NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE FOR MARINE ENVIRONMENTAL RESEARCH

CRUISE REPORT

RRS CHALLENGER 17/87

6th July - 2nd August 1987

OBJECTIVES

LEG 1

1. To measure the concentrations and distribution of major nutrients in the North Sea with particular emphasis on the sea areas bordering the major estuaries.

2. To measure the rates of primary production and nitrogen assimilation of phytoplankton, and their horizontal distribution in relation to nitrogen inputs.

3. To measure the variations in the natural abundance of ^{15}N in particulate and dissolved nitrogen and to relate these to the inputs and internal cycling of nitrogen.

4. To measure sedimentation rates of particulate matter at selected sites in the North Sea.

5. To measure the rates of denitrification in the sediments of the North Sea.

6. To characterize the natural phytoplankton populations using shipboard flow cytometry.

7. To determine the distribution and concentrations of dissolved and particulate-bound trace metals with particular emphasis on the regions around estuarine plumes.

8. To measure the concentrations and sizes of natural particulate material using in situ sizing techniques and to compare the results obtained with those from conventional techniques.

9. To determine the numbers of cyanobacteria in the North Sea and to measure their rates of photosynthesis and various physiological/ecological properties.

LEG 2

1. To deploy the IMER offshore mesocosm and to conduct time series experiments of 2 - 3 days duration in relation to enrichment of the water column by plant nutrients.

2. To investigate, in detail at one site, aspects of denitrification.

3. To conduct investigations on the populations, physiology, size and trophic structure of natural populations of plankton using shipboard flow cytometry.

PERSONNEL

LEG 1

N J P Owens (Principal Scientist)
E M S Woodward
I E Bellan
C S Law (Research student - Dundee University/IMER)
Elaine Drury (Sandwich student - Bath University)
C Barratt
D B Robins
A J Bale
R J M Howland
J A Stephens
Kate Howard (Research student - Warwick University/IMER)
S Ackleson (USA - Bigelow Laboratory)
A Jones (RVS)
C Woodley (RVS)

LEG 2

N J P Owens (Principal Scientist)
E M S Woodward
I E Bellan
C S Law
Elaine Drury
P H Burkill
D B Robins
N G Bowley
T Cucci (USA - Bigelow Laboratory)
A Jones (RVS)
K Smith (RVS)

ITINERARY: (Times GMT)

LEG 1

7th July	0700	Sailed Troon
8th July	0910 - 1050	Trial Station (SD)
	1500	Commenced surface monitoring
9th July	0722 - 0830	Station 1
	1909 - 2019	Station 2
10th July	0900 - 1348	Station 3
11th July	0115	Arrived Station 4
	0306	Sediment trap deployed
	0326	Incubation rig deployed
	1939	Incubation rig recovered
12th July	0255	Recovery of sediment trap
	0414	Departed Station 4
	1417 - 1520	Station 5

13th July	0152 - 0205	Station 6
	0717	Station 6A
	1444	Coring Station 6B
	1715	Coring Station 6C
	1737	Coring Station 6D
	1756 - 1822	Station 7
	2139 - 2216	Coring Station 7A
14th July	0713 - 0819	Station 8
	1751 - 1925	Station 9
15th July	0715	Station 9A
	1631	Arrived Station 10
	1726	Deployed Sediment trap
16th July	0835	Incubation rig deployed (delayed due to fog)
	1727	Recovered incubation rig
	1750	Sediment trap lost
	1757	Departed Station 10
17th July	0709 - 0741	Station 11
	2118 - 2201	Station 12
18th July	0610	Commenced Humber Grid
	0752	Station 12A
	1700	Completed Humber Grid
19th July	0243	Arrived Station 13
	0343 - 0355	Sediment trap and incubation rig deployed
	1813	Incubation rig recovered
20th July	0358	Sediment trap recovered
	0414	Departed Station 13
	1239 - 1329	Station 14
	2047 - 2128	Station 15
21st July	0330 - 0413	Station 16
	1120 - 1138	Station 17
	1950 - 2019	Station 18
22nd July	0725 - 0807	Station 19
23rd July	0900	Arrived Gt. Yarmouth - End of LEG 1
LEG 2		
24th July	1200	Departed Gt. Yarmouth
25th July	0958	Arrived Station 212 - CTD and coring at intervals
27th July	0530	Mesocosm deployed
	1546	Recovery of mesocosm
	1818	Departed Station 212

28th July	0756 - 0955	Station 207
	0846 - 0902	Box coring Station 207A
	0948 - 0953	Box coring Station 207B
	1326 - 1536	Box coring Station 207C
	1631 - 1708	Box coring Station 207D
	1719 - 1725	Station 207E
29th July	0820	Arrived Station 210
	0858	Sediment trap deployed
		CTD and coring at intervals
30th July	0408	Incubation rig deployed
	0845	Sediment trap recovered
		CTD and coring at intervals
	1900	Incubation rig recovered
	1928	Depart Station. Proceed towards Plymouth because of leaking stern gland
2nd August	1100	Arrived Plymouth. At anchor
3rd August	1000	Completed unloading. Cruise ends.

PROCEDURES AND METHODS

Two types of approach were adopted to meet the objectives of the cruise.

(a) Continuous monitoring of surface variables
(b) Discrete sampling for state and rate measurements.

CONTINUOUS SAMPLING

Continuous sampling of surface variables was carried out throughout the cruise period apart from periods when stations were occupied for vertical profiling and/or sediment traps. Sampling underway was carried out on water collected from a sub-surface pump (~ 1.5 m) and piped into the laboratory. Analyses were performed for nutrients: NO_3, NO_2, SiO_3,, PO_4, NH_4, and urea using colorimetric techniques. Temperature and salinity were measured continuously and logged on microcomputer using RVS thermosalinograph. Ship's position was continuously logged using microcomputer. IMER surface measurements were continuously logged using new (to IMER) logger and microcomputer. In addition a considerable amount of information on the horizontal and vertical distribution of chlorophyll fluorescence, temperature and underwater light environment was obtained using the Mark III UOR.

DISCRETE SAMPLING

Discrete samples were obtained from various depths using CTD rosette, NIO water bottles and, whilst underway, from a manifold in the pump system. Samples were collected for particulate C and N analysis, chlorophyll, phytoplankton species and abundance, soluble and particulate ^{15}N.

On board flow-cytometry was carried out using EPICS V and FACS instruments. Particles were further characterised using Coulter TAII

and in situ laser diffraction instruments.

RATE MEASUREMENTS

Surface phytoplankton production was measured using the ^{14}C assimilation technique. Samples collected underway were incubated at constant light (~ 100 μ Em^{-2} sμ) at surface seawater temperature. The use of this protocol enabled all incubations to be normalised for light, irrespective of their time of collection. Surface samples were collected at approximately 3 hourly intervals whilst underway but at more frequent intervals when steep gradients were encountered. Depth related production was also measured on four occasions using an in situ incubation rig. All primary production measurements were made using size-fractionation techniques. Size fractionated nitrogen assimilation rates were measured concurrently with primary production measurements using ^{15}N techniques. ^{15}N measurements were made at sea for the first time using an automated on line combustion analyser - isotope mass-spectrometer.

Sedimentation rates were measured using moored, DAFS designed sediment traps.

Denitrification in sediments was measured at a variety of sites using the acetylene blockage technique. Sediment samples were collected using a Calvert type box corer. Gas analyses from sediment core incubations were performed on board using a gas chromatograph.

EQUIPMENT PERFORMANCE AND OVERALL SUCCESS OF CRUISE

LEG 1

All the major objectives of the first leg were met. The ship performed well and no time was lost due to bad weather. One complete sediment trap system was lost during recovery. A number of logging systems were used for the first time - these proved very successful. 7 CTD rosette water bottles were lost due to failure to check locking nut. All surface measurements and chemical analyses were carried out successfully. An isotope mass-spectrometer was deployed for the first time. This worked with 100% success. Comments regarding other individual instruments are outlined below. Surface measurements were made over a total distance of 2400 N miles and 74 on-track, surface discrete samples collected.

LEG 2

This leg was less successful. The IMER mesocosm was launched but failed to deploy correctly. The skirt material and support hoops were damaged irrepairably during the recovery. The fault lay with an incorrect amount of ballast. The future of such as mesocosm is in doubt unless a considerable amount of professional design and testing can be found to support the project.

The cruise was terminated early due to the failure of the ship's stern gland.

PRELIMINARY RESULTS:

Hydrography : N J P Owens

Figure 1, the cruise track, shows that a good coverage of the North Sea was obtained. No particularly unusual features in the hydrography were observed. As expected, the area was divisible into a thermally stratified region to the north with vertically well mixed conditions to the south. Surface temperatures varied from 13°C in the north to 18°C in the near continental region in the south. The thermocline was situated between 20 and 30 m, there being typically a 7°C difference between surface and bottom water temperatures. Marked salinity gradients were observed in the southern, near-shore regions. The chlorophyll a distribution is shown in Figure 2. No exceptionally high concentrations were observed, the maximum concentration reaching 5 mg m^{-3} in the German Bight. Elevated concentrations were also observed off the mouths of the Humber and the Wash.

