Indexed

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE FOR MARINE ENVIRONMENTAL RESEARCH

CRUISE REPORT

RV. G.A. REAY 3/86

NORTH SEA

MAY 28 - JUNE 14 1986

N.J.P OWENS

INSTITUTE FOR MARINE ENVIRONMENTAL RESEARCH 1986

OBJECTIVES:

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 distributions 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 natural imputs and internal recycling.

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 measure the rates of bacterial production in the North Sea and its relation to estuarine plumes and particulate matter.

VESSEL: CHARTER VESSEL RV. G.A. REAY (J. MARR & SON. HULL)

RVS REF: P13/4/86

IMER FILE: VES 11.1

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ITINERARY: [TIMES BST]

27 May	Scientists travelled to Dundee.	
28 May	Loaded equipment and began commissioning.	
29 May	Continued commissioning.	
30 May	1215	sailed Dundee
	1500	overside pump deployed, sampling equipment tested.
	1600-1700	trial coring.
	1730	Commenced first monitoring leg. TAY - FORTH - TYNE - WEAR- TEES.
	1805-1950	UOR TOW 1
	Continued monitoring leg overnight.	
31 May	1200	arrived mouth of Tees estuary. Surface sampling.
	1245-1400	Coring
	1400	Started monitoring leg towards sediment trap station 1.
	1420-1930	UOR Tow 2.
	1945-2115	Vertical profile station - [WB 1].
	2115	Continued monitoring leg.
	2200	UOR tow 3 commenced.
	Continued tow and surface monitoring overnight.	
1 June	0515	recovered UOR.
	0650-1145	UOR tow 4 - continued surface monitoring.
	1145	arrived sediment trap station 1.
	1400	Deployed sediment traps.
	1550-1815	Vertical profiling.
	1900-2140	unsuccessful coring.
	Remained on station overnight, processing and incubating samples.	
2 June	0500-0630	Vertical profiling.
	0630-0715	Unsuccessful coring.
	0900,1230	Vertical profiling.
	1400	recovered sediment traps.
	1605	Commenced monitoring leg towards sediment trap station 2. Continuous monitoring of surface variables.
	1605-2030	UOR tow 5.
	2040-2050	Vertical profile station - [WB 2].
	2050-2250	Sediment coring - partially successful.
	2305	deployed UOR tow 6 - continued tow and continuous monitoring of surface variables overnight.
3 June	0810	recovered UOR.
	0817-0945	Vertical profiling station [WB 3].
	0945-1110	Coring.
	1110-1435	UOR tow 7 - resumed surface monitoring.
	1435	arrived sediment trap station 2.

		1500-1540	Vertical profiling.
		1830	deployed free-floating sediment trap.
	4	1935-2250	Coring.

Remained on station overnight incubating and processing samples.

4 June		0615-0745	Vertical profiling.
	5	0850-1155	Coring.
		1155-1210	Vertical profiling.
		1210-2020	Search for sediment traps.
		2130	Sediment traps recovered.

Remained on station overnight incubating and processing samples.

5 June		0700	Departed Trap 2 station. Commenced monitoring leg towards Skagerrak.
		0700-1230	UOR tow 8.
		1245-1445	Vertical profiling station [WB 4].
	6	1445-1610	Coring.
		1610	resumed surface monitoring.
		1835	deployed UOR - tow 9. Continued surface monitoring.
6 June		0235	recovered UOR.
		0300	arrived at intended station S. Skagerrak.
	7	0330-0625	coring.
		0640-1123	proceeded to more suitable station - N. Skagerrak.
		1143	deployed free-floating sediment trap. - Trap 3.
		1315-1455	Vertical profiling.
	8	1600-1945	sediment coring.

Traps lost during coring due to poor visibility - continued searching overnight.

		0630-0715	Vertical profiling.
	9	0115-1045	coring.
		1255	departed vicinity of station to continue search for traps in SW direction. Commenced surface monitoring leg towards Danish coast.
		1445-1515	UOR Tow 10, located sediment traps.
		1620	recovered sediment traps.
		1630	resumed continuous monitoring of surface variables.
		1655-1955	UOR Tow 11.
		2135-2330	UOR Tow 12.
8 June		0050-0150	Vertical profiling station [WB 5].
	10	0155-0300	coring.
		0300	resumed monitoring leg.
		1150	arrived off Esbjerg, Denmark. Transferred chemicals from MFV "Rona Ahall" in heavy seas.
		1200-1700	recalibrated instruments/coring.
		1700	commenced monitoring leg, Esbjerg-Elbe.
		1900-2300	UOR Tow 13.
		2335-2345	Vertical profiling off mouth R. Elbe [WB 6].
	11	2345	commenced coring.

9 June	0040	completed coring.
	0100-0115	Vertical profiling.
	0115	commenced monitoring leg towards Terschelling Bank.
	0305-1410	UOR Tow 14.
	1440-1650	UOR Tow 15.
	1700	arrived sediment trap station 4.
12	1730-1950	coring.
	2030	deployed moored sediment trap.

Remained on station overnight, incubating and processing samples.

	0600-0700	Vertical profiling.
	0915,1230	Vertical profiling.
	2000	recovered sediment traps.
	2005	commenced monitoring leg towards Dutch coast continuous measurement of surface variables.
	2140-2355	UOR Tow 16. Continued surface monitoring overnight.
11 June	1035-1115	UOR Tow 17.
	1220-1245	Vertical profiling station [WB 7].
13	1245-1330	coring.
	1330	commenced monitoring towards Scheldt estuary.
14	1445-1645	Coring and recalibrating instruments.
	1645	resumed monitoring leg towards Scheldt and Thames estuaries.
	1700-2120	UOR Tow 18.
	2305	deployed UOR - Tow 19, towed overnight.

Continuous monitoring.

12 June	0555	recovered UOR.
15	0630-1300	coring in various positions off N. Thames estuary.
	1300	commenced surface monitoring. Thames - Dover.
	1300-1500	UOR Tow 20.
	1615-1650	Mouth of Thames Vertical profiling station [WB 8].
	1650	resumed continuous surface monitoring.
	2100	Dover Straits - ended surface monitoring.

Proceeded on passage into English Channel. Continued processing samples and incubations overnight.

13 June	0900	recovered overside pump.
	0915	deployed UOR Tow 21.

Continued processing samples. Commenced packing equipment.

