Species	58°00' 4°23'	58°00' 3°08'	58°00' 3°02'	57°30' 3°16'	57°30' 4°23'	57°24' 5°00'	57°00' 4°19'	57°00' 3°08'	56°40' 3°17'	56°30' 3°10'	56°30' 4°23'
Herring	106		10	168	52		28	40	6	38	20
Sandeel					138		22		6		188
Catfish							4				158
Gadoids					2		70		18	86	22
Others					2				2		34

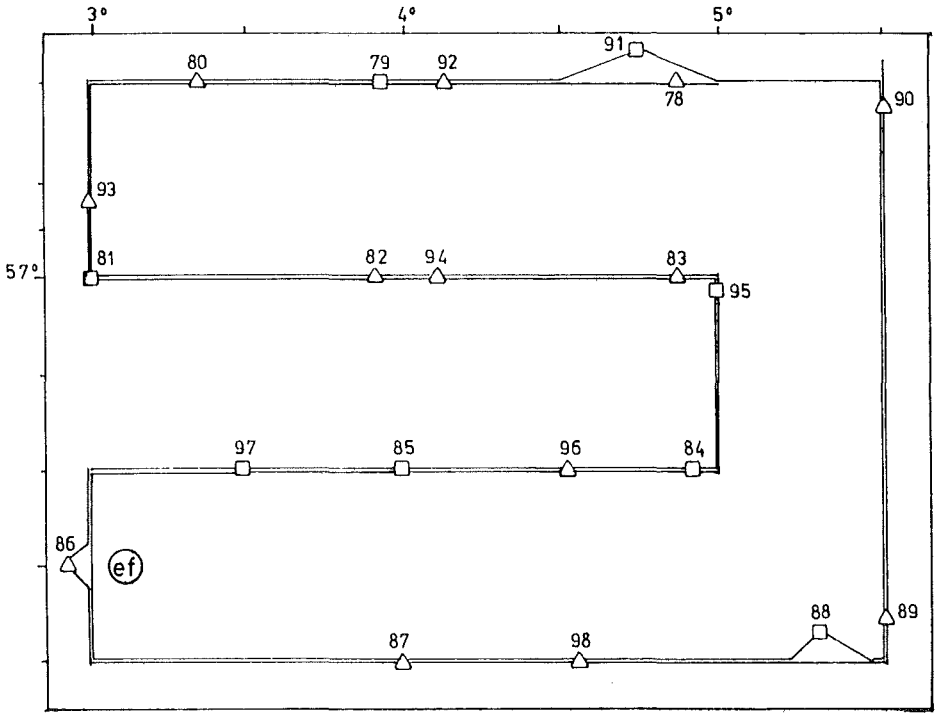

Fig. 11.1 Positions of trawl hauls 27 April - 5 May 1977. "ef" indicates Ekofisk Bravo.