Nutrients : E M S Woodward and R J M Howland

Using conventional techniques, nutrient concentrations approaching undetectable amounts were observed over the majority of the stratified region. The bulk of the data remains to be calculated but qualitatively, high concentrations of all nutrients were observed to the south. Maximum NO_3 and NH_4 concentrations were generally found in the German Bight and were respectively 8 µ mole l^{-1} and 2.5 µmol l^{-1}, however, concentrations of NO_3 of approximately 20 µmole l^{-1} were observed off the mouth of the Scheldt estuary.

By using chemiluminescence techniques it was possible to obtain a realistic distribution of NO_3 in the severely nutrient depleted waters (see Figure 3). The lowest concentrations were <10 nmole l^{-1} and were found in the extreme north-east of the sampling region and off north-east Scotland. Elevated concentrations - up to 1 µmole l^{-1} were observed around the Shetland Isles - possibly due to island induced upwelling, and an unexplained area in the central North Sea where concentrations exceeded 100 nmole l^{-1}. Vertical profiles of NO_2 and NO_3 (not shown) consistently showed an increase in concentration at the surface.

Ammonia and Aluminium - R J M Howland

This cruise marked the first deployment of a prototype FIA system for measuring ammonia. The system worked extremely well with good data being obtained for the Humber, Weser, Ems and Rhine plumes. However, one problem that was identified was the build-up of tiny bubbles in the transmission tubing due to an excessively high temperature (up to 34°C) in the temperature-controlled box that housed the system. This was made worse by the fact that it was extremely difficult to clear bubbles from the flowcell which is presently being used. This problem should be straightforward to rectify.

Aluminium samples were taken four hourly over the whole grid, and at all depths worked on the vertical profiles. The samples were taken in

triplicate and analysed on board. Good replication was achieved, even at the trace levels (0.2 µg l^{-1}) found in the north of the region. Highly elevated levels of aluminium were observed in the plumes of all the major rivers (up to 5 µg l^{-1}) and were generally an order of magnitude above those in the north.

Primary production and nitrogen assimilation : N J P Owens and E Drury

A total of 73 surface measurements of primary production and nitrogen assimilation and four *in situ* incubations were made. A notable success achieved during the cruise was the analysis of all ^{15}N tracer samples by on board mass-spectrometry. This was the first deployment at sea of a fully automated sample preparation and mass-spectrometer system. Figure 4 shows the distribution of f NO_3^- - the proportion of primary production supported by nitrate. The figure shows that over much of the North Sea during this period nitrate supported only a small proportion of the total primary production.

UOR : I E Bellan and C Barrett

The UOR was towed on 29 occasions for a total of 209 h and 1921 N miles (Figure 5). The data logger failed on two tows resulting in a loss of 9% of data. The servo motor failed on two tows resulting in loss of undulations. Data from Tow 22 are shown in Figure 6. This tow traversed the front between the thermally stratified northern North Sea and mixed water to the south. This can be seen clearly from the depth distribution of temperature where the 16°C isotherm (highlighted) increases in depth from approximately 5 m to 20 m along the course of the tow. Associated with the breakdown of the thermocline (front) was a marked increase in chlorophyll concentration, from approximately 0.5 mg m^{-3} in the stratified water to over 5 mg m^{-3} at the front.

Physiological ecology of cyanobacteria : K Howard

Photosynthesis/irradiance experiments were carried out, at 20 sites. 50 ml sample bottles were inoculated with ^{14}C bicarbonate and incubated for 5 hours in a light gradient (cooled with circulating water at ambient temperature). These samples were size-fractionated into, >1.0 µm fraction ad 1.0 - 0.2 µm fraction, on nucleopore filters.

In addition, a time course for cellular ^{14}C incorporation and extracellular organic ^{14}C release, was set up for each of the 20 sites. 50 ml samples were inoculated with ^{14}C and incubated at near to *in situ* conditions in a lab incubator, for up to 48 hours. At various times 4 bottles were removed and size-fractionated into the two fractions. The filtrate was collected, acidified and returned to the lab for analysis. Preliminary results for the cellular fractionation of these samples show that for both size fractions most ^{14}C is incorporated into protein. There is slightly more label in the lipid than the polysaccharide fraction after 48 hours and the amount of label in small molecular weight metabolites remains low throughout the time course.

Numbers of cyanobacteria were counted and size-fractionated chlorophylls measurements were taken at each of the 20 bottle drops.

The abundance of cyanobacteria in the North Sea was investigated using epifluorescence microscopy. Surface samples were taken at 4 hour intervals and a number of vertical profiles were also investigated.

Surface numbers of cyanobacteria ranged from 2×10^3 cells/ml to 1.6×10^5 cells/ml, there being no apparent trend in the distribution.

Denitrification : C S Law

Denitrification was measured at a number of sites in undisturbed sediment cores using the acetylene blockage technique with on board measurement of the products using electron capture gas chromatography. The results are summarised in Figure 7. Highest rates of denitrification were found in the east of the North Sea where approximately 100 µmole N_2 production M^{-2} day^{-1} was measured. The rates of N_2O production were generally low throughout averaging approximately 1 µmole N_2O m^{-2} day^{-1}.

Trace metals : A J Bale

Fifty-three large volume water samples were collected to give a thorough coverage of the North Sea but with extra emphasis placed on sampling in the estuarine plumes. The samples were filtered and the metals extracted using ion-exchange resins under clean-air conditions on board. The eluted metal concentrates were returned to the laboratory and have been analysed for selected trace metals (Zn, Cu, Ni & Cd). Spatial distributions of the metals will be prepared when the data is combined with navigational information.

In situ Particle sizing : A J Bale

In situ particle sizing with the submersible laser diffraction apparatus was attempted at depths down to 70 m on three vertical profile stations. Although the instrument functioned well in every other respect, it appeared that physical distortion of the underwater housing at depths >10 m was leading to optical mis-alignment problems and further work with this system at depth was abandoned. Measurements of discrete samples were undertaken successfully during the cruise using the apparatus as a bench instrument and a comprehensive series of intercomparisons between the EPICS, FACS Coulter and submersible were obtained (Figure 8).

The deleterious effect of pressure on the housing has subsequently been confirmed. Measurements carried out at simulated depths of 60 m in the recompression chamber at HMS Drake clearly showed how the housing was distorting with pressure and it is presently being strengthened.

Analytical flow cytometry : D B Robins, P H Burkill, J A Stephens, S Ackleson, T Cucci

Assessment of instrument performance

1. Both instruments performed well throughout the cruise (leg 1), in part this was due to generally good weather conditions.

2. Both instruments were often prone to orifice blockages; initially samples were pre-filtered through 40 µm gauze, this was soon reduced to 30 µm and eventually 20 µm gauze. There was a significant improvement when changing from 30 µm to 20 µm, this is interesting as both instruments were using an orifice of 76 µm. Therefore, in these mixed natural populations of particulates some particles must 'clump' after pre-filtering; for example cells with spines etc or secretions adhere during analysis.

3. On the sensitivity of both icnstruments; it became very clear that when gating on 'FALS' (EPICS) and volume (FACS) the EPICS was more sensitive, often displaying a double fluorescence peak (LIRFL) when the FACS only showed a single peak (the higher one). Gating on fluorescence would result in some improvement but at the expense of information on non-fluorescent material.

4. Neither instrument was geared towards quantitative analysis of particles, however flow rates based on analysis time were calculated for the EPICS and time was recorded for each analysis although these values are at best an indication of volume analysed and no more! Beads were not spiked into the samples as this is now widely regarded as an erroneous means of quantifying volumes and particle concentrations.

Beads were used to monitor instrument stability, but not as internal calibrants, within the sample, but run as separate samples before and after each set of samples.

5. Laser stability on the EPICS was noted to fluctuate with sea state; in the heaviest sea conditions there were distinct oscillations in laser output. This was reduced by regularly maximizing laser output power, the normal procedure for doing this was not possible due to only 30 amps available on the three phase, but a modified procedure was used successfully. The implication from this is that the laser assembly is prone to ship movement and excessive vibration; the other 'sensitive' area on the EPICS, the optical alignment region, showed variable stability - consistent to some degree with laboratory use!

Results

1. A total of 25 vertical profiles were analysed by the flow cytometers/Coulter Counter; 24 of these were done using the EPICS. All 25 were analysed using the FACS analyser and Coulter Counter TAII (which was used with a two glassware stand configuration, analysing particles in the range 1.0 - 80.7 µm).

2. Total particle volume from the TAII generally reflected physical structure of the water column (eg temperature); TPV usually increased at the chlorophyll maximum, displaying many well defined populations in terms of particle size. Particle data in the shallower southern stations showed some interesting trends which need interpreting in conjunction with other cruise data.

Generally the particle volume distributions showed the flow-cytometers, which were analysing in the range 1 - 12 µm (EPICS) and 4 - 20 µm (FACS), were missing the more significant populations. However many

smaller (particle size) peaks measured on the TAII were reflected in the flow cytometric data.

3. EPICS data was routinely displayed as "% LIRFL" ie the percentage of particles giving red fluorescence (ie chlorophyll); some interesting data were collected as often the data in this size range (1 - 12 µm) did not reflect total fluorescence profiles from the CTD. Values of <10% within the euphotic zone were observed in some areas, while the highest % LIRFL was ~50% in a 'bloom'. Particle fluorescence below the thermocline showed a general trend of declining, but a few profiles showed suprisingly high levels.