	2220	recovered UOR.
14 June	0130	arrived off Plymouth remained hove to overnight awaiting pilot.
	0745	berthed Plymouth.
	0800-1600	unloaded equipment, transferred to IMER. Scientists disembarked.

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, salinity and turbidity were monitored using a 'Partech' instrument package. Chlorophyll fluorescence was measured using an IMER developed fluorometer. Uncalibrated results were obtained in semi-real time.

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 developed at IMER

DISCRETE SAMPLING:

Discrete samples were obtained from various depths using NIO 7.1 ℓ water bottles and, whilst underway, from a manifold in the pump system. In addition to the variables measured above, samples were also collected for chlorophyll determination using spectrophotometric techniques, POC/PON (Dumas combustion), O_2 (automated microwinkler titration), salinity, phytoplankton numbers and species, bacterial number and soluable and particulate ^{15}N analyses. Samples were stored under the appropriate conditions for their later analysis in the laboratory.

A total of eight stations were occupied for the investigation of vertical sections plus four sediment trap stations.

RATE MEASUREMENTS:

Surface phytoplankton production was measured using the ^{14}C assimilation technique. Samples collected underway were incubated at constant light (~ 100 μ E m^{-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 in a deck incubator which simulated light levels within the water column. All primary production measurements were made on three size fractions [> 5 µm; >0.8 < 5 µm; > 0.2 >0.8 µm].

Size fractionated nitrogen assimilation rates were measured concurrently with primary production measurements using ^{15}N techniques.

Sedimentation rates were measured using DAFS design sediment traps, deployed either moored or free-floating depending upon water depth.

Bacterial production in surface waters was measured at approximately 3 hourly intervals whilst underway and also on samples from various depths collected during vertical profiling. The incorporation of 3H-thymidine was used to measure the rate of bacteria production. All samples were size fractionated to examine the relative proportions of free-living and particle associated bacteria.

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

EQUIPMENT PERFORMANCE AND OVERALL SUCCESS OF CRUISE

All the major objectives of the cruise were met. The ship performed well and proved to be a very stable platform under the occasional poor weather conditions experienced. No time was lost due to bad weather. The situation of the main-lab proved to be inconvenient but workable. All RVS equipment worked satisfactorily. The only breakages and losses were to 3 trigger mechanisms on NIO water bottles and one messenger weight.

All IMER equipment worked relatively satisfactorily. Difficulties were experienced in obtaining sediment cores using the Craib corer in sediments other than soft mud. The gas-chromatograph was inoperable under sea conditions other than a gentle swell. The problem is thought to lie in the design and age of the electron-capture detector. It is imperative, if denitrification assays are to form part of future IMER cruises, that an alternative gas-chromatograph be utilized. Alternative sediment collecting devices should also be employed on future cruises.

The technicon autoanalyser worked effectively, being run almost continuously throughout the course of the cruise. It was necessary to obtain additional chemicals for the analyser midway through the cruise. These were transferred under heavy swell conditions off Esbjerg. The NO_x-chemiluminescence analyser was required for the measurement of low NO_3/NO_2 concentrations in certain areas in the north of the cruise area and worked well. The combined urea and ammonia analyser was inoperable for the first part of the cruise period. The fault appeared to lie in the degree of cooling for the reaction coils; this was rectified and the instrument performed effectively thereafter.

The sediment traps were deployed and recovered relatively easily, the only loss being damage to a spar buoy.

The UOR operated at ~ 98% success rate. One breakdown on one of the two fluorometers was experienced during the part of a tow. The fluorescence package was also utilized in vertical profiling mode with complete success.

PRELIMINARY RESULTS:

The nature of the cruise necessitates that much of the sample processing remains to be completed. However, some preliminary results and observations are available. Names associated with the following sections are those responsible for the measurements at sea.

HYDROGRAPHY [N J P OWENS]

It was not the intention of the cruise to carry out a detailed hydrographic survey of the North Sea. Rather, hydrographic measurements were made as appropriate to aid interpretation of the nutrient data. As expected, the cruise area was divisible into two general regions: a) southern, vertically well mixed and b) northern, thermally stratified. The boundary between the two regions, at approximately 55° N, was further south than expected from predicted H/U^3 values (~ 53° N). The poor weather conditions and increased wind mixing prior to the cruise may account for the discrepancy. A well marked thermocline, centred at approximately 35 m, was evident in the thermally stratified region. The temperature difference between surface and bottom water was typically ~ 4° C. Interestingly, thermal stratification was not evident at the most northerly stations (WB 3, TRAP 2). This northern boundary occurred at approximately 58° N and was probably due to the influence of far-north water entering in a southerly direction. Measurements made in this area will allow the boundary nutrient concentrations, in this northern region, to be determined with a good degree of certainty. A further feature of interest was the presence of eddies formed between northerly flowing ex-Baltic water and North Sea water. Both lower and higher salinity features (~ 1‰ difference from surrounding water) were observed. There was evidence of generally higher chlorophyll concentrations in this region (see figure 2) and further elevated chlorophyll concentrations in the lower salinity structures.

Elsewhere on the cruise track a good distribution of salinity was observed; over the whole cruise track salinity varied between ~17 ‰ and 35 ‰. This range will enable the riverine input of nutrients to be characterised. These data will be combined with ^{15}N distributions to attempt to characterise sources of nutrients. The lowest salinities were observed off the Hook of Holland where salinity stratification was also apparent. Salinity induced stratification was also observed in the Skagerrak.

NUTRIENT ANALYSES [E M S WOODWARD]

One of the primary objectives of the cruise was to examine the distribution and concentrations of nutrients, particularly nitrogen, in relation to sources and sinks. To this end nutrient analyses were carried out continuously over the entire cruise track. The sampling track was approximately 1500 NM. It is estimated, when the buffering of the sampling system and the cruising speed of the ship are taken into account, that a spatial resolution of sampling better than 0.5 NM was achieved. This is equivalent to over 3000 individual analyses for six nutrients [NO_3; NO_2; PO_4; S_1O_4; NH_4; UREA]. In addition, fourteen vertical sections were also investigated.