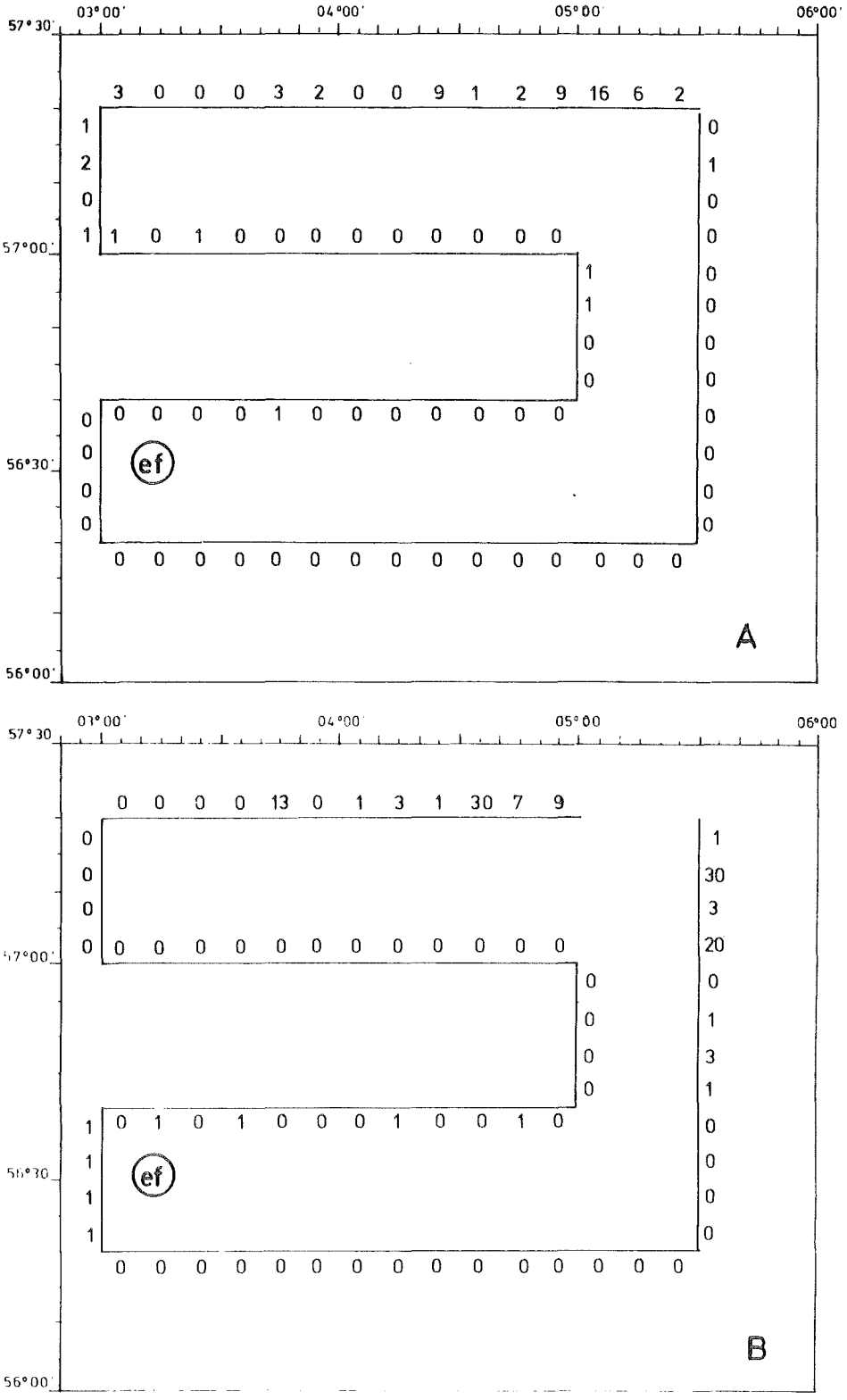

Fig. 11.2 Relative abundance of demersal fish 27 April-1 May (A) and 1-4 May (B) 1977, from readings of echo integrators. "Johan Hjort" (mm defl. per n.mile). "ef" indicates Ekofisk Bravo.