4. An intercalibration experiment was performed to compare and interpret data from both flow cytometers, the FACS having Coulter volume for sizing, the Coulter Counter TAII and Malvern in situ laser particle sizer. Data from the EPICS can only be used after being run through a computer model, however the other three analysers gave data which was normalised and compared on board ship (Figure 8). There appeared to be good agreement between all three analysers down to 4/5 µm, with the TAII differing under that size (although the TAII was capable of resolving smaller particles than the other two systems).

5. An experiment to determine the effect of holding samples in the light or dark before flow cytometric analysis was carried out. Natural populations were held for up to 2 hours and analysed at regular intervals (15 min), a small change in fluorescence was observed after about one hour.

2. Examples of sample analysis: (Figure 9)

(i) Vertical profile 20 showing a well defined fluorescence peak, accounting for 46% of particles at the surface and persisting but falling to 15% near the bottom at 24M.

(ii) Vertical profile 21 showing a more typical, widely distributed fluorescence (double peak at the surface) ranging from 17 to 14% of particles.

Acknowledgements:

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TABLE 1. STATION LIST.

LEG 1

STATION	DATE	TIME (GMT)	POSITION	ACTIVITY
SD	8/7	0900	58°06'.23N; 06°05'.99W	C, PA,
1	9/7	0722	60°28'.0N; 02°06'.8W	C, WB, PA
2	9/7	1910	60°35'.7N; 00°25'.25E	C, WB, PA
3	10/7	0908	59°34'.76N; 03°50'.38E	C, WB, L, BC, PA
4	11/7	0130	58°48'.10N; 00°56'.40E	C, WB, L, BC, ST, IR, PA
5	12/7	1417	57°39'.00N; 00°04'.57W	C, WB, PA
6	13/7	0152	56°19'.60N; 02°24'.2W	C, PA
6A	13/7	0717	56°21'.6N; 01°17'.40W	WB
BB	13/7	1442	56°39'.6N; 00°34'.4E	BC
6C	13/7	1705	56°30'.00N; 01°01'30E	BC
6D	13/7	1737	56°30'.70N; 01°00'.0E	BC
7	13/7	1756	56°31'.70N; 00°59'.9E	C, WB, PA
7A	13/7	2139	56°41'.56N; 01°53'.54E	BC
8	14/7	0723	57°20'.2N; 04°07'.99E	C, WB, PA
9	14/7	1751	57°49'.42N; 06°52'.5E	C, WB, BC, PA
9A	15/7	0715	56°11'.53N; 07°43'.14E	WB
10	15/7	1650	56°01'.40N; 05°57'.30E	C, WB, BC, ST, IR, PA
11	17/7	0722	55°30'.3N; 02°19'.10E	C, WB, PA
12	17/7	2124	55°00'.8N; 01°10'.10E	C, WB, BC, PA
12A	18/7	0752	53°45'.68N; 00°09'.89E	WB
13	19/7	0243	54°02'.98N; 02°51'.35E	C, WB, BC, St, IR, PA
14	20/7	1239	54°09'.96N; 04°55'.30E	C, WB, PA
15	20/7	2106	54°41'.63N; 06°39'.00E	C, WB, PA
16	21/7	0336	54°05'.20N; 07°53'.20E	C, Wb, BC, PA
17	21/7	1120	53°54'.00N; 06°07'.90E	C, WB, PA
18	21/7	1958	53°18'.44N; 04°18'.77E	C, WB, PA
19	22/7	0728	52°12'.00N; 04°04'.36E	C, WB, BC, PA

LEG 2

STATION	DATE	TIME (GMT)	POSITION	ACTIVITY
212	25/7	0958	55°07'.22N; 01°08'.23W	C, WB, BC, PA
207	28/7	0813	56°30'.02N; 01°00'.1E	C, WB, BC, PA
207E	28/7	1719	56°20'.23N; 01°57'.81E	C, PA
210	29/7	0820	56°00'.19N; 06°00'.43E	C, WB, BC, ST, IR, PA

NOTES: Date, time and position refer to start of station.

Key to activities: C - CTD profile; WB - NIO water bottle cast
BC - Box core; L - in situ laser; ST - sediment trap deployed;
IR - in situ incubation rig deployed; PA - Particle Analysis by flow cytometry and coulter counter.

TABLE 2. VERTICAL PROFILES.

LEG 1

STATION	DATE	TIME(GMT)	CTD No/WB	DEPTHS SAMPLED (M)
SD	8/7	0907	SD/001	30, 38, 82,
SD	8/7	0956	SD/002	S, 10, 20
1	9/7	0722	WB	10
1	9/7	0732	001/001	
1	9/7	0758	WB	S, 10, 20, 30, 50, 100
2	9/7	1910	002/001	27
2	9/7	1931	WB	S, 10, 20, 50, 80
3	10/7	0908	003/001	26
3	10/7	0930	WB	S, 10, 20, 50, 100, 250
3	10/7	1000	WB	10
4	11/7	0130	004/001	S, 10, 20, 26, 30, 40, 66, 100
4	11/7	0150	WB	S, 10, 20, 30, 40, 50
4	11/7	0520	004/002	66
4	11/7	0538	WB	S, 10, 20, 30, 30
4	11/7	0611	WB	10
4	11/7	0935	004/003	8, 25, 35, 52, 71
4	11/7	1009	004/004	
4	11/7	1714	004/005	1, 10, 20, 35, 70
4	12/7	0411	WB	10
5	12/7	1417	005/001	
5	12/7	1434	WB	S, 10, 20, 30, 40, 80
6	13/7	0152	006/001	S, 10, 21, 31, 43
6A	13/7	1717	WB	10
7	13/7	1756	0707/001	42
7	13/7	1812	WB	S, 10, 20, 30, 50, 80
8	14/7	0723	008/001	28
8	14/7	0739	WB	S, 10, 20, 30, 40, 65
8	14/7	0749	WB	10
9	14/7	1751	009/001	354
9	14/7	1832	WB	S, 10, 20, 50, 100, 200
9A	15/7	0715	WB	10
10	15/7	1650	010/001	25
10	15/7	1703	WB	S, 10, 15, 30, 40
10	16/7	0348	WB	S, 2, 6, 10, 15, 25
10	16/7	0720	WB	10
10	16/7	1413	010/002	1, 10, 23, 30, 43
11	17/7	0722	011/001	27
11	17/7	0735	WB	S, 10, 15, 20, 35, 50
11	17/7	0740	WB	10
12	17/7	2124	012/001	29
12	17/7	2137	WB	S, 10, 20, 40, 55
12A	18/7	0752	WB	10
13	19/7	0243	WB	S, 2, 6, 10, 15, 25
13	19/7	0720	WB	10
13	19/7	0916	013/001	23
13	19/7	0930	WB	S, 10, 30, 40, 50, 60
13	19/7	1737	013/001	
13	20/7	0411	WB	10
14	20/7	1239	014/001	23
14	20/7	1253	WB	S, 10, 15, 30, 40
15	20/7	2106	015/001	12
15	20/7	2120	WB	S, 20, 25, 35
16	21/7	0348	016/001	18
16	21/7	0404	WB	S, 10, 25, 35
17	21/7	1120	017/001	25
17	21/7	1133	WB	S, 10
18	21/7	1958	018/001	24
18	21/7	2009	WB	S
19	22/7	0751	019/001	20
19	22/7	0800	WB	S, 10

LEG 2

STATION	DATE	TIME(GMT)	CTD No/WB	DEPTHS SAMPLED (M)
212	25/7	1056	212/001	
212	25/7	1245	212/002	S, 10, 20, 30
212	25/7	1321	212/003	S, 10, 20, 30
212	26/7	1142	212/004	S, 5, 10, 15, 20, 25, 30, 35, 40, 50, 60
212	26/7	1459	212/005	S, 5, 10, 15, 20, 25, 27, 30, 35, 40, 55
212	26/7	2024	212/006	
212	27/7	1149	212/007	S, 5, 10, 15, 20, 25, 30, 25, 40, 45, 52
207	28/7	0813	207/001	S, 10, 30
207	28/7	1719	207/002	S, 10, 20, 40
210	29/7	0832	210/001	S, 10, 22, 27, 27, 42
210	29/7	1748	210/002	S, 5, 10, 15, 20, 28, 29, 30, 40
210	30/7	1047	210,003	S, 27, 30
210	30/7	1537	210,004	S, 10, 20, 30, 30

TABLE 3. UOR TOW LIST.

TOW NO.	TIME (GMT).	EVENT.	LAT.	LONG.	TOW TIME.	TOW LENGTH.
01						
8.7.87	1108	L	58°08'N	06°03'W		
	1704	R	58°56'N	05°04'W	5h56	57
02						
8.7.87	1914	L	59°11'N	04°36'W		
9.7.87	0715	R	60°27'N	02°06'W	12h01	110
03						
9.7.87	0926	L	60°32'N	01°54'W		
	1901	R	60°35'N	06°27'E	9h35	107
04						
9.7.87	2309	L	60°20'N	01°15'E		
10.7.87	0854	R	59°35'N	03°50'E	9h35	90
05						
10.7.87	1345	L	59°34'N	03°48'E		
11.7.87	0114	R	58°48'N	00°58'E	11h29	79
06						
12.7.87	0450	L	58°46'N	00°40'W	LOGGER FAILED	
	1409	R	57°39'N	01°04'W	9h41	88
07						
12.7.87	1758	L	57°20'N	01°33'W		
	2357	R	56°35'N	02°17'W	5h59	52
08						
13.7.87	0741	L	56°24'N	01°14'W		
	1406	R	56°40'N	00°31'E	6h25	59
09						
13.7.87	1524	L	56°39'N	00°34'E		
	1655	R	56°30'N	00°58'E	1h31	16
10						
13.7.87	1852	L	56°32'N	01°12'E		
	2137	R	56°41'N	01°54'E	2h45	25

TABLE 3. Cont.