The data obtained for the sampling track within the German Bight is shown in Figure 3. The concentrations of NO_3 varied over nearly two orders of magnitude; ~ 9 µmoles l^{-1} off the Danish coast and <0.1 µmoles l^{-1} off the Terschelling Bank, Netherlands. If the abundance of phytoplankton, as indicated by chlorophyll fluorescence, is also examined (see figure 4) it can be seen that similar chlorophyll concentrations were observed in the two regions. Distinct phytoplankton blooms were observed in this area and some data from two are shown in Figure 4. Bloom A was located off the Danish coast and Bloom B off the Dutch coast (see Figure 2). Very clear differences were apparent. In bloom A, NO_3 concentrations varied approximately inversely with salinity and chlorophyll fluorescence. High NO_3:PO_4 ratios were also observed. Conversely, no obvious relationship was observed between NO_3 and salinity or fluorescence. The NO_3:PO_4 ratios observed in bloom B indicated that nitrate was a limiting nutrient rather than phosphate. There are many possible explanations for these observations and the bulk of the data remains to be examined. However, one explanation is that the two blooms were at different stages in their development. Bloom A appears to have been at an early stage, while bloom B appears to be relatively much more advanced.

PO_4, NH_4 and urea distributions did not co-vary with NO_3. It can be seen, for example, that particularly high concentrations, especially of NH_4, were observed at approximately 53° 45'N; 06° 00'E. This structure was not apparent in the NO_3 distribution. Conversely, all nutrients were virtually undetectable in the region of bloom B (see Figure 3) to the west of 05° E. A major objective of the cruise is to interpret these distributions and the role in which terrestrially derived nutrients play in governing phytoplankton production and potential eutrophication.

In addition to using conventional colorimetric techniques, a sensitive chemiluminescence method was also employed to measure low concentrations of NO_3 and NO_2. It was necessary to use this method in the stratified, northern section of the North Sea, where NO_3 concentrations were typically below the detection limit of colorimetric analyses. Representative vertical sections are shown in Figure 5. It is important to have an accurate estimate of NO_3 concentrations at these low levels in the stratified region because of the potentially large contribution that they may make in any budget calculations. With conventional analyses it would only have been possible to describe these concentrations as undetectable and any subsequent budget calculations would have been grossly in error.

OXYGEN CONCENTRATIONS [J L MORRIS]

Oxygen concentrations were measured during the cruise to provide information on

a) potential areas of eutrophication.
b) rates of primary production and total community respiration.
c) the form of nitrogen assimilated by phytoplankton.

Surface concentrations of oxygen were high; the average percentage saturation of all sites (14) was 113%; at one site within a large bloom values up to 130% saturation were observed. These data indicate that the cruise period was conducted during a particularly productive period.

Measurements of oxygen at depth generally indicated that O_2 concentrations were highest sub-surface (Figure 6). This probably reflects the loss of O_2 to the atmosphere from the surface. However, changes in O_2 concentration over time in incubation experiments also suggest that the highest rates of primary production occurred sub-surface at both stratified and unstratified sites. Incubations indicated that highest respiration rates also occurred at sub-surface depths (See Figure 7).

PRIMARY PRODUCTION AND NITROGEN ASSIMILATION [N J P OWENS]

Primary production and nitrogen assimilation incubations were of two types.

a) Surface only incubations.
b) Depth profiles.

Sixty-seven surface incubations and four depth profiles were carried out.

Figure 8 shows untransformed carbon assimilation data for the four depth profiles (sediment trap stations). These data cannot be used directly to calculate carbon assimilation rates but they do allow approximate comparisons to be made. Large differences in carbon assimilation were observed between the sites. These data represent carbon assimilation by all size classes of algae. Table 1, however, shows the relative proportions of carbon assimilated by the three sizes examined. It can be seen that the highest carbon assimilation rates were at sites dominated by large organisms, that is, sites "Trap 3" and "Trap 4". It is possible that the early seasonal diatom bloom was in progress at these sites. This will be confirmed by the analysis of samples collected for the identification and enumeration of phytoplankton. It is significant to note, however, in the well established, thermally stratified region represented by the "Trap 1" station, that not only was the production dominated by the smaller organisms (84% < 5 µm) but also the assimilation rates were lowest. The seasonal cycle was clearly advanced at this site over other regions of the North Sea and the carbon assimilation data obtained resembled those observed, elsewhere, on previous cruises; for example the summer situation in the Celtic Sea.

Nitrogen assimilation data are not yet available but it is expected, from the variety of conditions observed, that marked differences in the form of nitrogen assimilated (that is, either NO_3 or NM4) should be found.

BACTERIAL PRODUCTION [D PLUMMER]

The objectives of the bacterial production investigation were two-fold:

a) To examine the horizontal variation in bacterial production in relation to rates of primary production and the influence of riverine nutrient inputs.
b) To examine the relative roles of free-living bacteria and those associated with particles.

To meet objective a), bacterial production assays were performed at approximately 3 hourly intervals throughout the cruise period, and more frequently in areas of steep horizontal gradients. A total of 66 individual surface analyses were carried out. The data for two vertical sections are shown in Figure 9. Bacterial production is shown in CPM and is thus not an absolute rate. However, the data are approximately comparable between and within profiles. There was a sub-surface maximum in bacterial production at the stratified site (WB 1) and at the surface of the vertically well mixed site. There are few data available on bacterial production rates in the North Sea, but on first examination these data would indicate that they are relatively high; for example being at least twice those observed in the Celtic Sea.

The relative role of free and attached bacteria in the sea has important consequences for mineral cycling yet it is still open to question. The preliminary indications from this study are that the relative activities vary quite markedly. Table 2 shows the relative production rates at four sites. It can be seen that bacteria associated with particles can account for up to 36% of the total activity in the surface waters. This is an interesting observation because, generally, particle concentrations were low (< 20 ppm - typically ~ 5 ppm). These preliminary indications suggest that particle associated bacterial production may be a significant proportion of the total production.

DENITRIFICATION [C S LAW]

Denitrification represents a potentially important sink of nitrogen, yet virtually nothing is known of its extent in the North Sea. To our knowledge the denitrification measurements made on this cruise are the first attempt to examine, on a large scale, the process in the North Sea.

Despite experiencing some difficulties in both obtaining suitable sediment cores and the operation of the gas-chromatography on board ship, an initial examination of the data indicates some interesting results.

A typical set of data is shown in figure 10. This figure shows the increase over time in N_2O in cores incubated after the addition of acetylene. Acetylene blocks the final reduction of $N_2O \longrightarrow N_2$; thus N_2O accumulates in the system at a rate equivalent to the production of N_2 (denitrification). Using this technique, denitrification was examined at seven sites (see Table 3). Highest rates were observed at sites "Trap 3" and "Trap 4". Denitrification was not apparent at all sites. An interesting observation was that when replicate cores were amended with organic carbon and/or nitrate, the latter stimulated the denitrification rate by as much as ~ 75%; the addition of an organic carbon substrate resulted in a reduction in the rate.

