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THE JUTLAND CURRENT: NUTRIENTS AND PHYSICAL OCEANOGRAPHIC CONDITIONS IN LATE AUTUMN 1989

by

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ABSTRACT

Hydrography, currents, nutrients, water transparency, in situ chlorophyll fluorescence and primary production were studied during a cruise with R/V "G.O. Sars" to the west coast of Denmark, Skagerrak and Kattegat from 27. November to 6. December 1989. The Jutland Current (JC) was partly blocked during this period, probably because of an intensified inflow of water from the central and northern North Sea (Northern Jutland Current, NJC). This suggests that the NJC can exert a substantial dynamic control of the outflow of nutrient-rich water from the coastal areas of the southern North Sea.

Silicate and phosphate showed approximately linear increases in concentration with decreasing salinity of the JC water. This indicates that physical mixing was the dominant process and that net biological consumption was low in comparison. The sum of nitrate and nitrite, in contrast, showed a non-linear relation with salinity. There was an apparent deficiency in nitrogen of 30-50 % which probably reflected denitrification processes in the coastal waters. The JC was characterized by relatively high concentrations of nitrite (up to 3 µM) and inorganic phosphate. The N:P ratio (based on nitrate plus nitrite and phosphate) was considerably lower than the Redfield ratio of 16, indicating an excess of P relative to N in the Jutland Coastal Water during the late autumn period. This is in contrast to the situation in late winter and spring, when there is a large excess of N.

Introduction

The Jutland Coastal Water (JCW), located along the west coast of Denmark, is strongly influensed by anthropogenic supplies of nutrients from the European Continent, and a number of processes decide the nutrient conditions of the JCW before it enters the Skagerrak and Kattegat. To evaluate what impact the JCW has on the environment in these areas, it is therefor necessary to know the water quality of the JCW as a function of time and the processes controlling the inflows to Skagerrak.
Therefore a pilot experiment were conducted in Nov./Dec.1989 by the Institute of Marine Research (IMR) in Bergen. The ship tracks of R/V G.O.Sars and CTD/nutrients/chlorofyll stations are shown in Fig.1. Acoustic Doppler Current Profiles (ADCP) were continously obtained every 10 minute, and also continous records of salinity, temperature, oxygen, nutrients, fluorescence and turbidity were obtained from 4 meter depth. The experiment were coordinated with IMR´s yearly nutrients and hydrography survey over the whole North Sea, Skagerrak and Kattegat (Lars Føyn, pers.com.).

The concentrations and amounts of nutrients in the JCW west of Denmark are steered by the following factors:

Supply of freshwater
Transport of water and nutrients (in/out)
Entrainment of North Sea Water (NSW)
Concentrations of nutrients in freshwater
Concentrations of nutrients in NSW
Consumption/supply of nutrients from plankton and biochemical prosesses

In the shallow regions (<30m) the JCW is vertically mixed due to strong tidal currents. However, both cross- and along-shore there are strong horizontal gradients. The mean "freshwater driven" volume transport of the JCW is approximately $0.1 * 10^6 m^3/s$. Large time-variations of this transport are mainly caused by short and long term variations in the wind field over the North Sea (c.g.Pedersen et.al 1988.). Therefore the flow of JCW into Skagerrak will be of a pulsative character, and large amounts of water can flow into Skagerrak and Kattegatt over relatively short time periods . The JCW is heavier than the Baltic Water (BW) and will therefore flow underneath the BW into Kattegat and along the eastern Skagerrak coast. (c.g. Aksnes et.al. 1989 and Richardson et. al. 1987)

Observations

Current/transport and watermasses

One of the main findings during this experiment was the major flow (order of 1 SV) of high salinity Atlantic water (AW) into the Skagerrak. This is demonstrated in a vertical section of the east-west current component from the ADCP measurements between Norway and Denmark (Fig.2). The main inflow (on the Danish side) was over the bottom range from 50 to 170 meter, with velocities of the order of 30 cm/s from near the surface to the bottom. This inflow of AW consisted of two partly separable currents. One being the main and direct inflow along the the western (southern) slope of the Norwegian Trench with a deep core located above the 150m bottom contour, and the other being a branch of the upper part of AW which further west has taken a more southerly route and is steered into Skagerrak approximately along the 70m bottom contour (Fig.3). The full arrows indicate the measured near surface circulation, while the open arrows indicate some of the the subsurface currents.

The southern and upper branch of AW is clearly seen in the horizontal distribution maps of the salinity (Fig.5). This clearly shows that AW (S>35) is steered onto the Danish coast near Hanstholmen, and that to the west of this there is a branch topographically steered southward at about 8 ^{0}E (see also Fig.3). These features in the flow of AW are espesially interesting with respect to the possible influence on the inflow to Skagerrak of JCW (defined here as the water with salinity <34.0 (Fig.5a). We believe that this massive flow of AW must act as a controlling choke on the flow of JCW into Skagerrak. This hypothesis will be further studied on the basis of SKAGEX data obtained in May-June, 1990.

Fig.3 displays a complicated current system north of Skagen. The topography forces part of the inflowing water toward the Skagen Rief, setting up a relatively narrow eastward jetstream toward the Swedish coast. Part of this stream follows the topography southward into Kattegat underneath the fresh outflowing Baltic water, while part of the water enters into a cyclonic eddy or meander. Indications of a cyclonic eddy (or meander) have earlier been reported in this area , which can be explained by the interaction of the two crossing watermasses and strengthened by the concervation of potential vorticity. This phenomena causes a westward displacement of a tongue of Baltic water at about 58^{0}N, interacting closely with the Jutland water. A very similar phenomena was found outside western Norway with the interaction between the Norwegian Coastal Current (NCC) and AW (Johannessen et.al.1989), and probably a similar process is taking place with respect to the interaction between the AW and the JCW in the Hanstholmen area.

A clear demonstration of the variability of currents into and within the Skagerrak is shown by the drift of an Argos buoy with a drough at 10m depth (Fig.4). The buoy was deployed on Dec.1 on the western front of the JCW near 56^0 N. For three weeks it was relatively stationary in the area, first mooving slowly southward and then northward to the deployment area. Then suddenly it took off into Skagerrak with speeds between 1-2 knots. In the eastern part it made a full cyclonic turn before it followed the NCC out of Skagerrak with speeds between 1-3 knots. The buoy spent about four weeks within the Skagerrak area, with two of these weeks within the cyclonic turn. Two other buoys deployed within the JCW also showed a similar southward drift just after deployment, but unfortunately these were caught by fishing nets after a few days.

Temperature-salinity (T-S) relations at different latitudal sections west of Denmark are shown in Fig.6, together with signatures of AW flowing into Skagerrak near Hanstholmen. The figure clearly identify three main watermasses; The low salinity JCW, the warm water >11^{0}C (here called Channel Water) which to our understanding must originate from the British Channel flowing northeastward outside the JC, and the high salinity Atlantic Water. The AW is separable in three "watermasses" according to depth; The deep and cold core found beween 200-225 meter depth which might have been recirculated in the deeper part of the Nowegian Trench/Skagerrak, the main inflow of AW at depths between 130-200 meter beeing one degree warmer than the deeper core, and the AW between 40-100 meter depth which is partly mixed with fresher water from the central North Sea. The figure also shows that during the observation period the Channel Water was mainly detected south of 57^0 N beeing clearly mixed with JCW. At 57^{0}N (and north of this) there was a more direct mixing between the JCW, the water from the central North Sea and the upper layer AW.

A T-S comparison between the water west of Denmark and the water in Kattegatt is shown in Fig.7. As expected a clear vertical mixing is seen between the fresh outflowing Kattegatt surface water and the deeper "inflowing" water. However, the most interesting question is which watermasses this Kattegatt "deep inflow" consists of. This water with salinity 33.0-34.3 is the warmest water in the whole area, indicating that it has been near the surface during summer, and has not been exposed to the autumn cooling. Fig.7 can not give the full answer to the question since the temperature in this case is far from being a conservative parameter. But we are quite sure that the Kattegat "deep inflow" is water which previously has obtained much of its signature in the complicated mixing zone near Hanstholmen. This means that it mainly is JCW (already mixed with Channel Water) which near Hanstholmen is being mixed with varying amount of Central North sea water and upper layer AW.

Earlier studies of the JC have concluded that the inflow of JCW to the Skagerrak is mainly locally winddriven (e.g.Pedersen et. al. 1988). The results from this study indicates however that also the variations in AW transports outside this area must be of great importance for the flow of JCW into Skagerrak/Kattegat.

Nutrients

The highest consentrations of nutrients were found associated with low salinity water off Esbjerg, closest to the outlet of the River Elbe in the German Bight. There was a clear relationship between nutrients and salinity, with decreasing nutrient concentrations with increasing salinity in the offshore direction and northwards along along the coast of Jutland (Fig. 8 and 9 a-d).

The lowest concentration of nitrate (0.5μM) was found in the southwest part of the investigated area at a salinity of about 34.6. the highest concentration (about 30 μM) was found in the coastal water off esbjerg (Fig.9 a). The inflowing Atlantic water in western Skagerrak contained 5-6 μM og nitrate, while the Baltic water in Kattegat contained less than 2μM and the Skagerrak water 2-3 μM.

Inorganic phosphate and silicate showed similar distributions to that of nitrate. The maximum concentrations of phosphate off Esbjerg was about 2.5μM, whereas the lowest concentration was about 0.3μM in the southwest area (Fig.9 c).The highest and lowest concentrations of silicate where repectively 15μM and 1.6 μM in the same area (Fig.10 d).

Nitrite showed a different pattern from the other nutrients, with the highest concentrations (1-3μM) occuring in offshore waters of relatively high salinty (Fig.9 b). This maximum in nitrite coincided with local maxima in silicate and phosphate (Fig. 9 c,d). The low salinity coastal water off Esbjerg contained less than 1μM of nitrite.. There was a marked decrease in nitrit concentrations in water with salinty above 34.5 (Fig. 8b and 9b). Atlantic water had a nitrit content of only 0.1 μM. The Baltic water in Kattegat contained more nitrite, but the concentrations were less than 1μM. The maxiumum concentrations of nitrite in the" high" salinity water west of Jutland probably had its origin in the River Rhine coastal area.

Chlorophyll fluorscence and suspended particles

The highest values of in situ chlorophyll fluorescence were observed in the coastal water off Esbjerg (Fig.10a). The fluorescence values decreased in the offshore direction and northwards along the western coast of Jutland. The distribution of suspended particles, based on measurments of water tranparency, showed a similar pattern to that of fluorescence. The highest values were found in the coastal water in south (Fig.10b). A local, offshore maximum in suspended particles west of Jutland coinsided with the maximum of nitrite found in the same area (Fig.9 b).

Chlorofyll fluorescence and suspended particles showed deacreasing values with increasing salinity for the stations in the area of the Jutland Current (Fig,11 e,f). Chlorophyll fluorescence is a relative measure of the amount of phytoplankton. Multiplication of the fluorescence with the depth of the stations indicated a fairly constant phytoplankton biomass per surface area at salinities less than 34 in the Jutland Current.