TOW NO.	TIME (GMT).	EVENT.	LAT.	LONG.	TOW TIME.	TOW LENGTH.
11						
13.7.87	2225	L	56°42'N	01°54'E		
14.7.87	0712	R	57°20'N	04°07'E	8h47	78
12						
14.7.87	0818	L	57°23'N	04°11'E		
	1702	R	57°48'N	06°49'E	8h44	88
13						
14.7.87	1957	L	57°49'N	06°50'E		
	2320	R	57°21'N	07°41'E	4h23	40
14						
15.7.87	1400	L	55°52'N	06°40'E		
	1620	R	56°00'N	05°59'E	2h20	25
15						
16.7.87	1811	L	56°02'N	05°52'E		
17.7.87	0629	R	55°31'N	02°26'E	12h18	118
16						
17.7.87	0839	L	55°27'N	02°05'E	SERVO FAILED	
	1321	R	55°18'N	00°55'E	4h42	40
17						
17.7.87	1404	L	55°16'N	00°45'E		
	2116	R	55°00'N	01°08'E	7h12	66
18						
17.7.87	2213	L	55°00'N	01°08'E	SERVO FAILED	
18.7.87	0500	R	54°14'N	00°00'	6h47	61
19						
18.7.87	0511	L	54°07'N	00°09'E	2h45	25
20						
18.7.87	0857	L	54°40'N	00°24'E	FIXED DEPTH	
19.7.87	0057	R	54°03'N	03°01'E	16h0	160

Figure 1a. Cruise track and station positions. Leg 1.

RRS Challenger 17/87.

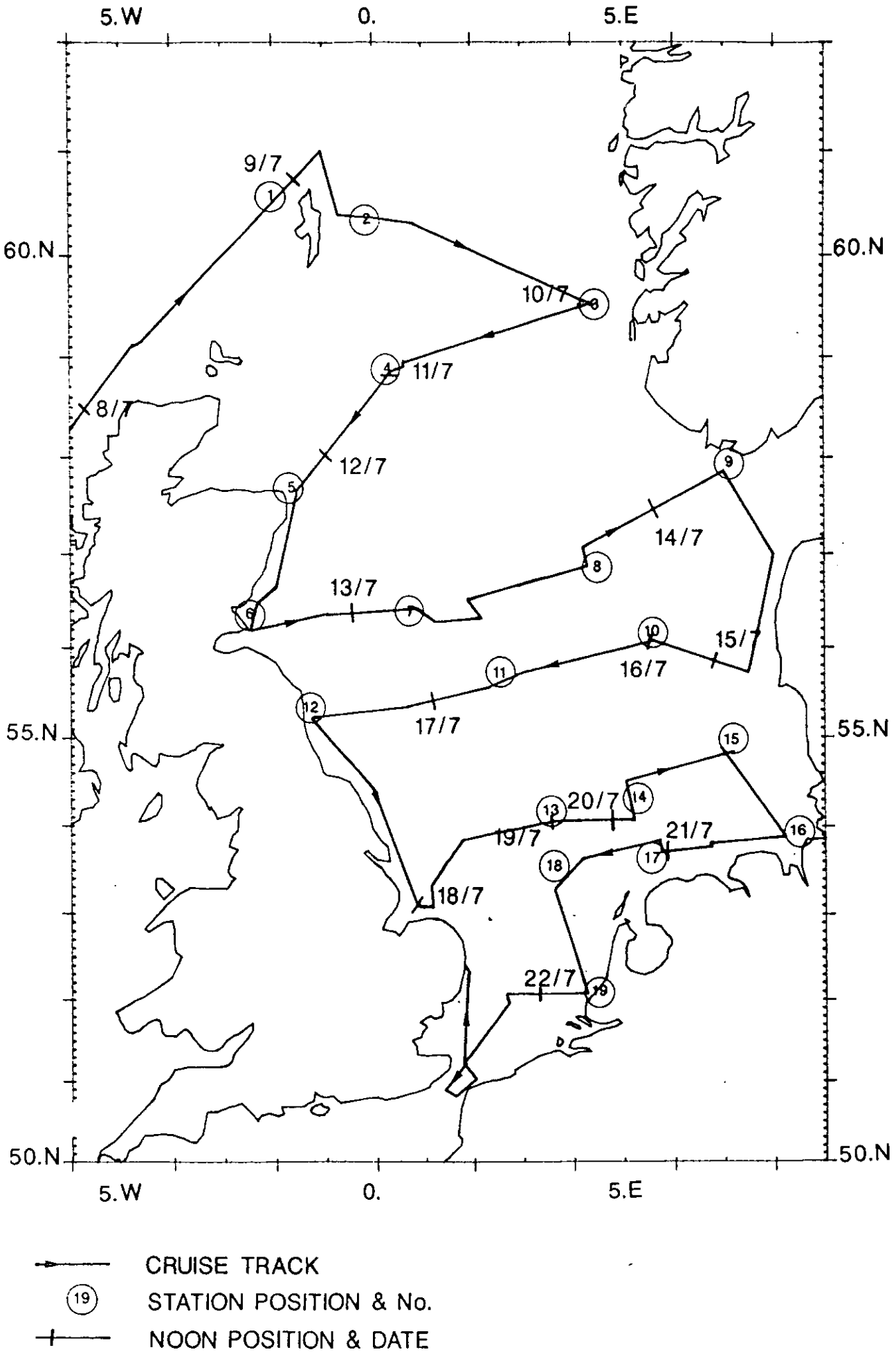
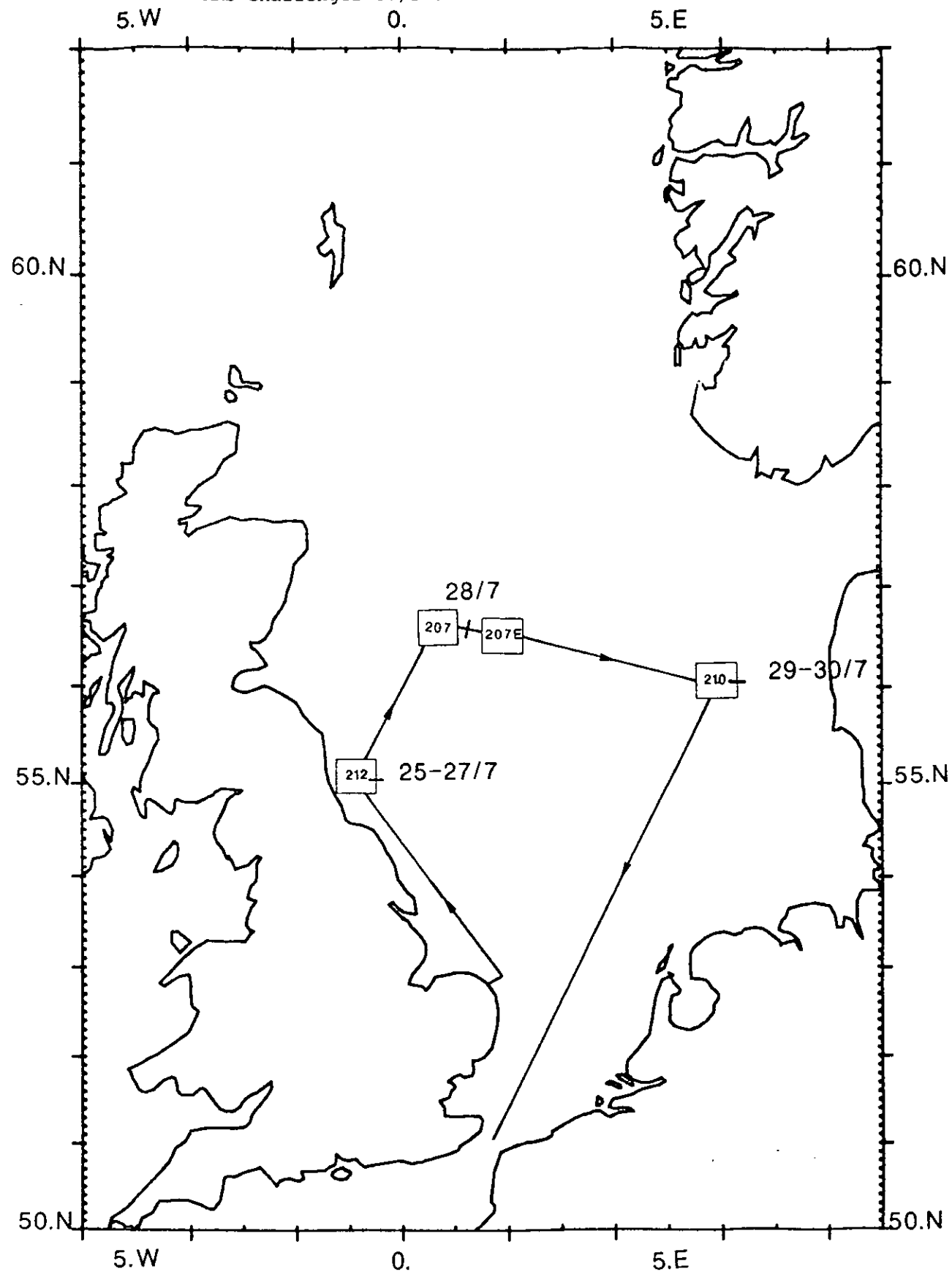


Figure 1b. Cruise track and station positions. Leg 2.