The significance of these data have yet to be determined, however, the denitrification rates observed at "Trap 4" are of the same order as those found at some sites on mud flats in the Tamar estuary.

UNDULATING OCEANOGRAPHIC RECORDER (UOR) [I E BELLAN]

The UOR is a powerful instrument to employ in the largely survey type approach adopted in this cruise. It provides information on the distribution of chlorophyll fluorescence, temperature and upwelling and downwelling irradiance in both the horizontal and vertical.

During this cruise the UOR was towed for 1036 NM in twenty-one deployments. The positions of the individual tows are shown in Appendix 4 and Figure 11. Data collection was achieved at better than 98% success rate, there being a slight malfunction in one of the two fluorometers during part of one tow. The ability to examine the data after each tow provides much useful information in semi-real time. This information was used to assess the progress of the cruise.

Data on chlorophyll and temperature for Tow 2 is shown in Figure 12 (a) and (b). It can be seen that the temperature stratification along the section gradually steepens and deepens. Associated with this increase in stratification is a gradual decline in chlorophyll fluorescence. The start of the tow was close to the presumed position of the front between stratified and mixed water off the East coast of England. The elevated chlorophyll concentrations (up to 4 mg m^{-3}) and their increasingly shallow position towards the start of the tow are evidence that enhanced chlorophyll concentrations were associated with this front.

The fluorometers from the UOR were also used for vertical profiling. This facility is invaluable in describing the structure of the water column in semi-real time and aids in the positioning of water bottles for the collection of samples for chemical-microbiological analyses.

An example of the chlorophyll structure at 'WB 1', together with the temperature profile obtained by an XBT deployment, is shown in Figure 13. A distinct sub-surface chlorophyll maximum was evident situated immediately above the thermocline. The chlorophyll concentration of the surface was approximately 0.05 mg m^{-3} and increased to approximately 1.3 mg m^{-3} at the maximum at 30 m. Similar profiles were obtained at all sites in the thermally stratified northern section of the cruise area.

A slight modification in the deployment and recovery procedure of the UOR was developed during this cruise. This simple modification allows the instrument to be deployed safely from the "A" frame of a research ship in conditions which would otherwise be possibly untenable. The modification is shown diagrammatically in Figure 14 and involves two restraining ropes attached to the main warp via a steel "Figure of eight" loop. The towing wire is free to run through the loop but by applying tension to the two restraining ropes when the instrument is clear of the water, and particularly when between the arms of the "A" frame, lateral, swinging movement is reduced almost completely.

ACKNOWLEDGEMENTS:

The assistance of the Master, officers and crew of the RV G.A. Reay is gratefully acknowledged. Particular thanks are due also to Mr S Mayle the NERC liaison officer who gave very valuable technical assistance at sea. We thank IMER workshop staff for their patience in handling last minute problems before sailing and R Howland for his efforts in arranging the transfer of chemicals from IMER to the ship off Esbjerg. Dr J Aiken kindly carried out the computing for the UOR data contouring.

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REPORT PREPARED BY : Nicholas J.P. Owens

N J P OWENS 23/7/86

DATE:

APPROVED BY: Brian L Bayne

B L BAYNE

DATE:

CIRCULATION:

INTERNAL: B L BAYNE — CRUISE PERSONNEL
R F C MANTOURA — NOTICE BOARD
P H BURKILL — FILE VES 11.1
P WILLIAMSON

EXTERNAL:

NERC H Q SWINDON	J WOODS
	D PUGH
	S WHITE
I O S WORMLEY	MRS P EDWARDS (MIAS)
DAFS	McINTYRE
RVS	SKINNER
	ADAMS (5)
MBA	DENTON
UNIVERSITY OF DUNDEE	STEWART
	HERBERT
	CORBET
J MARR & SONS (HULL)	HINDE (2)
DOE	OTTER (2)