Relationship between nutrients and salinity

A plot of temperature vs. salinity in the Jutland current between 55 Deg. N and up to Limfjord revealed a close to linear relationship (Fig.11a). This indicates mixing of the freshwater with a relatively uniform Noth Sea water.
Similar plots of phosphate and silicate vs. salinity revealed also approximately linear relatinionship, indicating that physical mixing was the dominant process affecting the concentrations of these nutrients (Fig.11c,d). Elevated concentrations particulary of silicate at salinities around 34.5 suggest however different properties of the North Sea water. This might reflect water from the Southern Bight influenced by the River Rhine. Nitrate differed from phosphate in showing a non-linear relationship with salinity, with a marked change in slope around a salinity of 33.0 (Fig.11b). Below salinity of 33, there was an apparent linear increase in nitrate with decreasing salinity. The deviation from linearity suggest that nitrate was influenced by biological processes. Denitrification was probably the most important process since nitrate differed from phosphate in its behaviour.The high concentrations of nitrite in the Jutland current support the notion that denitrification was an important process in the coastal waters.

By exstrapolating the linear relatinoships between nutrient concentrations and salinity (below 33.0) to zero salinity, one can obtain estimates of the apparent nutrient concentrations in the freshwater source. The main freshwater source contributing nutrients is in this case the River Elbe and to a less extent the River Weser. The estimated apparent concentrations were 400µM and 20 µM for nitrate and inorganic phosphorus, respectivily.

Table 1. Apparent concentrations in µM of N,P og Si in freshwater and ratio between the nutrients (atomic) . Redfield ratio in parantes .

NO_3+NO_2	PO_4	SiO_4	N/P	N/SiO_4	SiO_4/P
400	20	200	20 (16.0)	2.0 (1.1)	10 (14.0)

The apparent N/P values of nutrients in the freshwater source was 20 which is somewhat higher than the Redfield ratio of 16 (Table 1). Despite this, the N/P values in the Jutland Current were significant lower than the Redfield ratio (Fig. 12a). This discrepancy probably reflected the removal og nitrate by denitrification. The largest relative loss of N compared to P occured at about 0.7 µM in phosphate and salinity of 33.0.
The apparent N/Si values of the freshwater source were higher than the Redfield ratio (Table1),whereas the N/Si values in the JCW was close to the Redfield ratio (Fig.12 b). The Si/P values was somewhat lower than the Redfield ratio in both the freshwater source and in the JCW(Table1,Fig.12c).

Water volumes and total amounts of nutrients

The percentage distributions of volume and area as functions of salinity in the JCW between 55 degr. N and the Limfjord and definitions are shown in Fig.13a. About 50 % of the JCW (S <34.0) was made up of water with salinity less than 33.2.

The volumes of freshwater(Vf) and seawater (Vs) in the coastal water that makes up the Jutland current can be calculated according to the following equations :

1) $Vf = 1/Sr \int V(s).\, ds$ $\quad$ Sr = Reference salinity (NSW)

2) $Vs = Vtot - Vf$ $\quad$ Vtot= Total volum= $35 * 10^{10}$ m^3

The average salinity (Sa) and the percentage content of freshwater (%F) in the coastal water are calculated as:

3) $Sa = Sr.\, Vs/Vtot$

4) $\%F = Vf/Vtot.100\% = (1 - Sa/Sr).100\%$

The average water depth(Ha) and average freshwaterdepth (Hf) are derived as:

5) $Ha = Vtot/Atot$

Atot= $1.59 * 10^{10}$ m^2

6) $Hf = Vf/Atot$

Table 2. Totalvolum (Vtot) , freshwater (Vf) and seawater volum(Vs), % freshwatercontent (%F), average salinity (Sa) and depth(Ha) and freshwaterdepth (Hf) in JCW (S< 34.0 %).

Vtot*10 ^6 (m3)	Vf*10^6 (m3)	Vs*10^6 (m3)	%F	Sa	Ha(m)	Hf(m)
350000	9000	341000	2.6	33.1	22	0.55

The resulting values derived from the above calculations are summearized in Table 2. The total amount of freshwater was $9 * 10^9$ m3 or 9 km^3. This was about 2.6% of the total volume in the JCW.
Relationships between the percentage of the total water volume and nutrient concentrations were estimated based on the the distributions of the nutrients in JCW (Fig. 14 b-d)

7) $NUTtot = \int V(NUT)\, .\, dNUT$

Where NUT is nitrate plus nitrite,phosphate or silicate. The resulting estimates of total amounts are given inTable3 together with the corresponding nutrient ratios and average concentrations.

Tabell 3 . Total amounts in tonnes of NO_3+NO_2 +(NH_4), PO_4 og SiO_4 in JCW (S<34%) . Observed(O) and with conservative mixing (C) between freshwater and NSW. Redfield ratio in parantes (atomic ratio). Average nutrient concentration i µM.

	$NO_{3,2}$	PO_4	SiO_4 (tonnes)	N/P	N/Si	Si/P	$NO_{3,2}$-	PO_4	SiO_4 (µM)
O	40500	13500	81000	6.6 (16)	1.0 (1.1)	6.6 (14)	8.2	1.2	8.2
C	80000	13000	84000	13.6(16)	1.9(1.1)	7.1(14)	16.3	1.2	8.5

The total amounts of observed nitrogen (nitrate plus nitrite) and phosphorus (inorganic phosphate) were 40.000 and 13500 tonnes respectivily, corresponding to an N/P ratio of 6.6 (atomic). Ammonium was not included in our program. If one assumes concentrations of 5µM and 2 µM at the lower and higher end of the range in salinity (L.Føyn Pers. comm.), this gives an additional amount of about 10.000 tonnes of N. This increase the total amount of N to about 50.000 tonnes and the N/P ratio to 8.2. Compared to rhe Redfield ratios, the estimated total amounts of nutrients revealed a nearly balanced situation between nitrogen and silicate, but a marked surplus of phosphorus relative to N and Si (Table 3) .
The apparent linear relationships between nutrient concentrations and salinity (Fig.11) have been used as basis for an alternative estimation of total amounts of nutrients (Table3). This calculation assumes negligible net biological consumtion of nutrients (conservative mixing) . Comparisons of the two sets of estimates of total amounts of nutrients reveal very similar results for phosphate and silicate. This strongly suggest a conservative behaviour of these nutrients in the autumn situation, with physical mixing being the predominant process affecting their concentrations. For nitrogen, in contrast, there is a large discrepancy between the two estimates. The total amount of nitrate and nitrite observed is only about half of what should have been present if physical mixing alone influenced the concentrations. Our calculations suggest therefore that about 50% of the nitrate plus nitrite had been removed by biological consumptions. As already stated, this was most likely due to denitrifcation.

Residence time of JCW

The ADCP current measurements in a section off Hanstholm in the period of 29. November- 1. Desember showed a northwards flow of JCW of 0.035 SV (1SV=10^6 m^3/s) . The width and the average depth of the current in this section were about 15 km and 15m respectiely and the average current velocity about 18 cm/s..The freshwatertransport during the observation period was about 700 m3/s. The annual average freshwater supply to the Southern North Sea is about 4500m3/s or about 150 km3 per year (ANON

-1987). When dilutet with North Sea water to a salinity of 33.0, this freshwater input is equivalent to a mean flow of about 0.1 SV in the Jutland Current. With a total volume of JCW of 3.5* 10 11 m3 (Table 2), this gives a mean residence time of JCW, from 55 Degr.N to Limfjord, of 40 days. By comparison, the flows and volumes of sea and freshwater found in this study (Table 2) give residence times of about 115 and150 days, respectively. This suggest that the situation in early December 1989 was characterized by redused flow of the Jutland current and a build up of coastal water off western Denmark.

The transport of nutrients was corresponding low. From the mean concentrations of nutrients (Table3) and the flow of the JutlandCurrent , the daily transports of N (nitrate plus nitrite) and P were 350 and 110 tonnes per day , respectivily.

Comparisons with the late autum situation in 1980-88

Our data from the JCW in the late autum 1989 have been compared to nutrients data from late autum in the years 1980-88 (L. Føyn unpupl. data), (Fig.14). The relationship between temperature and salinty in 1989 was close to the average situation for the years 80-89 (Fig 14a). This was also the case for the silicate- salinity relationship (Fig.14 d). In contrast, nitrate concentrations in 1989 were lower than found during the period 80-88 for salinities around 33 and higher (Fig.14 b) . Phosphate concentrations in 1989 were in the higher range of values for the 80-88 period, especially for salinities below 32.0. (Fig. 14c).

The high content of Phosphate in the JCW suggests lower consumation and / or higher concentrations of phosphate in the freshwater source i 1989 compared to the years 1980-88. The relatively low concentrations of nitrate, on the other hand, suggest lower nitrate concentrations in the freshwater and/or higher denitrification rates in 1989 than in the preceeding years. High nitrite values in the offshore part of the JCW at salinities around 34, has been a common occurence also in previous years (Fig.14e).The water flow of Elbe in the autum of 1989 was approximately half of the long term average (ANON. 1990 b). Data from the period 1985-89 show an inverse relationship between concentration and water flow for inorganic phosphate, whereas there was a positive relations hip for nitrate (ANON,1990a). Inorganic phosphate concentrations in the River Elbe behaved according to a theoretical relationship based on a constant input of phosphate being diluted by increased river flow. The input of nitrate, on the other hand, increased disproportionally with increasing run off, and the resulting nitrate concentrations increased asymptotically with increasing river flow (ANON.1990 a). Accordingly, the low river flow in the autum og 1989 was assoiated with relatively high concentrations of phosphate and low concentrations of nitrate. This may explain the deviations in phosphate and nitrate late autumn 1989.

Concluding remarks

Choking of the Jutland current

Water masses of Atlantic origin entering Skagerrak outside Hanstholmen seems to have a great influence on the JCW outflow . In periods with strong inflow of AW the Jutland current are probably choked. The redused outflow will consequently increase the amount of water and nutrients in the Jutland Coastal water. In periods with relaxing Atlantic transports the accumulated JCW can be flushed into Skagerrak in 2-3 weeks (Aksnes et.al. 1889). The supply of inorganic nitrogen to Skagerrak during such a 2-3 weeks "pulse" can be in the order of 100.000 tonn (Aure 1989). To get a better understanding of the seasonal frequences of JCW "pulses" into Skagerrak/Kattegat we need a better understanding of the controll mecanism connected to variations in the Atlantic inflow and "local" wind conditions.

Seasonality in nutrients in the JCW

The freshwater supply to the German Bight by the river Elbe shows a marked seasonality, with high flow in late winter and spring and low flow in the autumn (ANON1990a). Because of the different patterns in relation to river flow, the highest concentrations of nitrate occur in spring, while the hioghest concentrations of phosphate occur in autumn(ANON1990a). This seasonality in the input of nutrients is reflected in the nutrient pattern in the coastal water, where the the low input of nitrate in the autum as well as extensive denitrification lead to a surplus of P over N in the autum. This is evident in the data here (Table3, Fig.12a) as well as in data from the Helgoland Bight (Radach & Berg 1986).