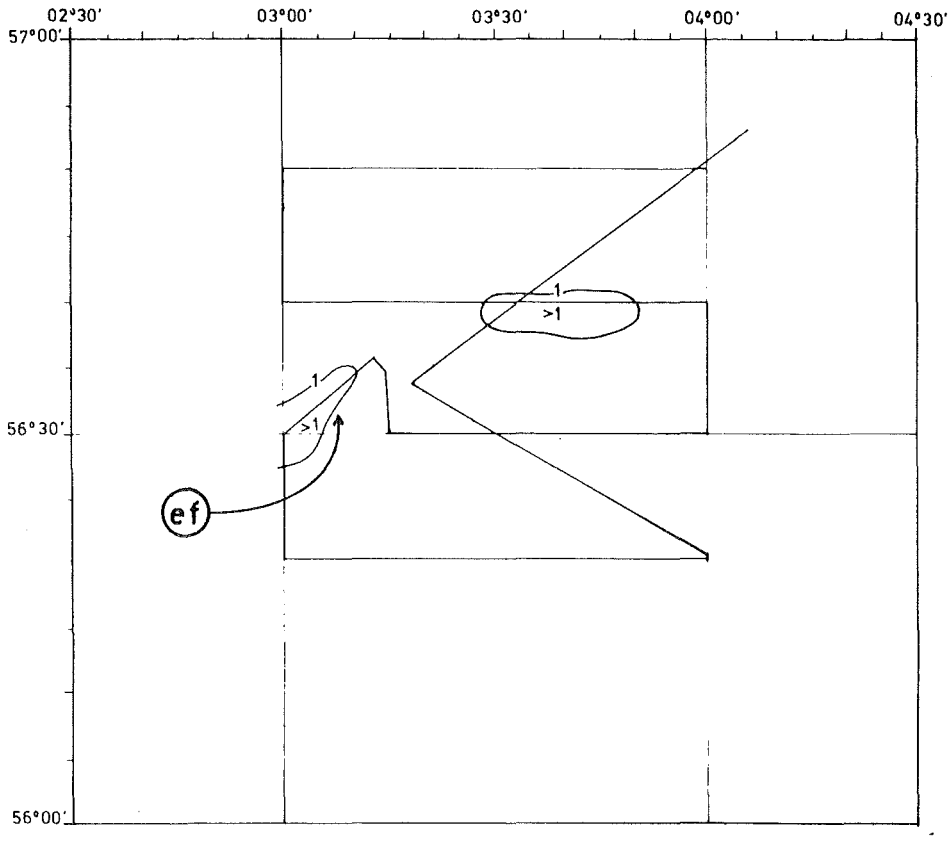

Fig. 11.3 Relative abundance of demersal fish in the vicinity of Ekofisk Bravo 27 April - 1 May 1977 as determined by echo integrators, "G. O. Sars". (mm defl. per n. mile).