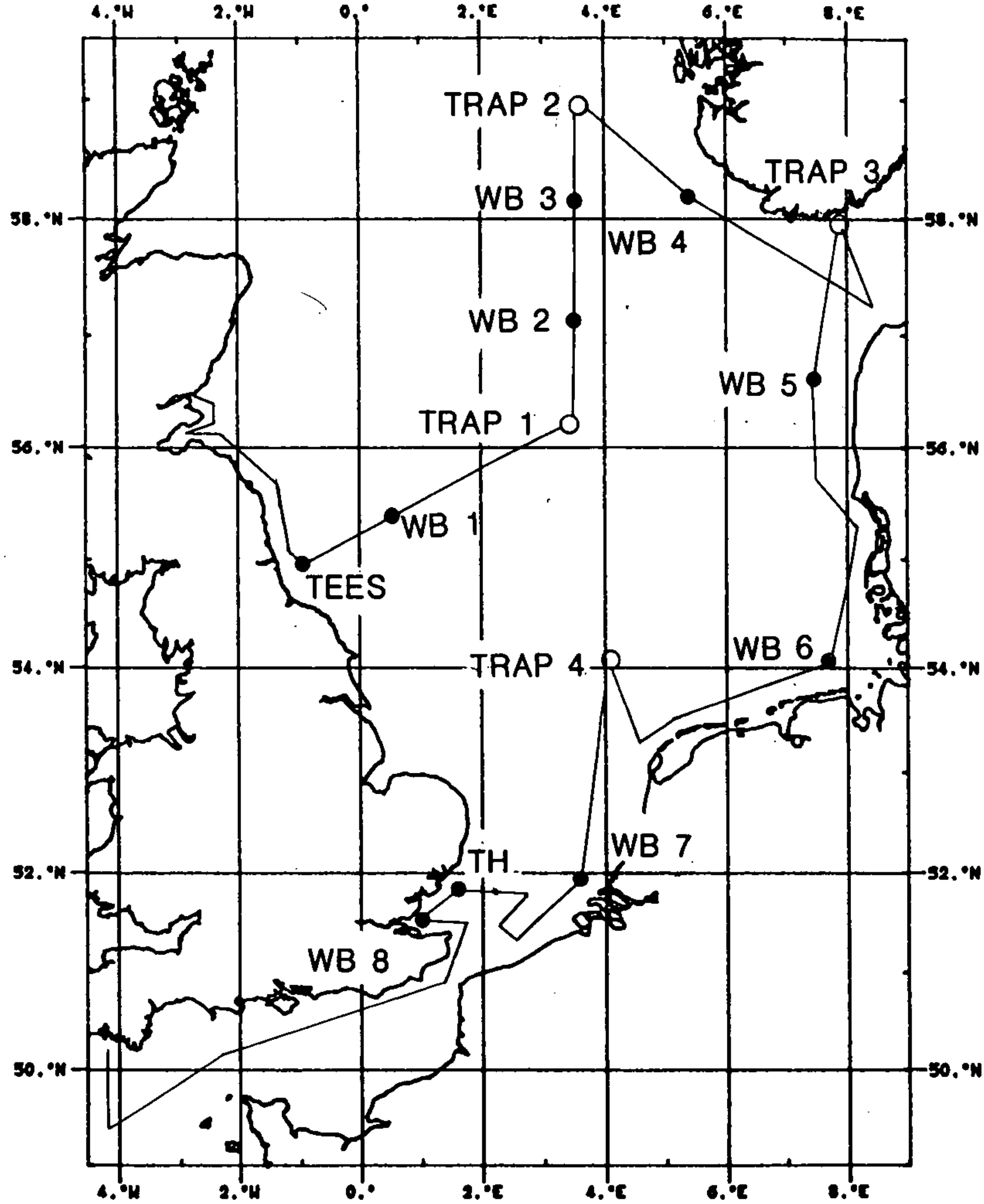


FIGURE 1 CRUISE TRACK AND STATION POSITIONS - G.A. REAY MAY/JUNE 1986

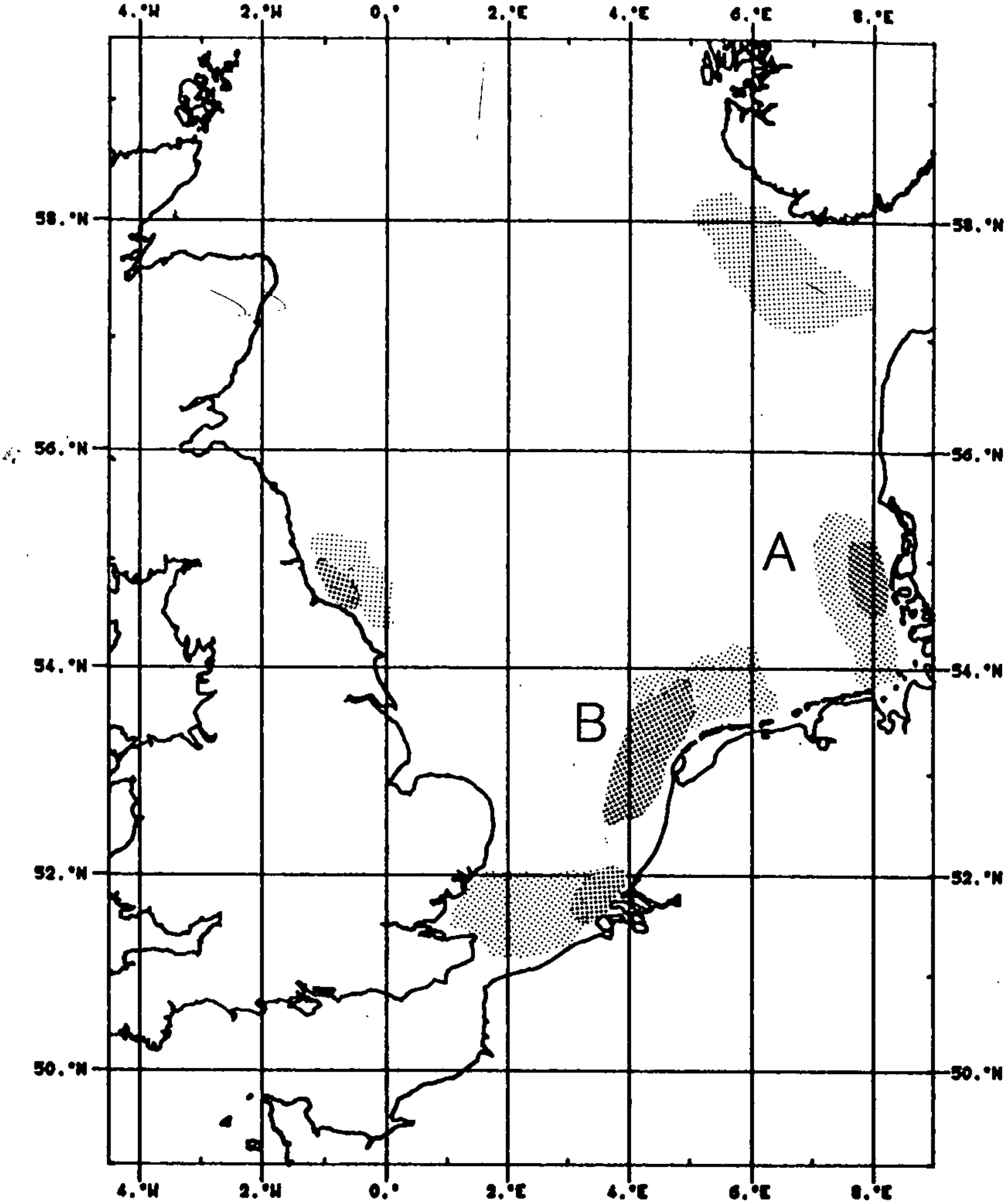


FIGURE 2 SEMI-QUANTITATIVE DISTRIBUTION OF SURFACE CHLOROPHYLL FLUORESCENCE.
(WHITE AREAS - NOT SAMPLED OR APPROXIMATELY < 0.5 mg m^{-3}; INTERMEDIATE SHADING 0.5 - 5 mg m^{-3} DARK SHADING >5 mg m^{-3}).