On an annual basis, there is a large surplus of nitrate over phosphate in the riverine inputs (c.g Gerlach 1988). This is paticulary pronunced in the winter and the spring period, due to the high nitrate input (ANON 1990 a). As a result, there is a large exess of nitrate over phosphate and phosphate is the first nutrient, after silicate, to become limiting for phytoplankton growth (Lancelot et al. 1989 and Skjoldal & Dundas, in press).. The coastal waters of the southern North Sea and the Jutland coastal water is therefore limited by phosphorus rather than nitrogen in spring.

Influence of the Jutland Current on Kattegat and inner Skagerrak

The Jutland Current is expected to show large variability in flow with even intermittent reversal of the flow (c.g Heinbucher et al. 1986 and Aksnes et. al. 1989). Nevertheless, the JCW is kept as a coastal water mass by the Coriolis force and will sooner or later end up in Kattegat and inner Skagerrak. The maximum flow of the Jutland current is expected to be about 0.3 SV, in which case the transport time from the german Bight to northern Danmark will be of the order of 2-3 weeks. The JCW is heavier than the outflowing Baltic water and gets layered under this. Part of the JCW will flow south as an intermediate water mass into Kattegat,while another part is diverted northwards along the west coast of Sweden. The water from the Jutland current will gradually become entrained into the outflowing Skagerrak water and contribute to the Norwegian Coastal Current.

During the winter and spring when nutrient concentrations are higher and biological consumption limited, the Jutland Current transports considerable amounts anthropogenic nutrients into Kattegat and inner part of Skagerrak. It is likely that the Juland Current is the major source of eutrophication in Kattegat and inner Skagerrak (Aksnes et. al. 1989 and Barth& Nielsen 1989).

The large excess of N over P in the Jutland current during winter and spring can be traced as unbalanced (high) N/P ratios in the water underlaying the outflowing surface water of Baltic origin. This was the case prior to the bloom of the Chryochromulina Polylepis in may 1988 (Aksnes et.al. 1989 and Skjoldal & Dundas , in press) and similar ratios were found also in the spring of 1989 and 1990 (Inst. of Mar. Res.Bergen- Norway, unpupl. res.). Although difficult to prove unambiguously in each case, the general eutrofphication by N and P and the shift to P limitation through excess of N during the winter/spring period, must be expected to increase the frequency of flagellate blooms and among them, also of toxic species or algea with toxic properties (Skjoldal 1989).

References

Aure,J. (1989). Langtransporterte og lokale næringssalttilførsler til kystområdene i Skagerrak og Østlige Nordsjøen. Fagkonferanse ved SFT 12. des. 1989.

Skjoldal, H.R. (1989). Eutrofiering: Fosforbegrensning og fremvekst av skadelige alger. Fagkonferanse ved SFT 12. des. 1989.

Pedersen ,B.L., Richardson,K., Jacobsen,T.S. & Warren,R.(1988). The Jutland current: where is it and when?. Conference of the Baltic oceanographics, Kiel 1988.

Richardson,K., Jacobsen,T.S. & Olsen O.V. (1987). The Jutland current: A mechanism for transporting nutrients to the Kattegat? Proceedings Vol.2, ooctober 1987, Cobenhagen. From the CBO 15th confereence,Cobenhagen 1986.

Aksnes,D.L. ,Aure,J., Furnes G.K., Skjoldal H.R. & Sætre, R. (1989) analysis of the Chrysochromulina polylepis bloom in the Skagerrak,may 1988. Bergen Scientific Centre BSC/1 Junuary 1989.

Radach,G. & Berg,J. (1986). Trends in den konsentrationen der nahrstoffe und des phytoplanktons in der Helgolander bucht (Heloland reede daten).Ber. Biol. Anst., helgoland 2: 1-63 (1986).

Hainbucher,D. Backhaus,J.O. & Pohlmann,T.(1986). Atlas of climatological and actual seasonal circulation patterns in the North Sea and adjacent shelf regions: 1969-1981. Institute of Oceanography, University of Hamburg. Technical Report 1-1986

ANON 1987. Quality status of the North Sea -Summary. Second international conference on the protection of the North Sea 1987.

Lancelot et.al. 1989 ?

Skjoldal,R. & Dundas,I. Editors (1990). Chrysochromulina polylepis bloom in the Skagerrak and Kattegat in may-June 1988 : Environmental conditions, possible causes and effects. ICES workshop on the Chrysochromulina polylepis bloom in the Skagerrak and Kattegat in may-june 1988. Bergen 28. Febr.-2. March 1989.

Barth, H. & Nielsen, A. (1989). The occurence of Chrysochromulina polylepis in the Skagerrak and Kattegat in May-June 1988: An analysis of extent, effects and causes. Commision of the European Communities. Water Research Report 10.