RRS Challenger 17/87.



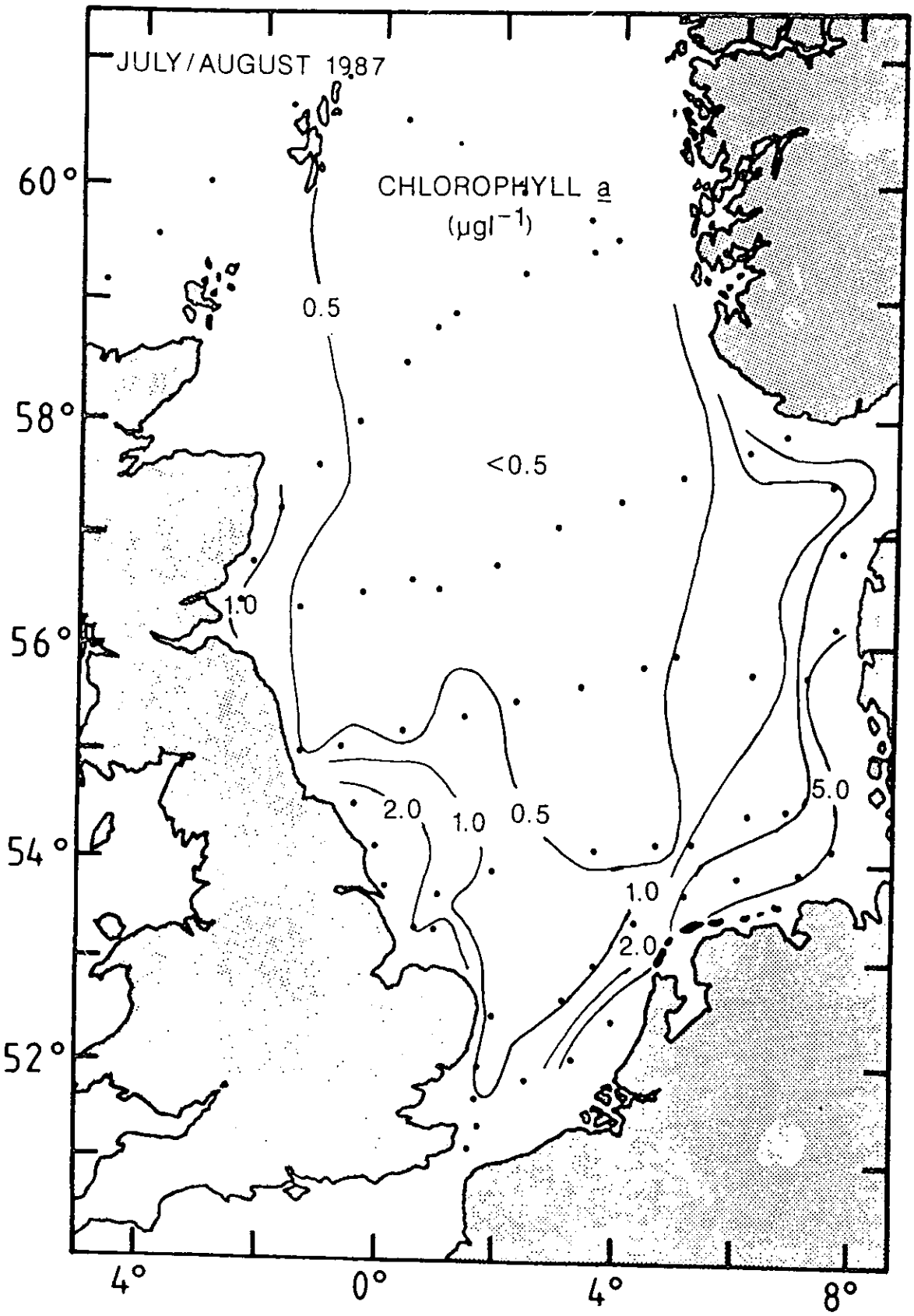


Figure 2. Distribution of Chlorophyll a.

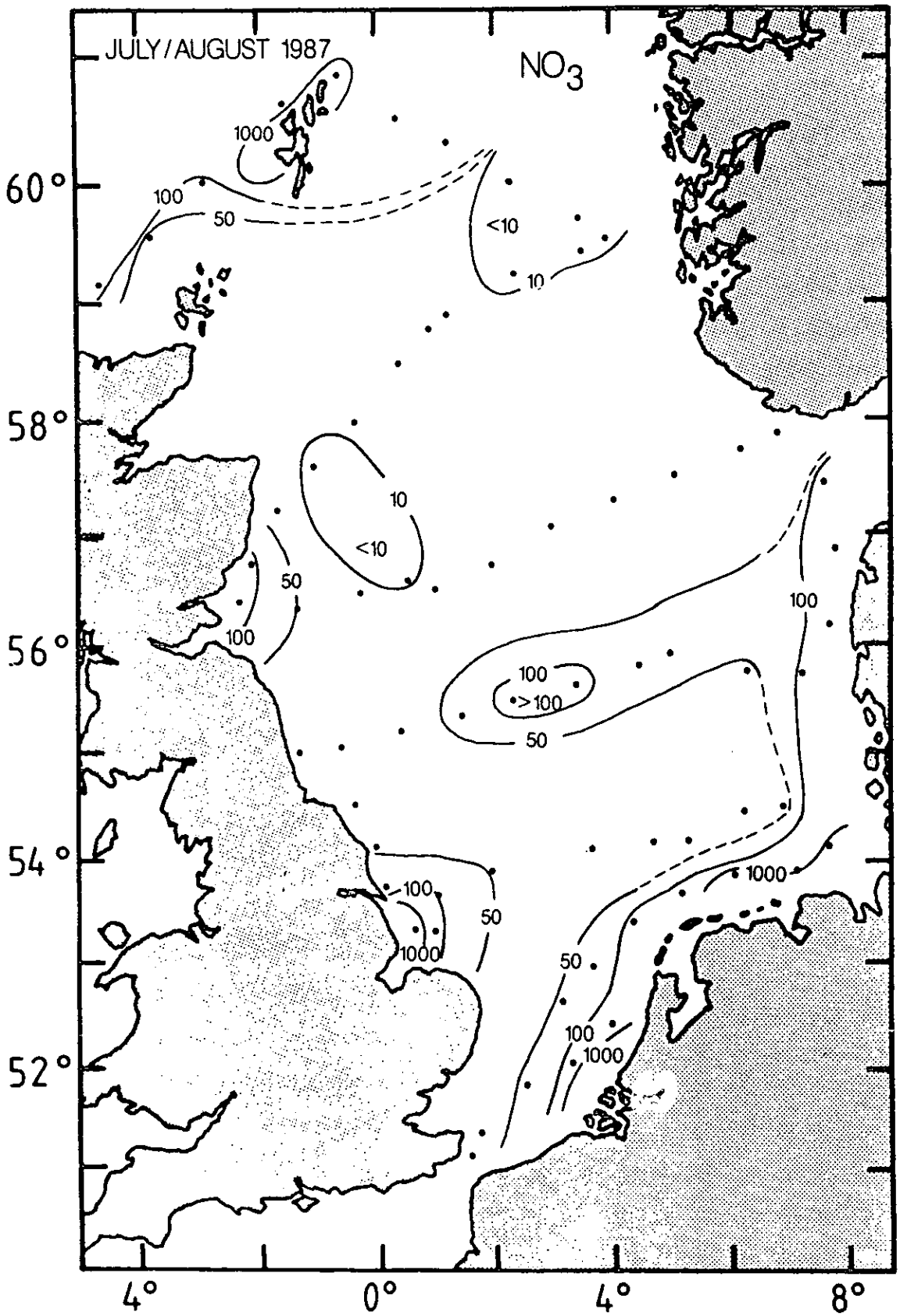


Figure 3. Distribution of NO_3 as measured by chemiluminescence (n.moles l^{-1}).