A & B: Blooms referred to in report

FIGURE 3 DISTRIBUTION OF DISSOLVED CONSTITUENTS IN THE GERMAN BIGHT. JUNE 1986

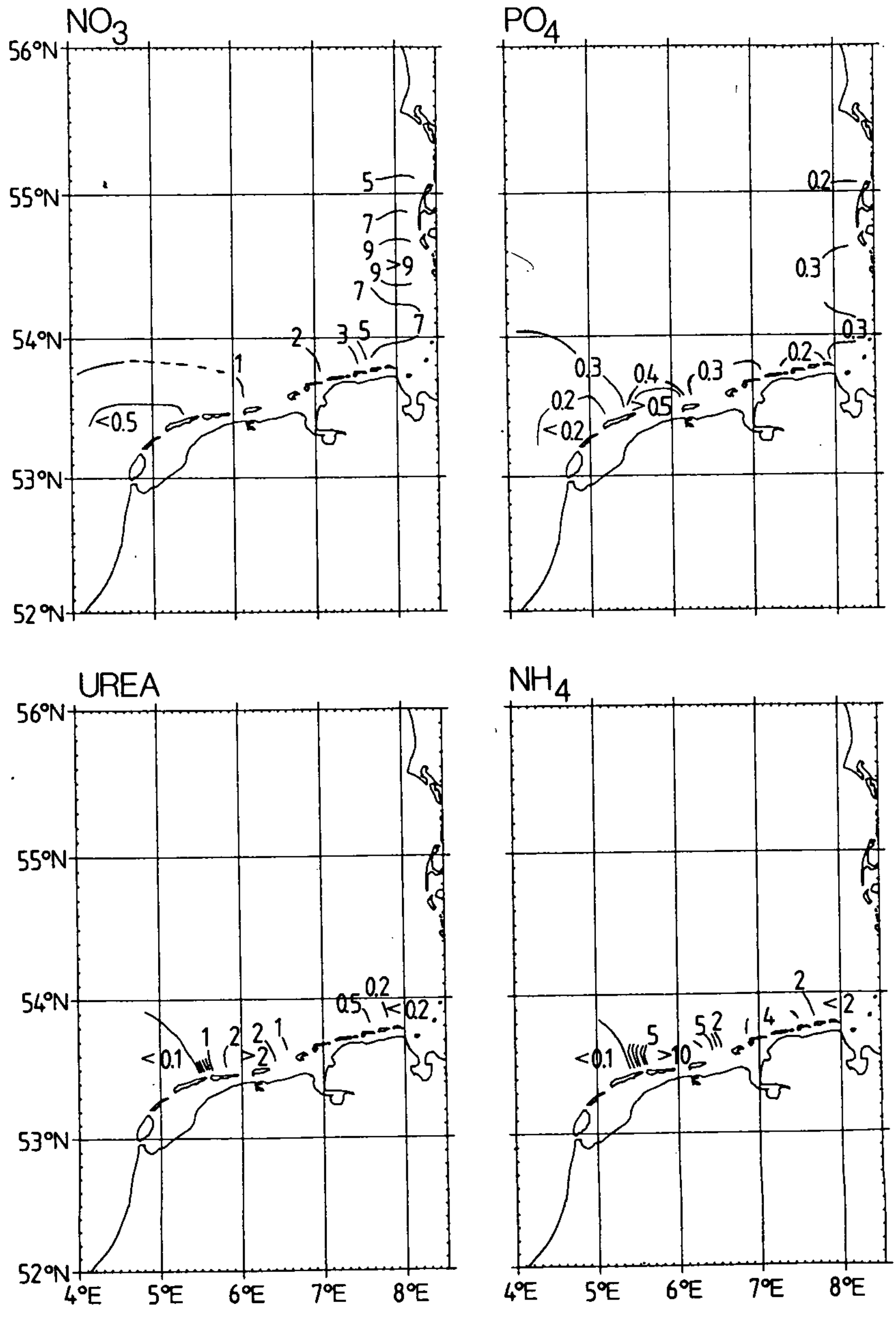


FIGURE 4 DISTRIBUTION OF NUTRIENTS, SALINITY AND CHLOROPHYLL FLUORESCENCE IN TWO BLOOMS IN THE GERMAN BIGHT. FILLED CIRCLES - BLOOM A OPEN CIRCLES - BLOOM B (SEE FIGURE 2).