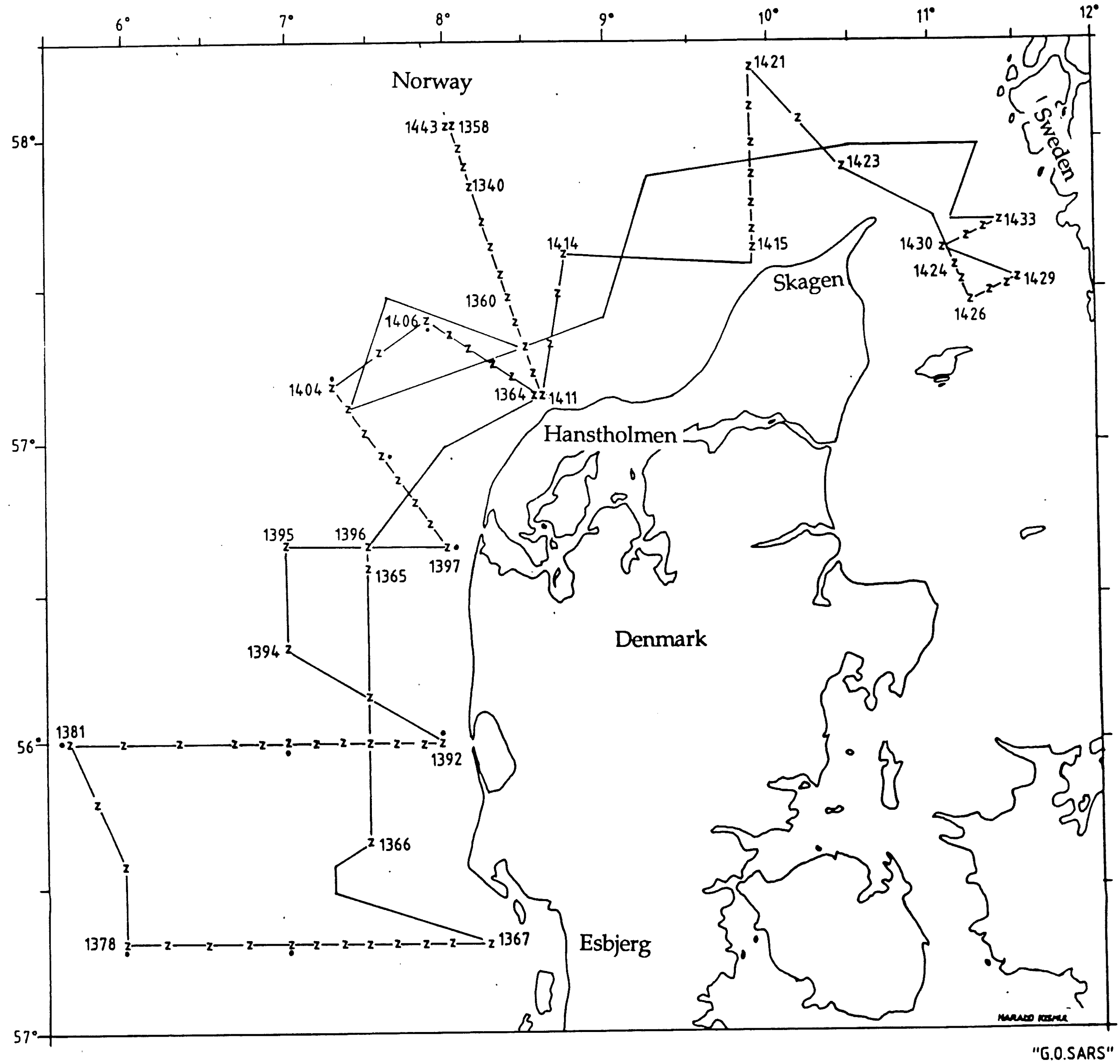

Fig.1 Ship tracks and CTD/Nutrients/Chlorofyll stations. Nov.27-Dec.6, 1989

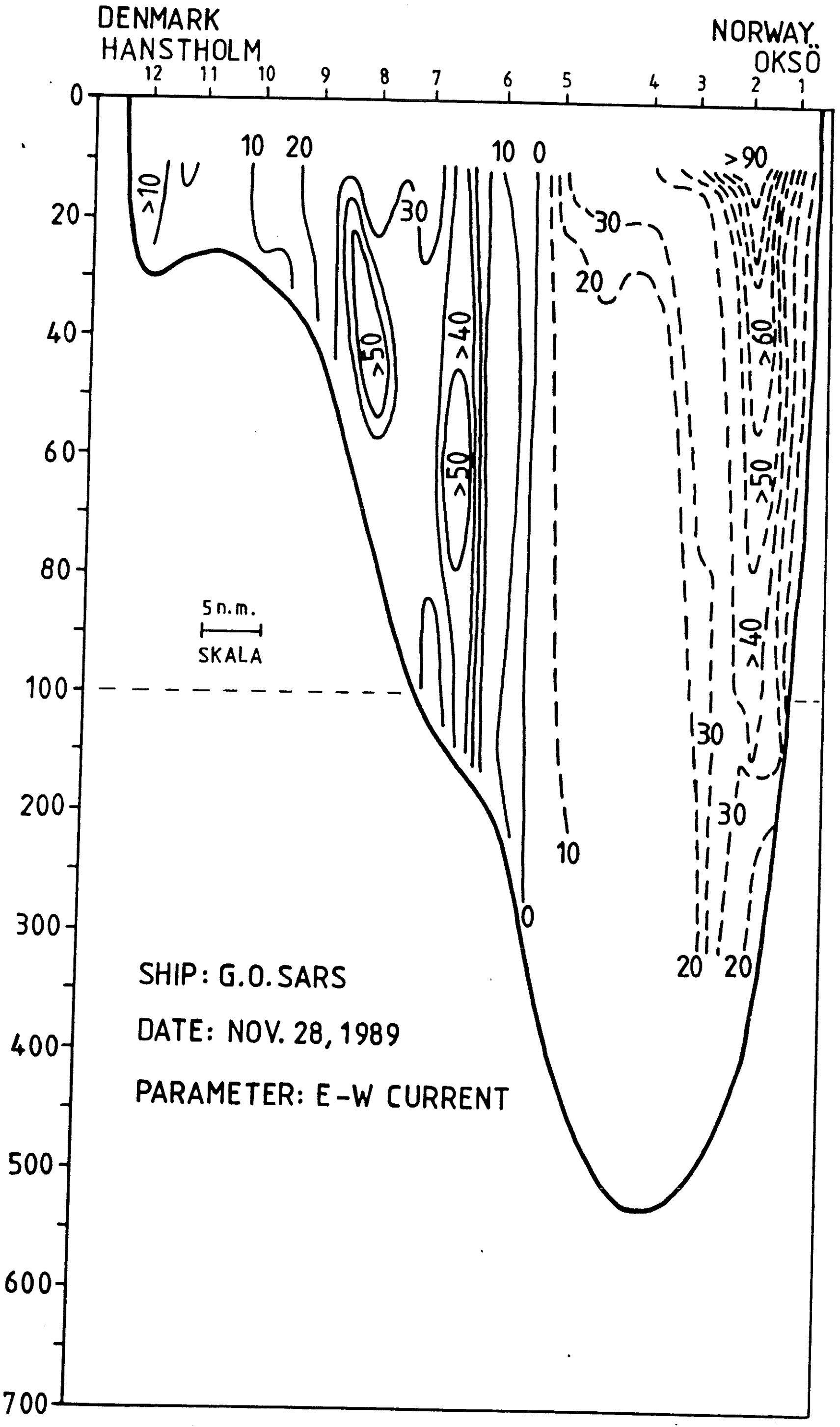

Fig.2 Vertical section of ADCP east-west current component between Norway and Denmark

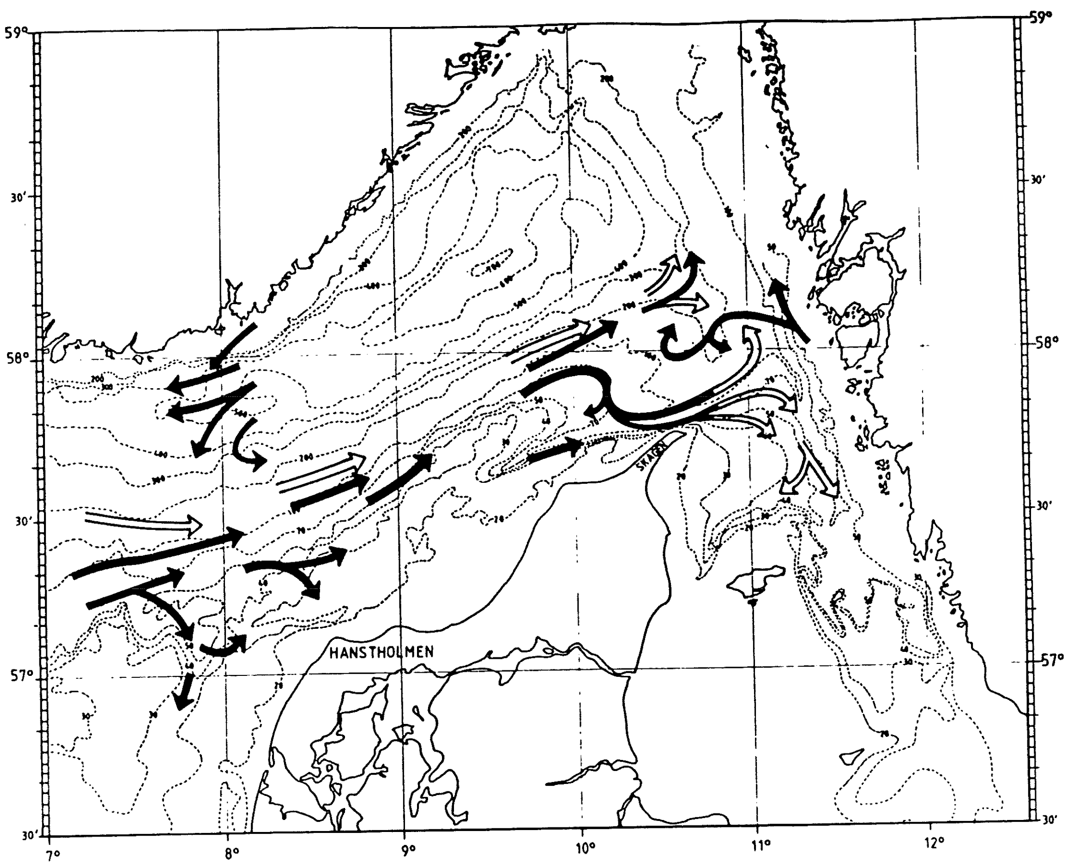

Fig.3 Schematics of observed circulation in the near surface (full) and "deeper" (open) water.

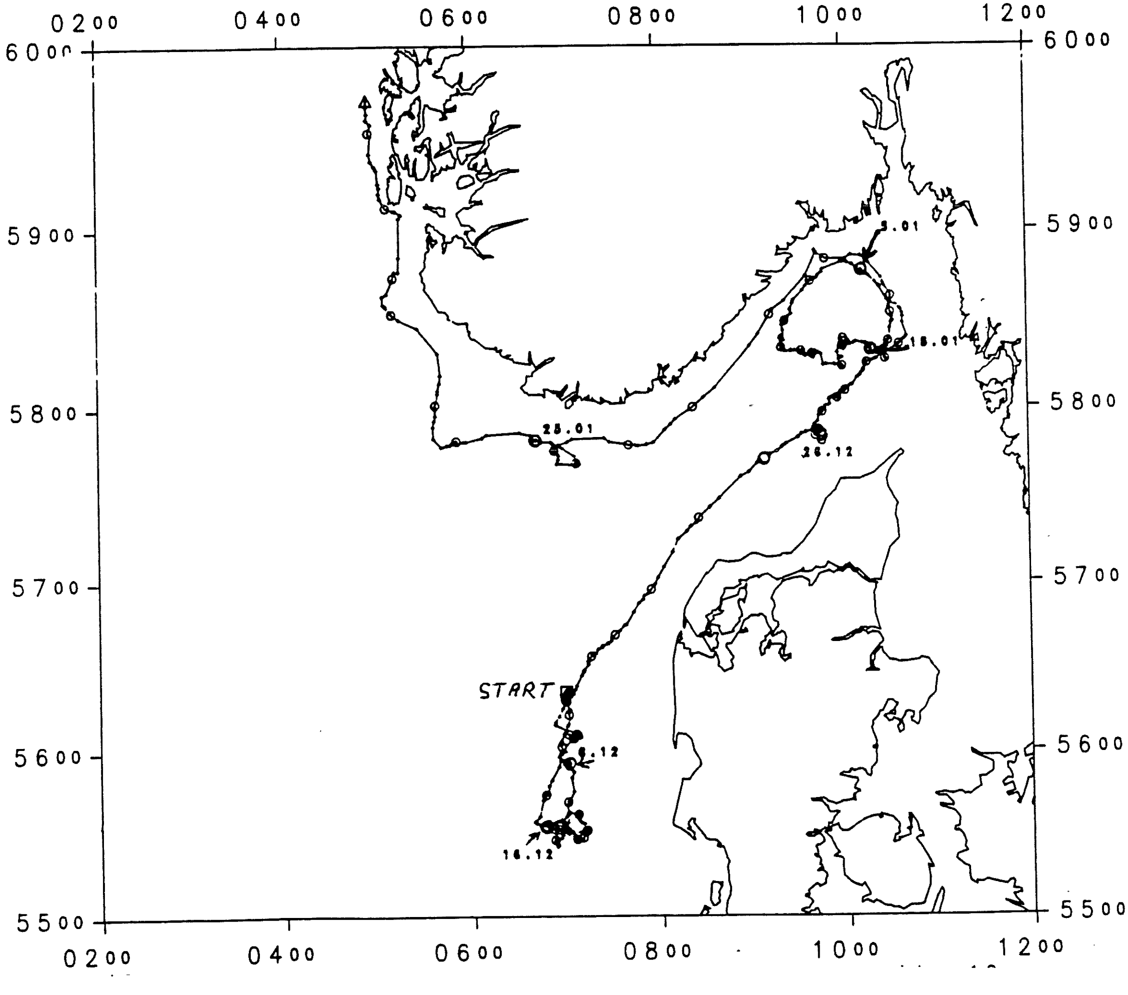

Fig.4 Argos (sail in 10m) drift tracks from Dec.1,1989-Jan.31,1990
Marks every day (every 10 day)

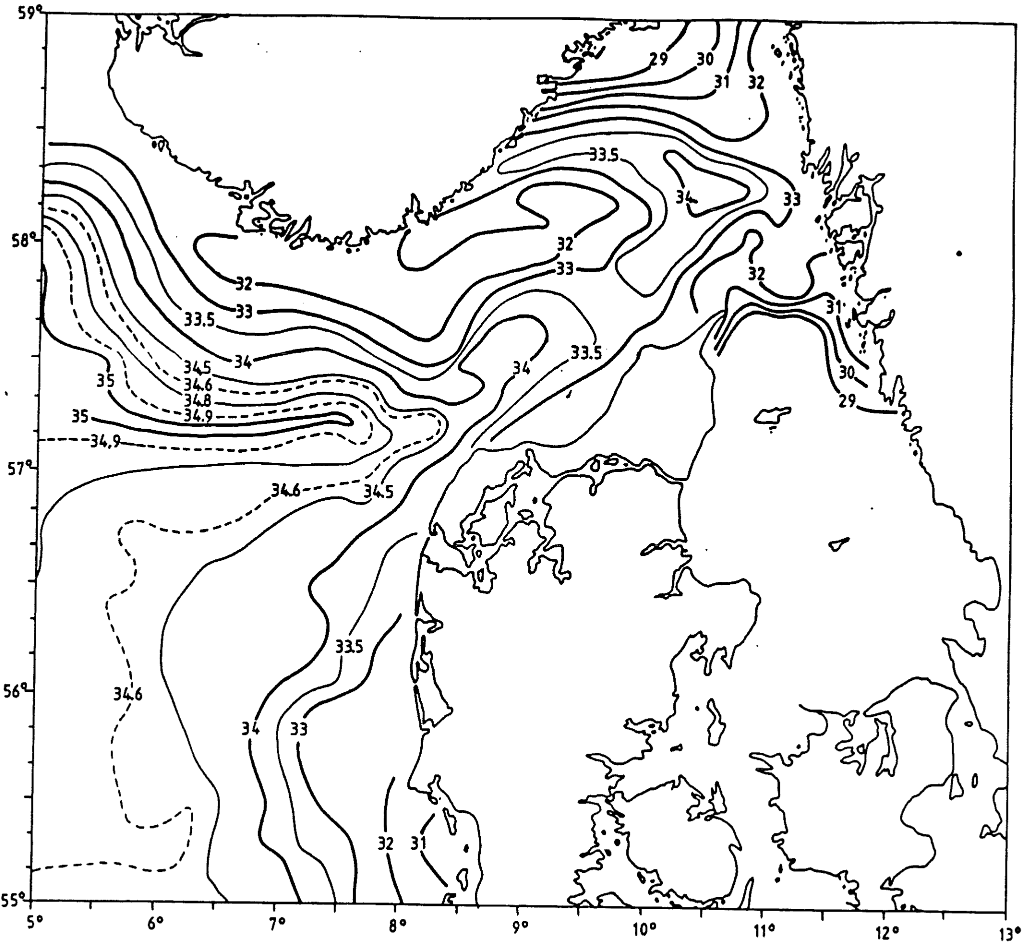

Fig.5a Salinity at 5-10m depth (combined G.O.Sars and Eldjarn)