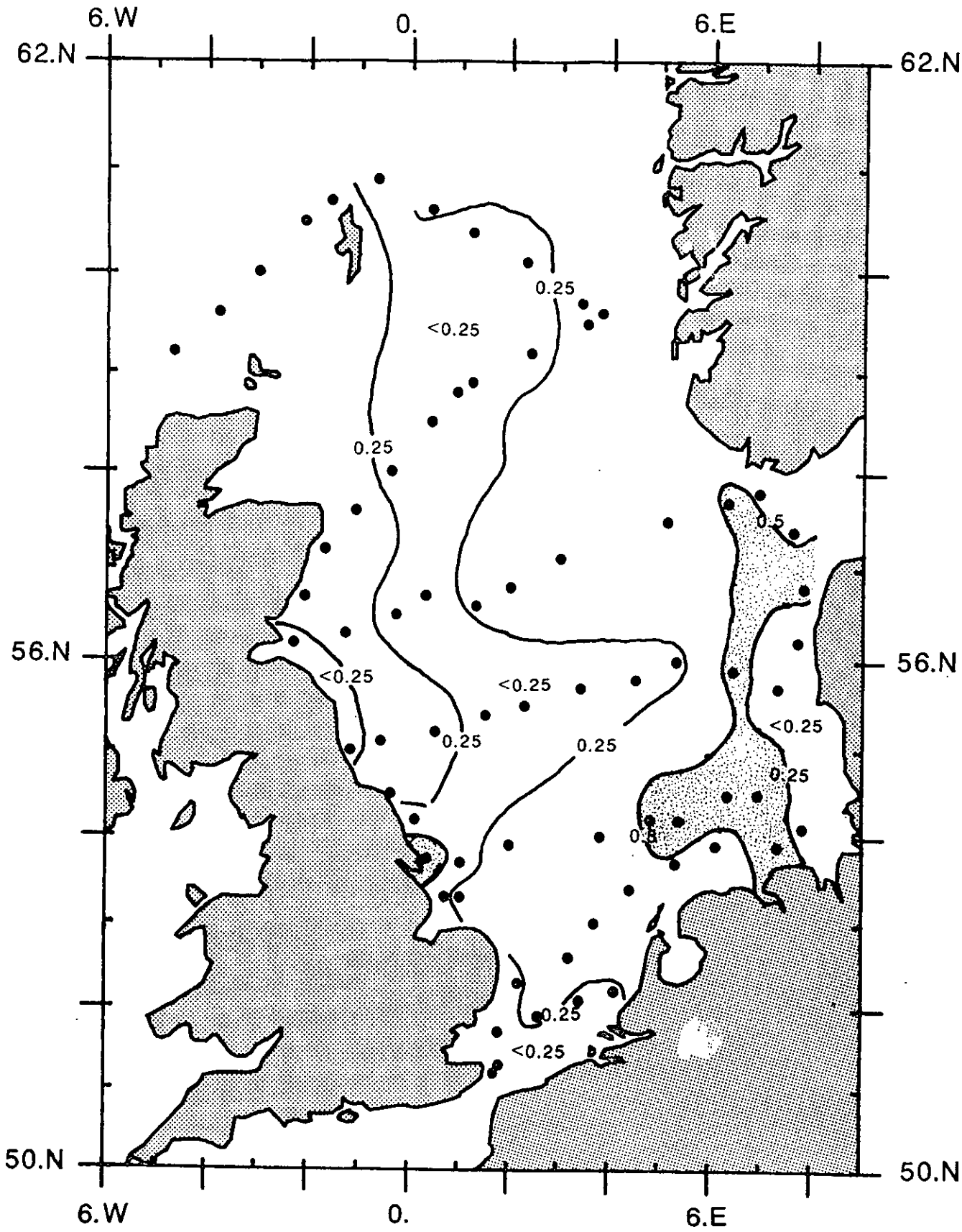


Figure 4. Distribution of f NO_3 - July 87.

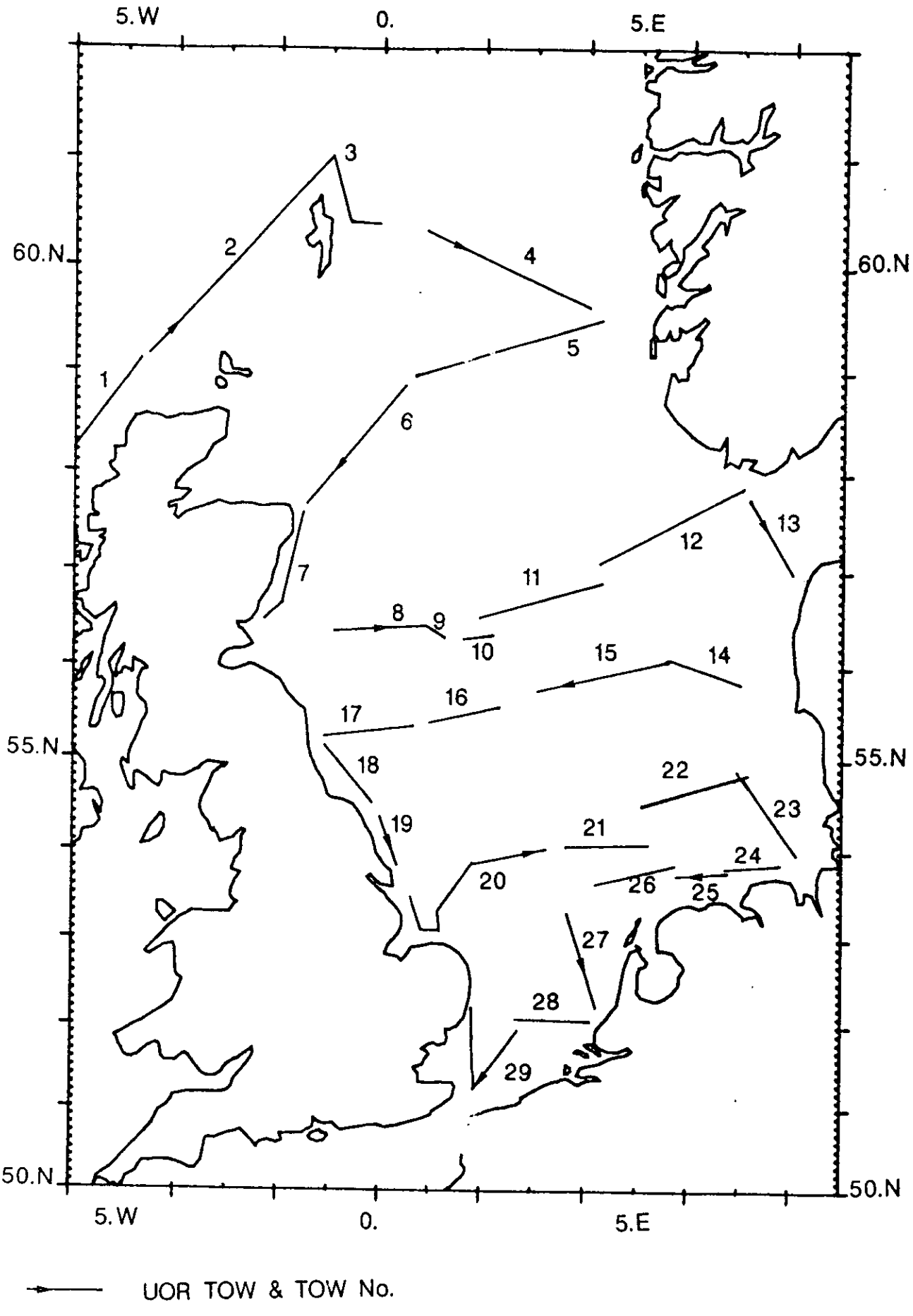
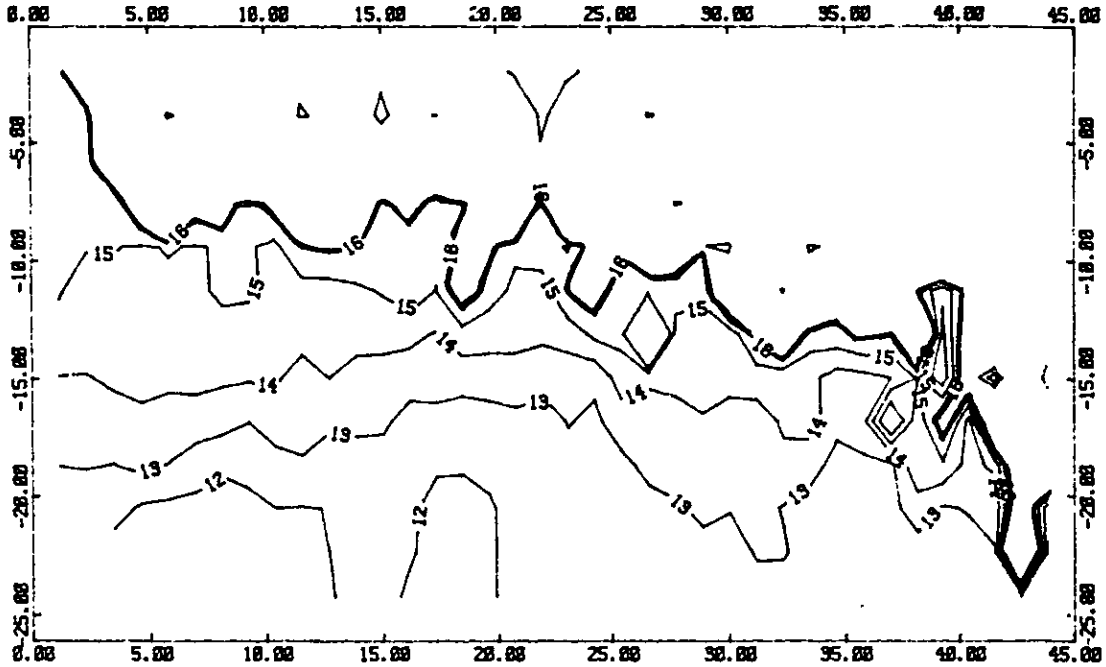


Figure 5. Positions of UOR tows Challenger 17/87.