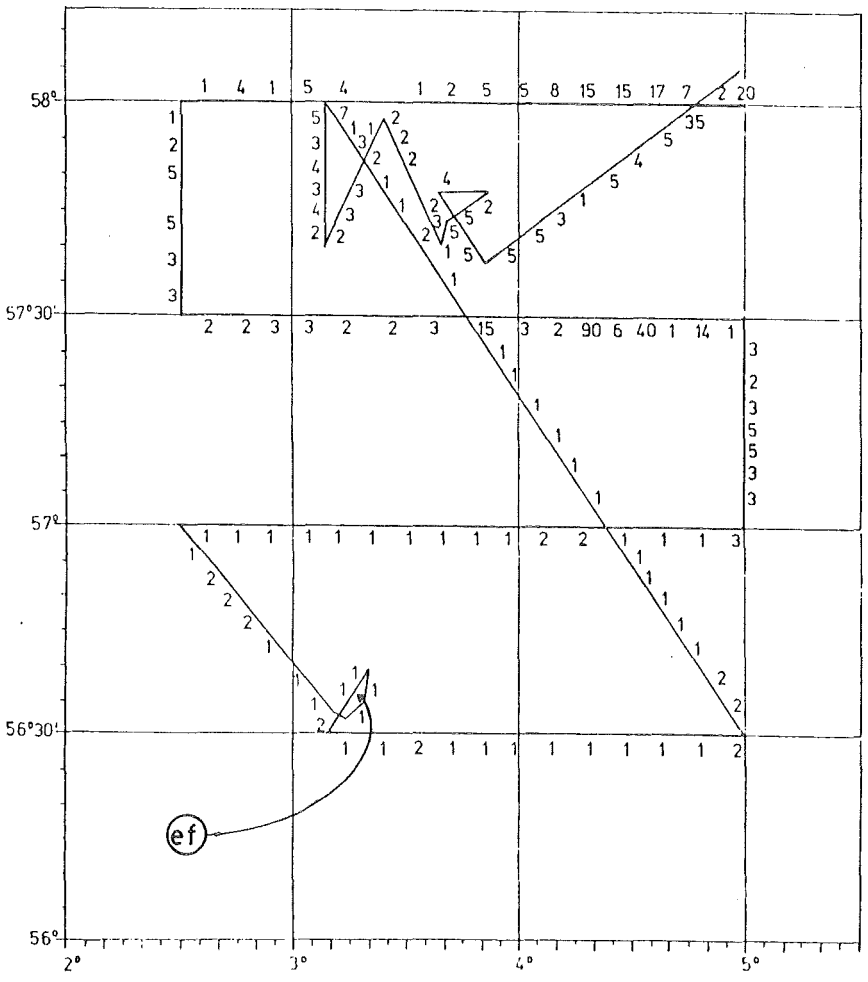

Fig. 11.4 Relative abundance of demersal fish 10-16 May 1977, from readings of echo integrators. "G. O. Sars". (mm defl. per n. mile).

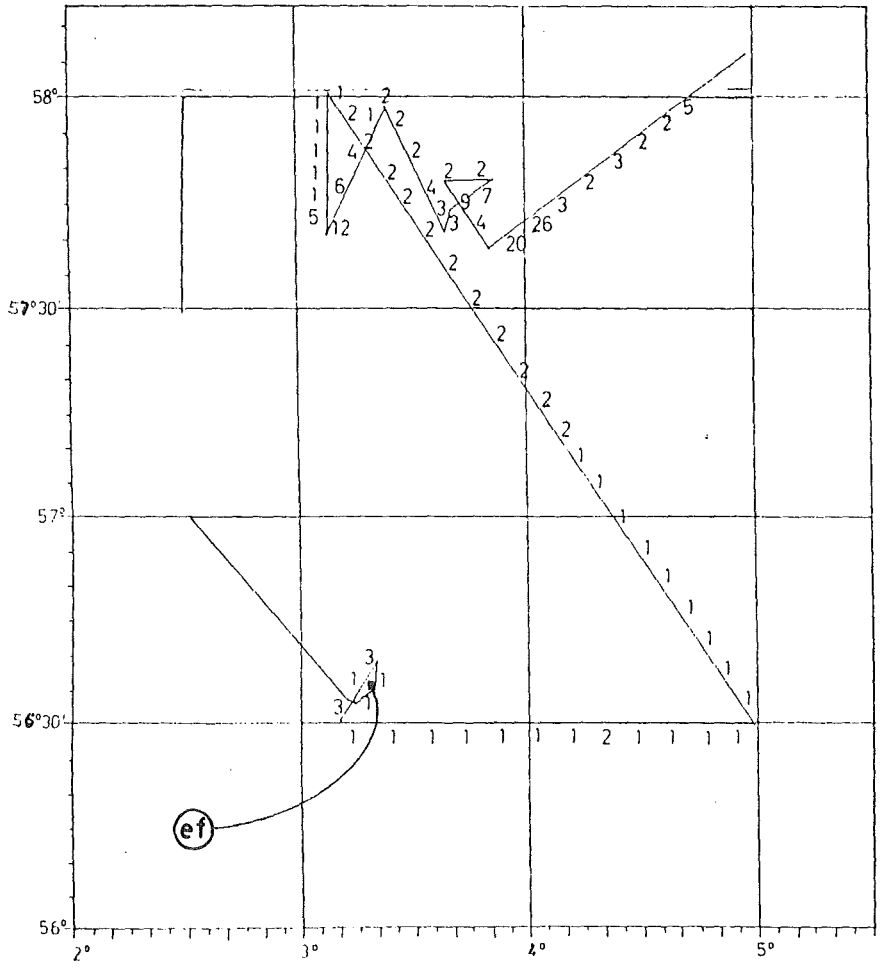

Fig. 11.5 Relative abundance of pelagic fish (mostly sandeel) 10-16 May 1977, from readings of echo integrators. "G. O. Sars". (mm defl. per n. mile).