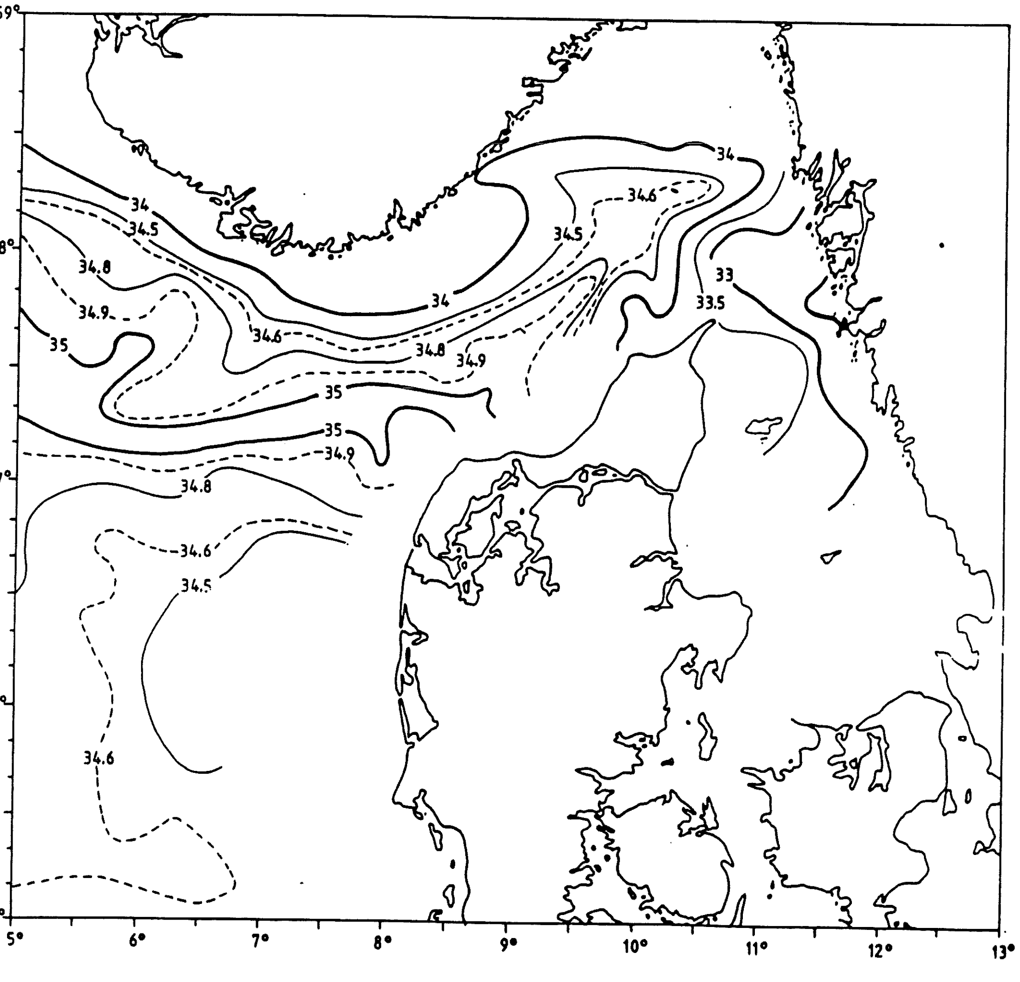

Fig.5b Salinity at 35-40m depth (combined G.O.Sars and Eldjarn)

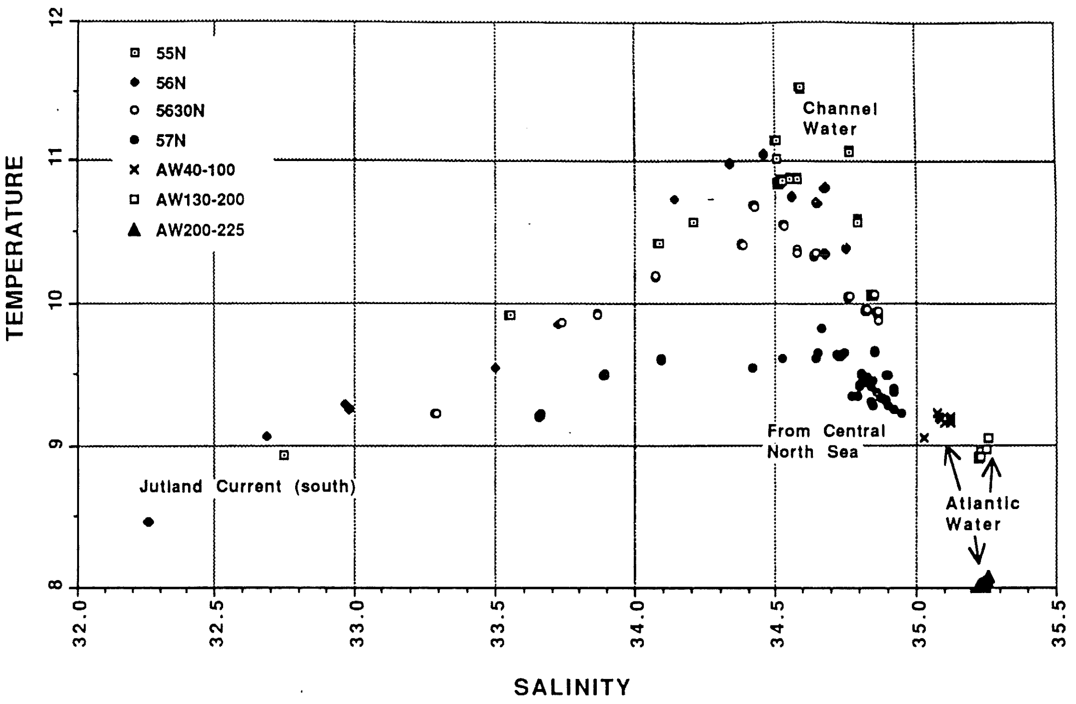

Fig.6 T-S relations from separate latitudal sections west of Denmark, and AW near Hanstholmen