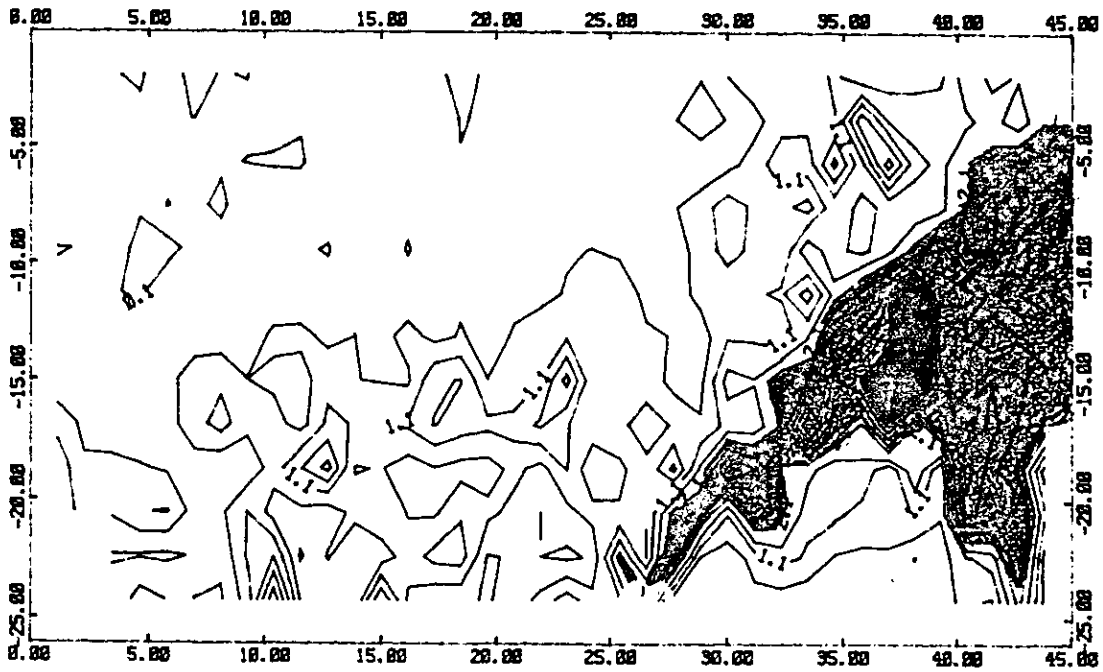
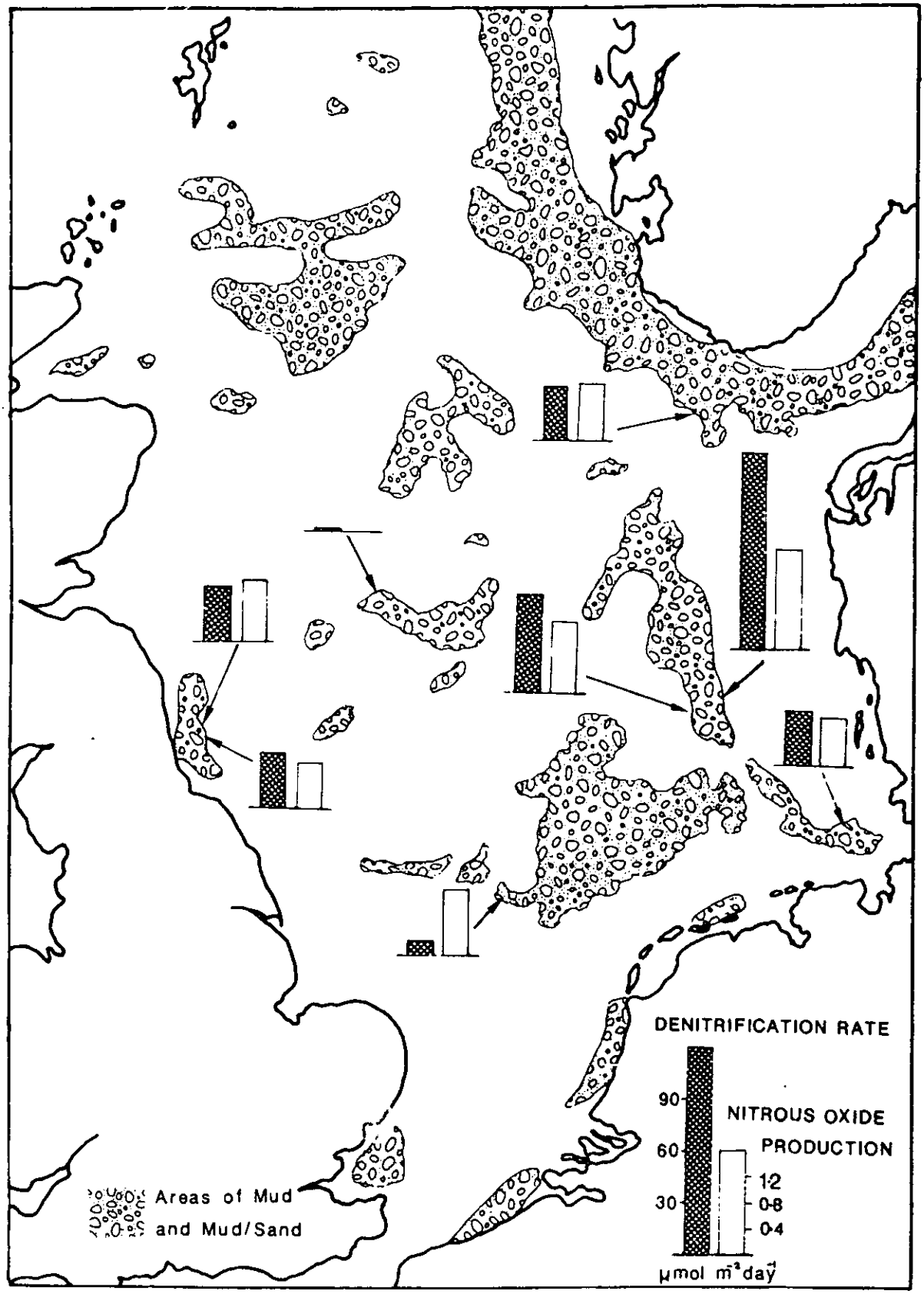


Figure 6. Distribution of Temperature and Chlorophyll - UOR Tow 22 Challenger Cruise 17/87.

Figure 7. Challenger 17/87.