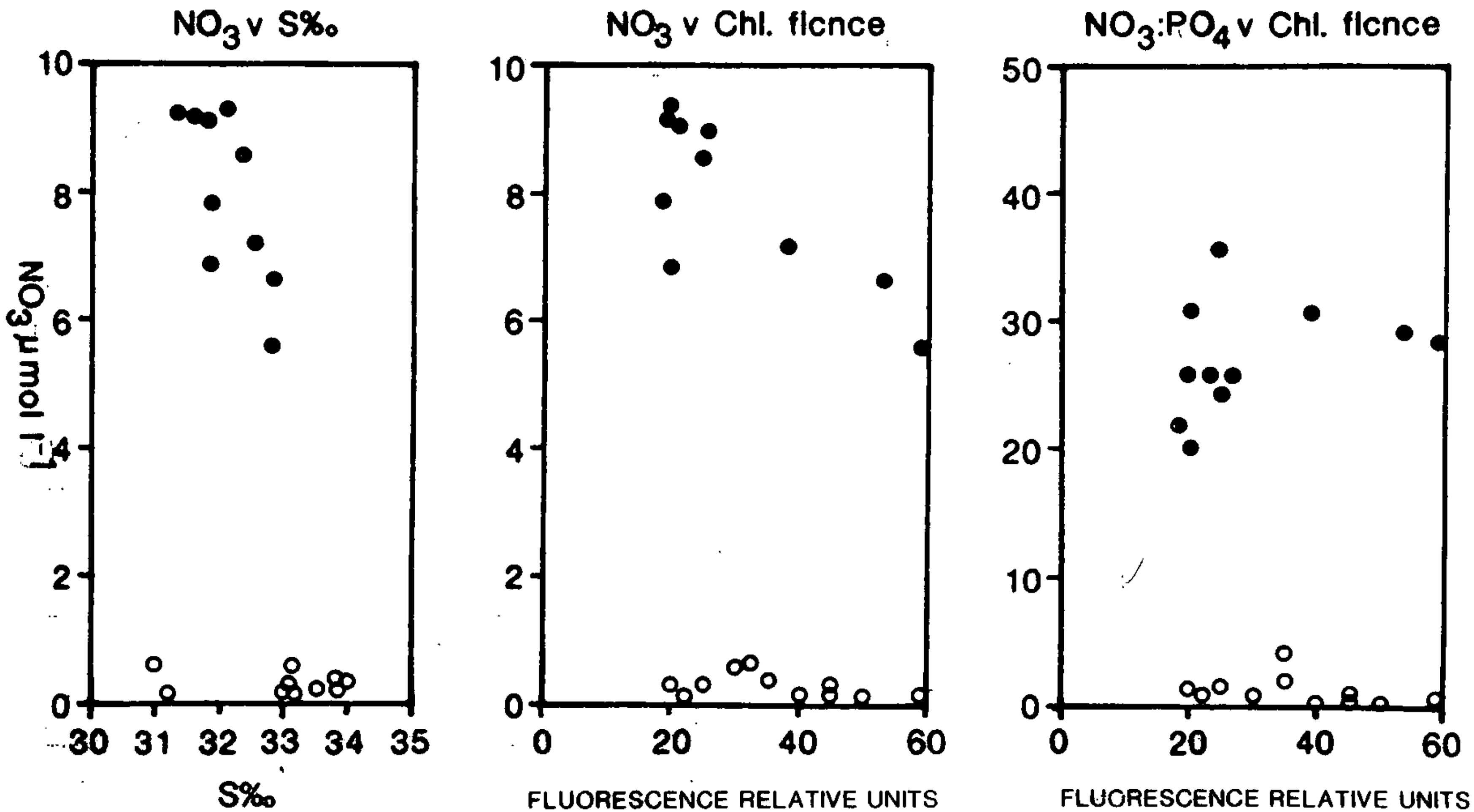
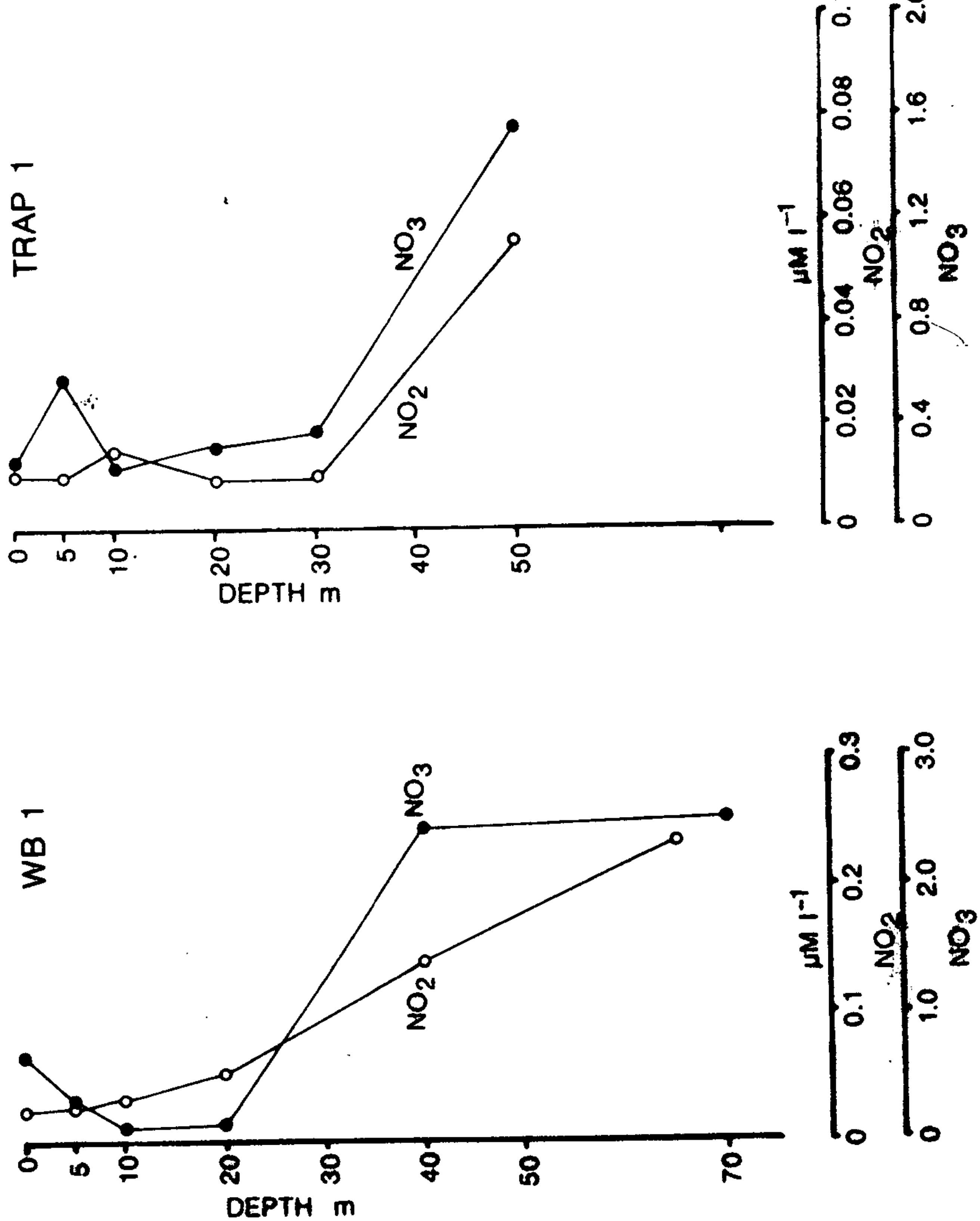


FIGURE 5 NO_2 AND NO_3 DEPTH PROFILE MEASURED BY CHEMILUMINESCENCE TECHNIQUES.