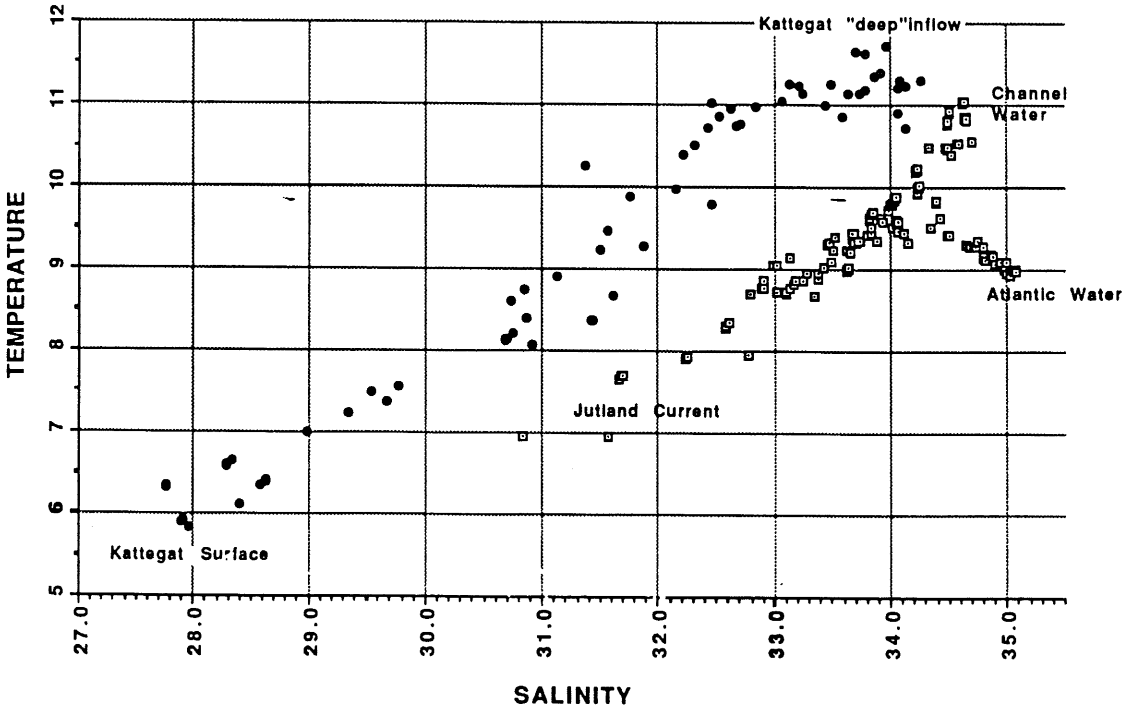

Fig.7 T-S relations separated west and east (Kattegatt) of Denmark

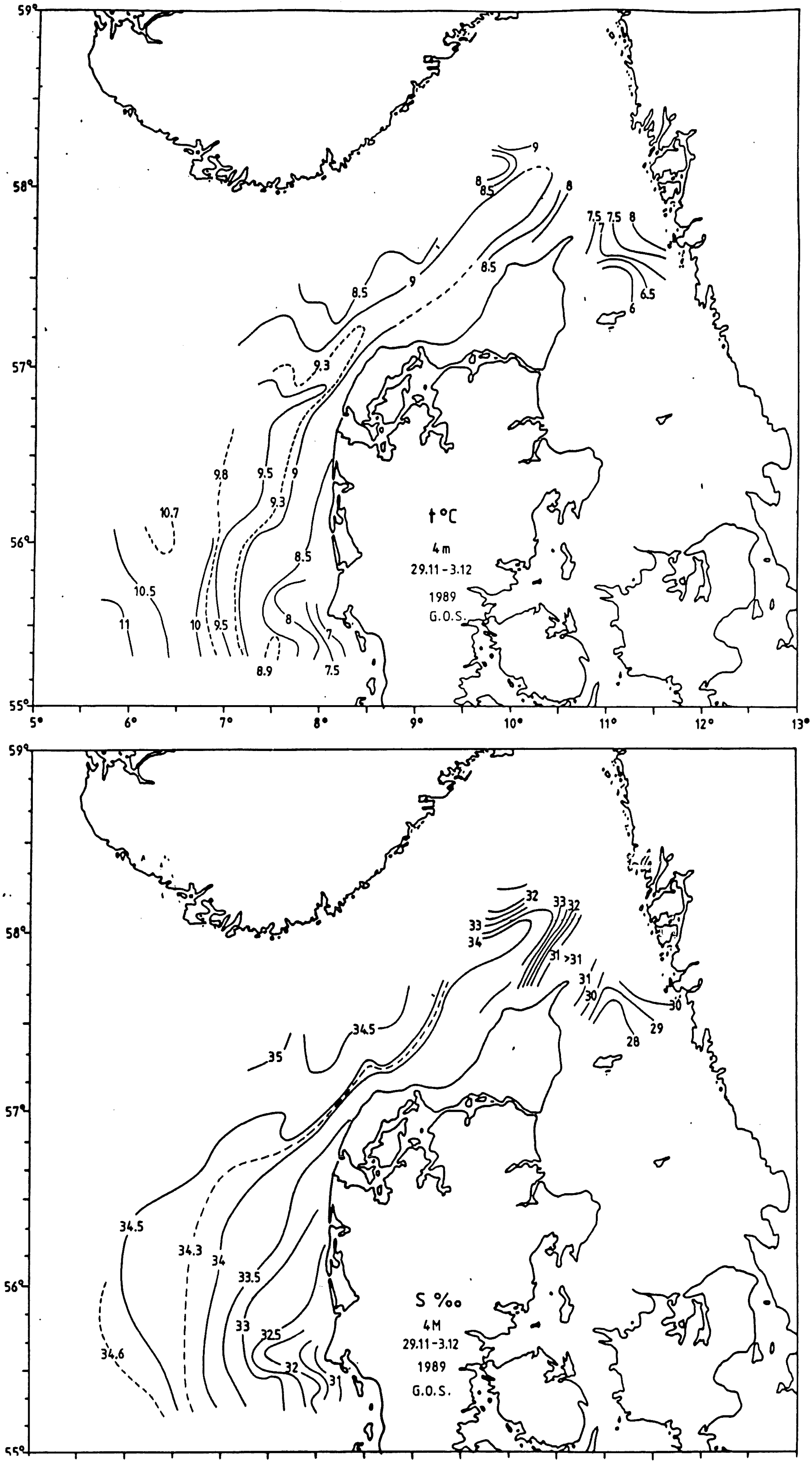

Fig.8 Horisontal distribution of temperature and salinity in 4m depth.

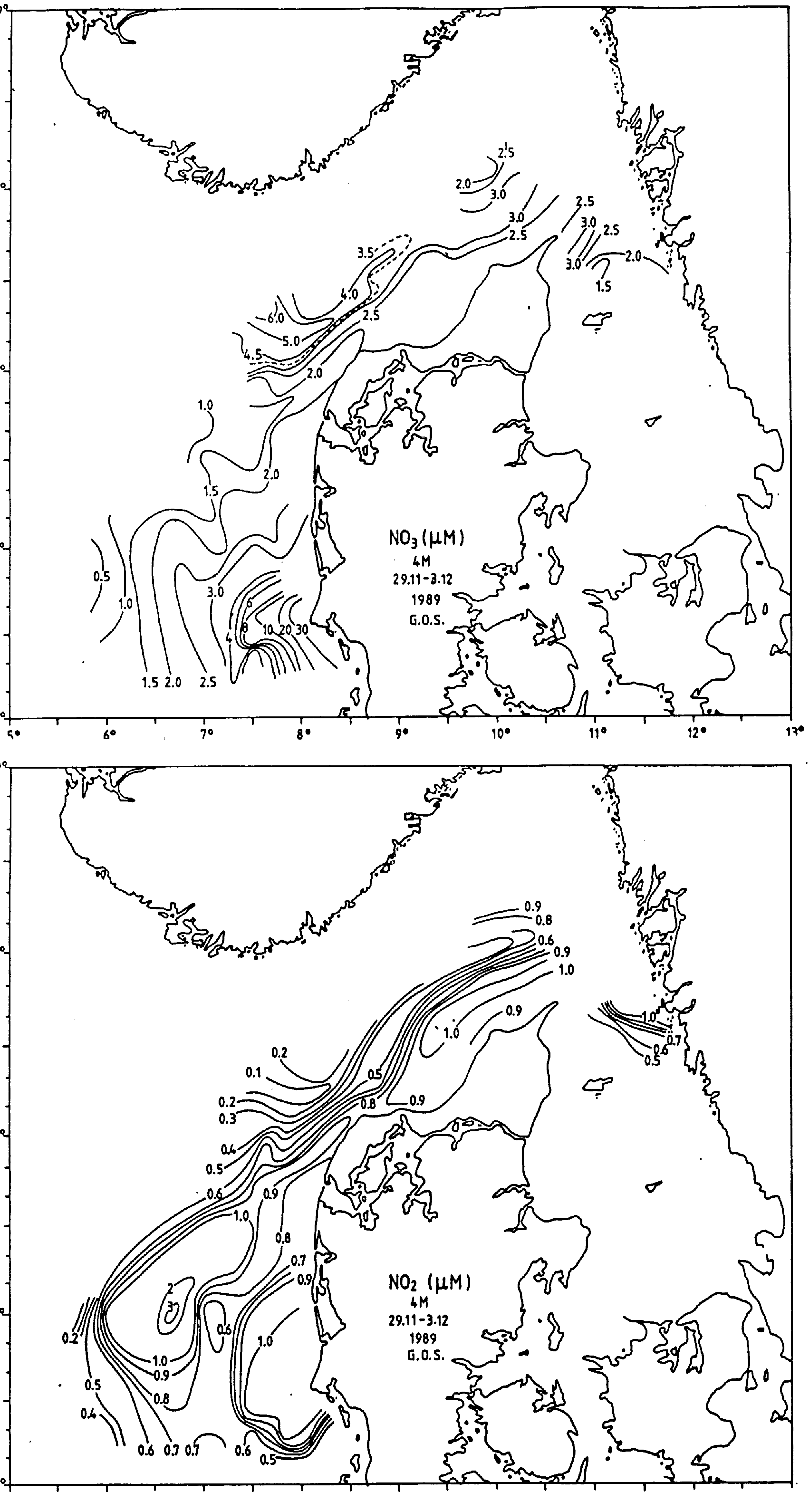

Fig.9 a,b Horisontal distribution of nitrate and nitrite in 4m depth.

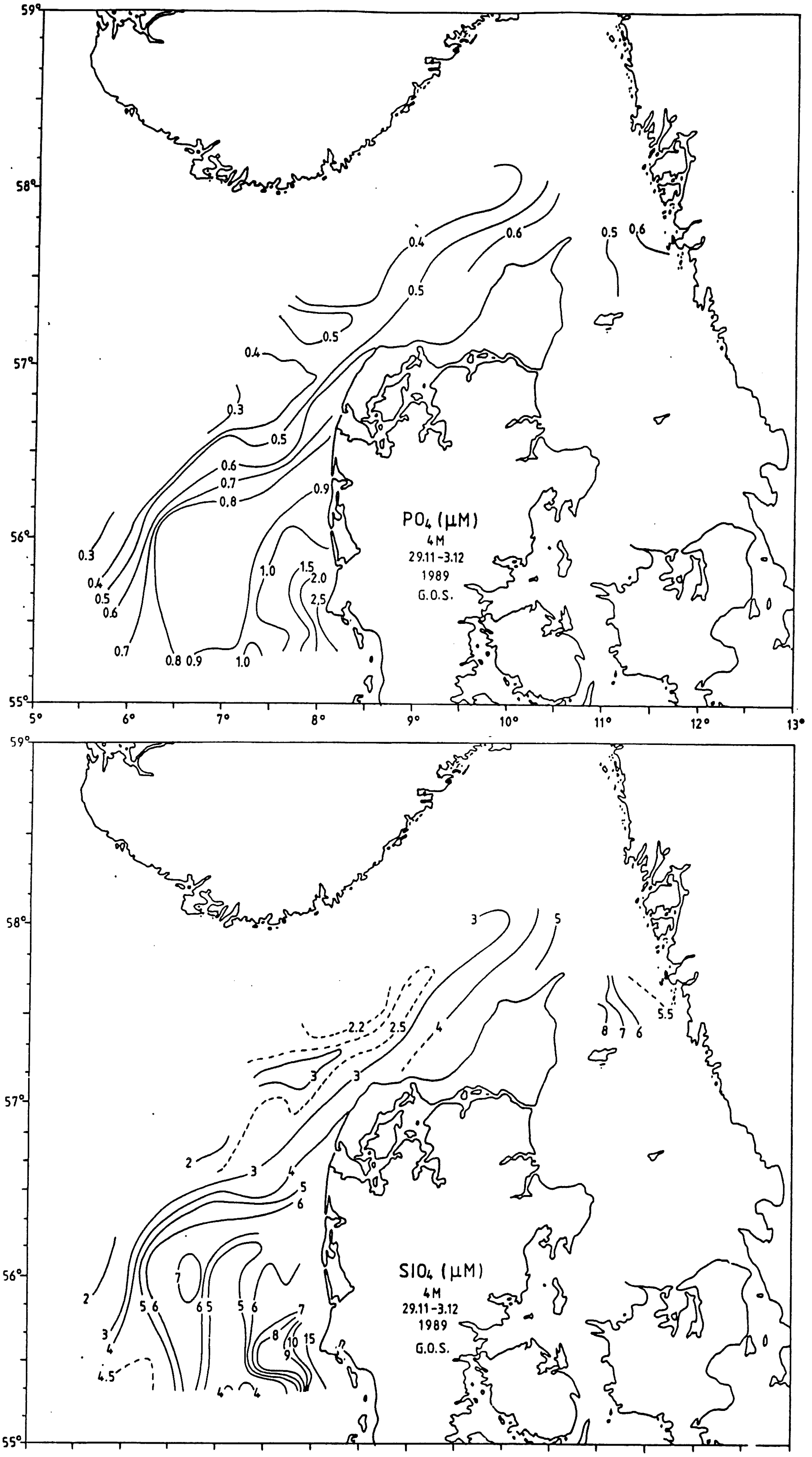

Fig.9 c,d Horisontal distribution of phoshate and silicate in 4m depth.