SEDIMENT DENITRIFICATION RATES AND NITROUS OXIDE PRODUCTION



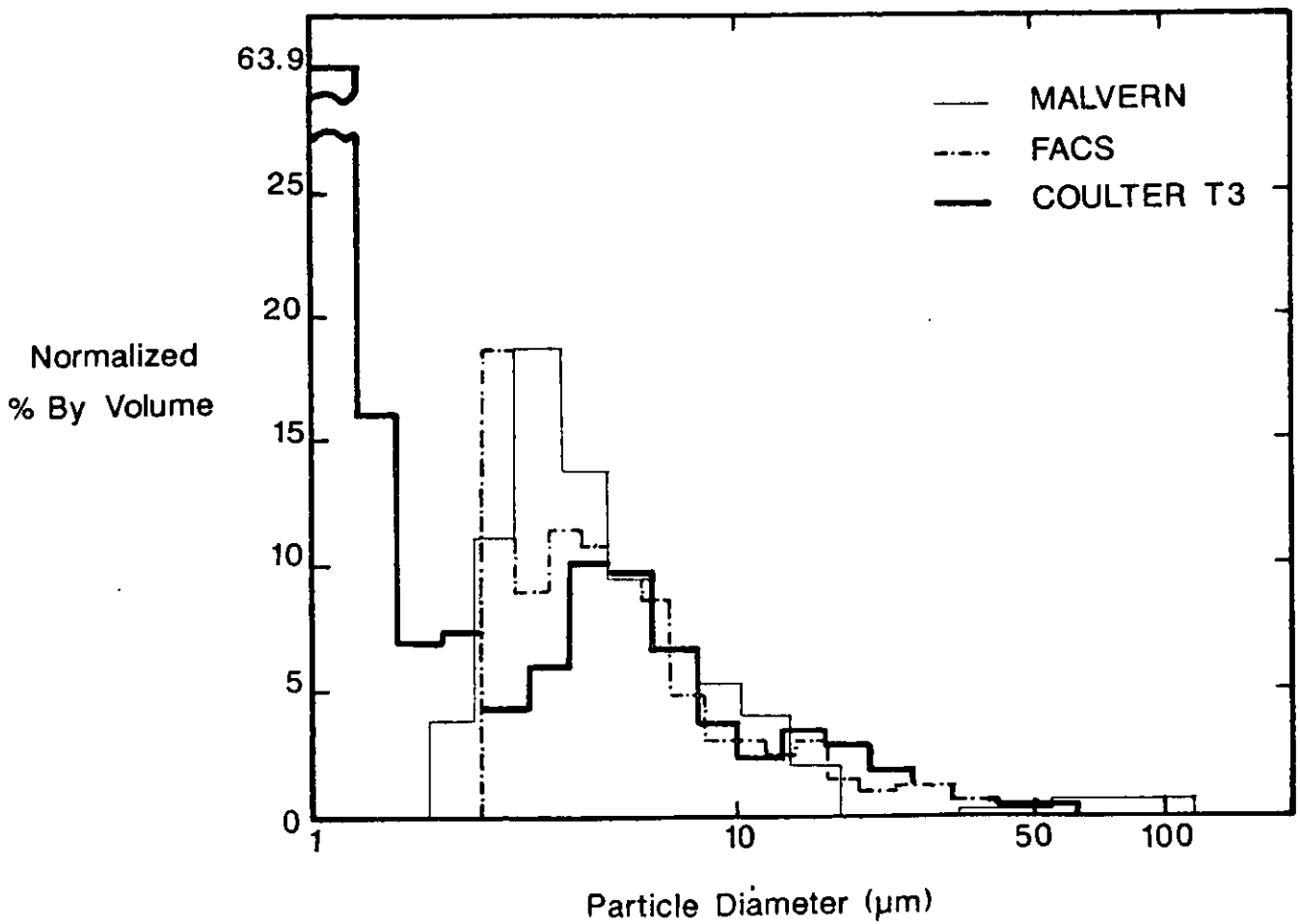
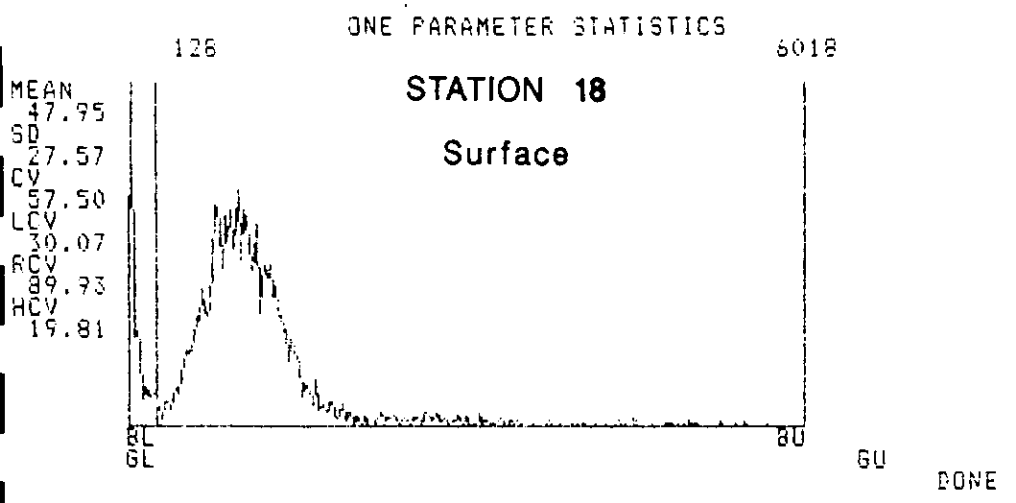


Figure 8. Comparison of particle sizing methods.



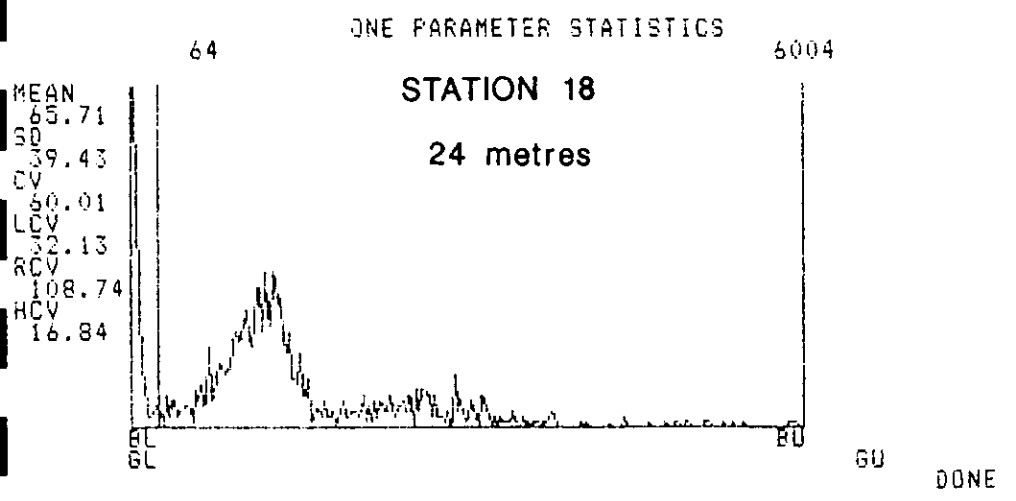


Figure 9a. AFC fluorescence profiles Station 18.

9b. Station 1 .

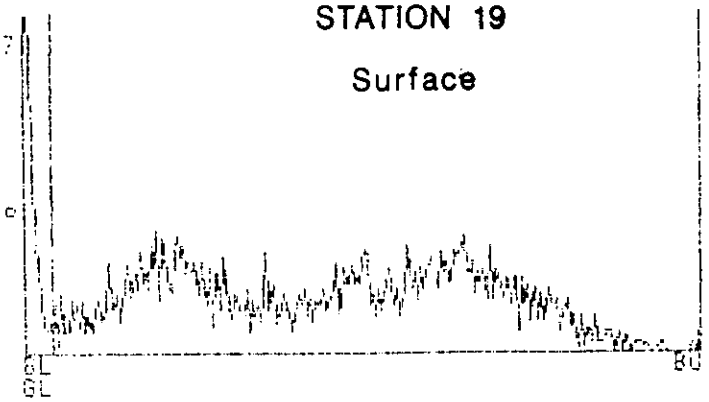
ONE PARAMETER STATISTICS

54 14011

MEAN 115.47
SD 57.88
CV 50.13
LCV 39.76
RCV 195.6°
HCV 9.90

STATION 19

Surface



DONE

SURFACE -10 21/ 7/87 10:38
IP256 VERT PROFILE/21
ADC5 / ADC1

PRINT

CHANNEL 10 TO 235 INTEGRAL 2396
PEAK 23 AT 49 % IN INTERVAL 17.10

EXIT

READY.ADJUST RIGHT CURSOR,PRESS DONE

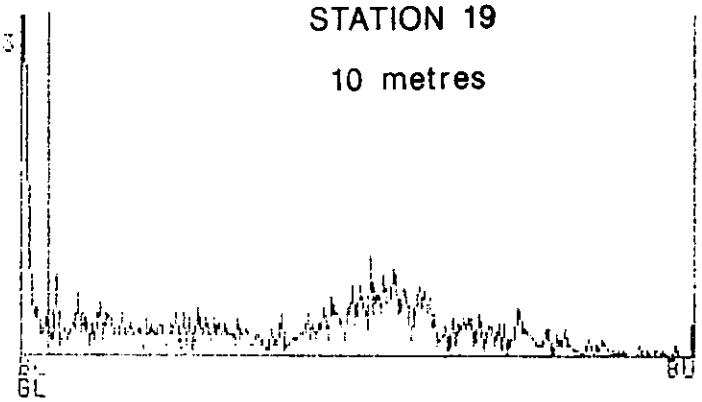
ONE PARAMETER STATISTICS

64 7424

MEAN 114.63
SD 57.64
CV 50.28
LCV 33.12
RCV 34.67
HCV 0.49

STATION 19

10 metres



DONE

10M -12 21/ 7/87 11:00
IP256 VERT PROFILE/21
ADC5 / ADC1

PRINT

CHANNEL 10 TO 255 INTEGRAL 1120
PEAK 19 AT 131 % IN INTERVAL 15.09

EXIT

READY.ADJUST RIGHT CURSOR,PRESS DONE

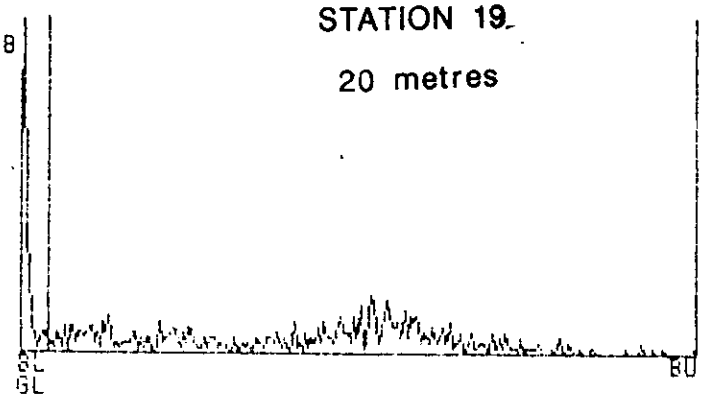
ONE PARAMETER STATISTICS

64 4015

MEAN 107.48
SD 53.72
CV 49.98
LCV 33.01
RCV 27.5
HCV 1.05

STATION 19

20 metres



DONE

20M -16 21/ 7/87 11:51
IP256 VERT PROFILE/21
ADC5 / ADC1

PRINT

CHANNEL 10 TO 255 INTEGRAL 565
PEAK 11 AT 132 % IN INTERVAL 14.07

EXIT