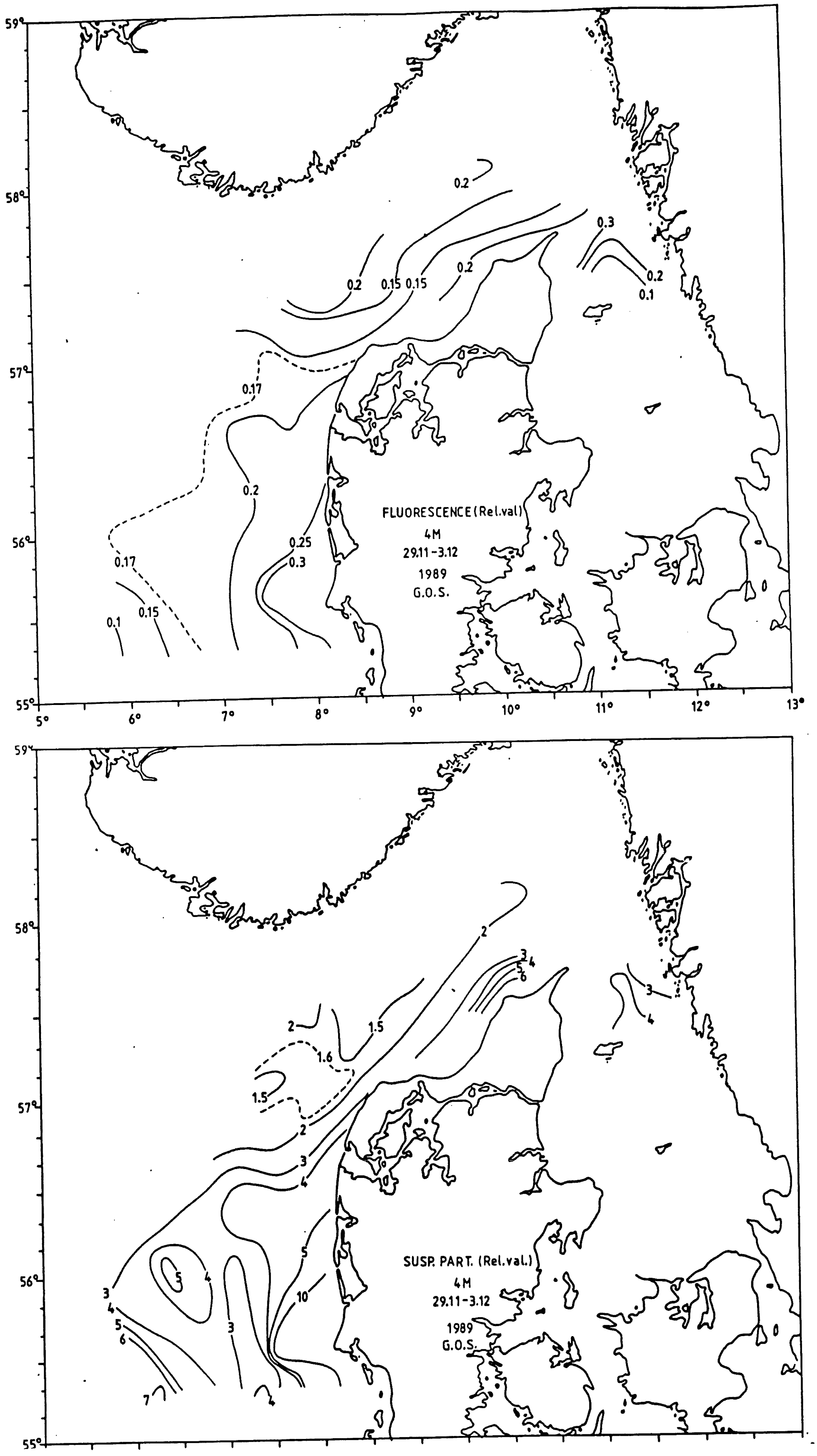

Fig.10 a,b Horisontal distribution of fluorescence and suspended particles in 4m depth.

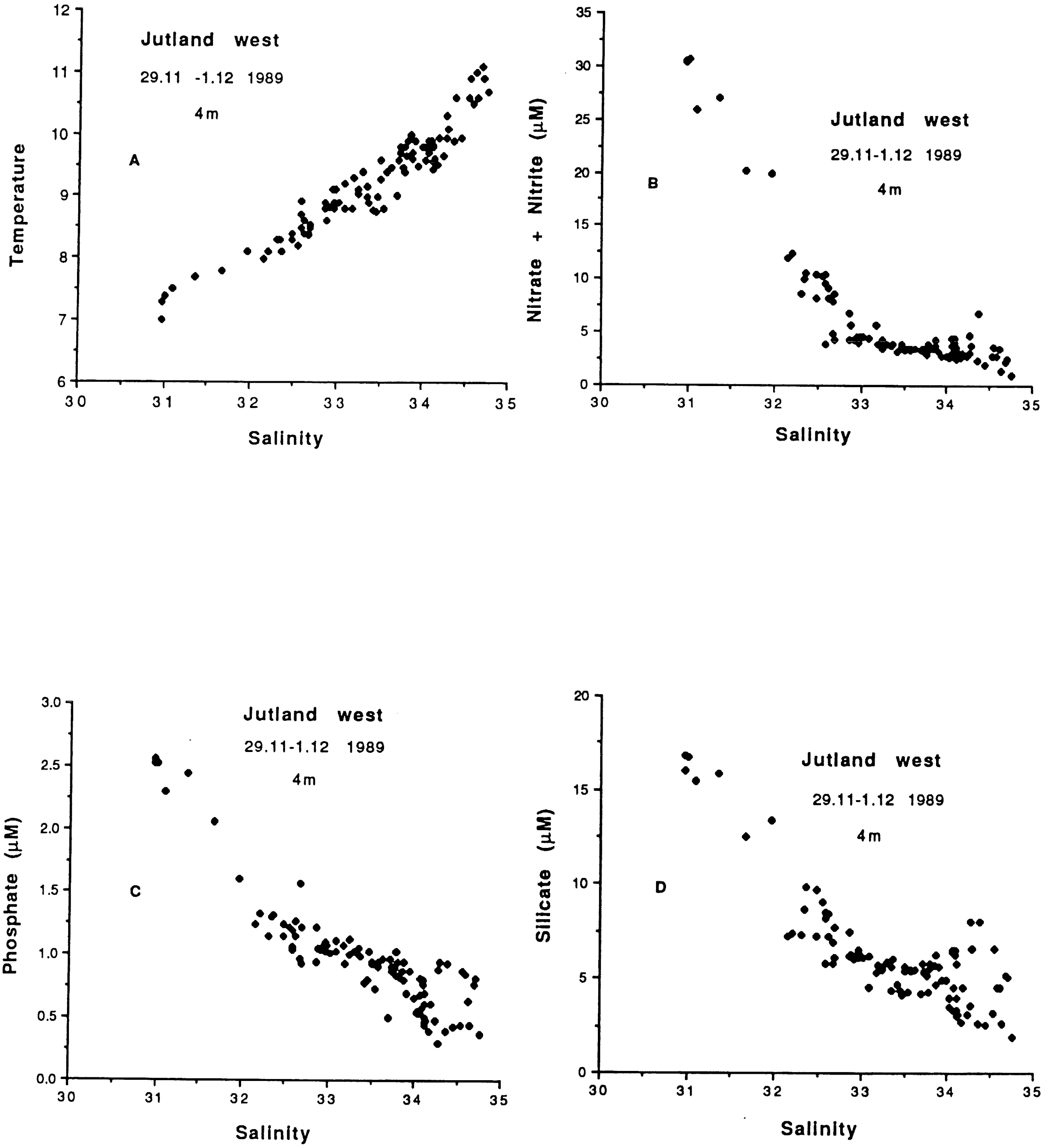

Fig.11 Salinity/ temperature(A), -/nitrate-nitrit (B), -/ phosphate (C) , -/ silicate(D),- /susp. - part.(E) and fluorscence (F) plots in Jutland Coastal Water 29.11-1.12 1989.

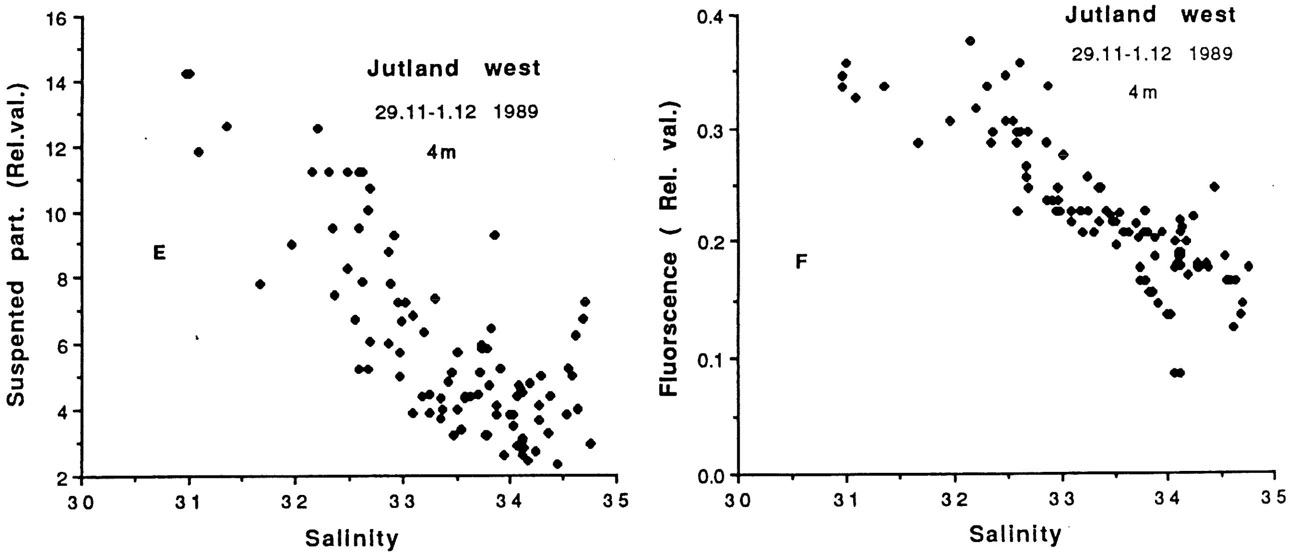

Fig. 11 Cont.

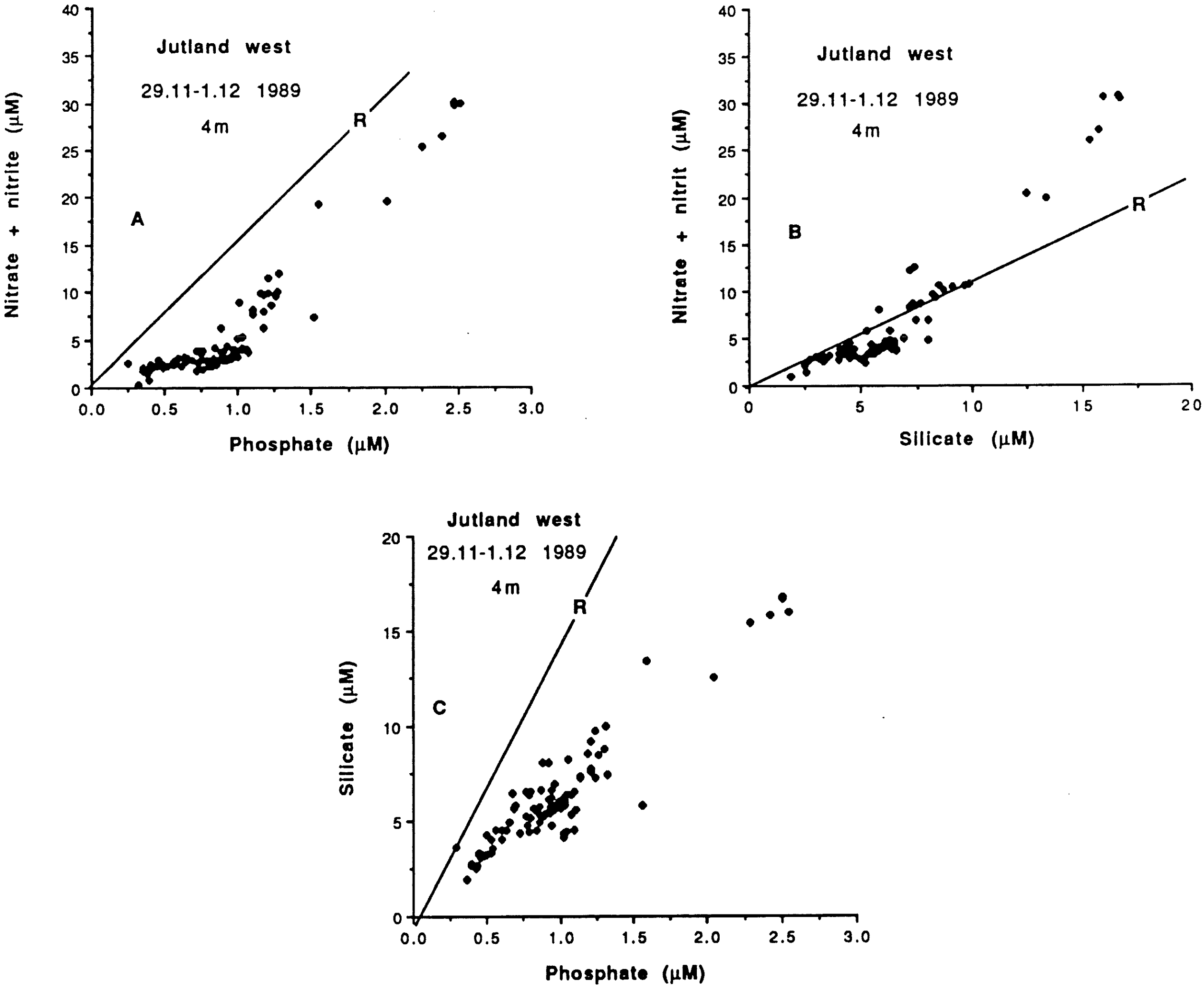

Fig.12 Nitrate-nitrite/phosphate (A), -/silicat (B) plots and silcate/phosphate plot(C) i Jutland coastal water 29.11-1.12 1989. Redfield ratio (R)

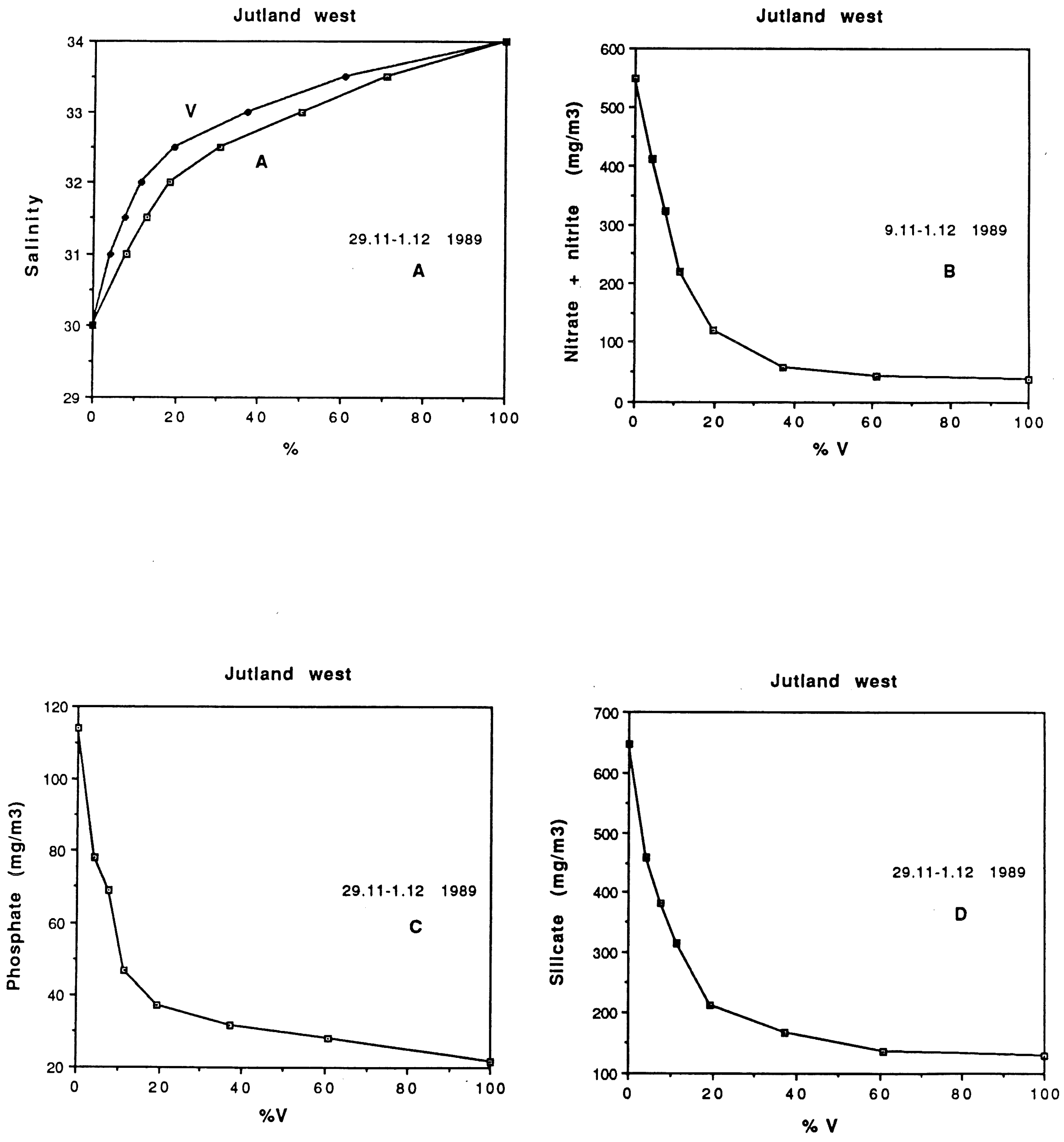

Fig. 13 % volume and area with salinity lower than S (A). % volume with concentration of nitrate-nitrite higher than N (B), higher than P (C) and Si (D).

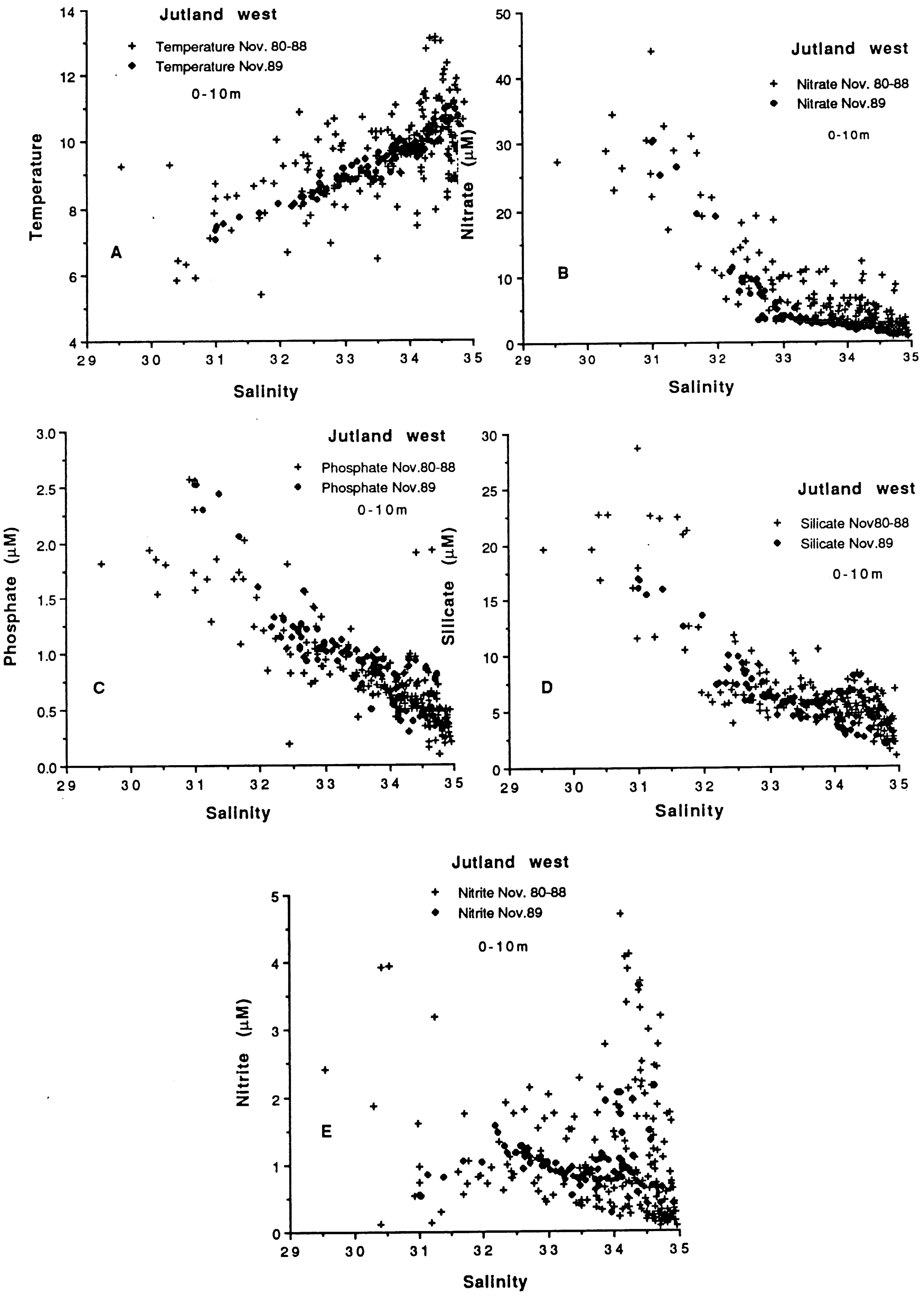

Fig. 14 Salinity / temperature (A), -/nitrate (B), -/phosphate(C),-/silcate (D) and -/nitrite (E) plots in late autum 1980-88 and in 1989.