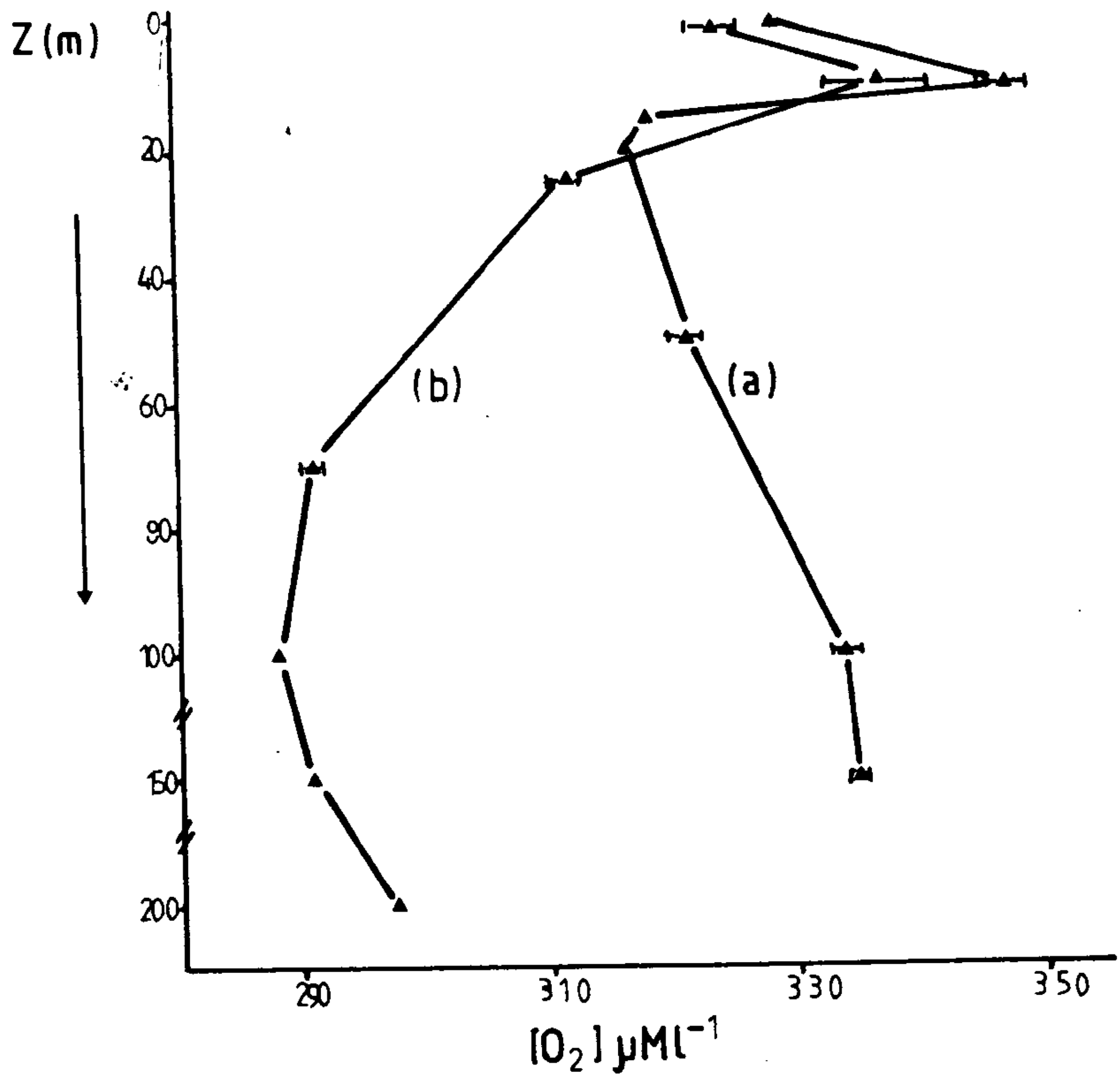


FIGURE 6 DISTRIBUTION OF O_2 WITH DEPTH.

(a) STATION-TRAP 3

(b) STATION-TRAP 2

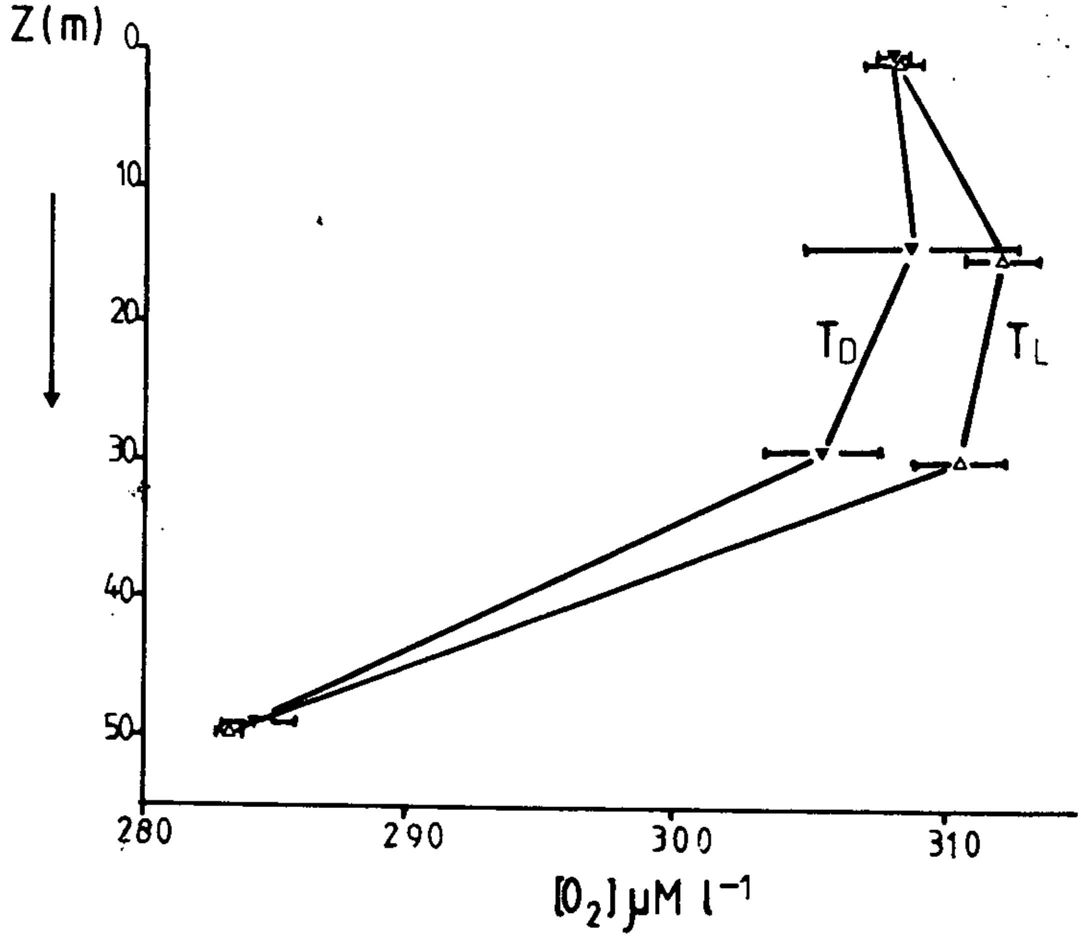


FIGURE 7 CONCENTRATION OF O_2 IN BOTTLES INCUBATED IN THE LIGHT (T_L) AND DARK (T_D) (STATION TRAP 1) INDICATING GREATEST NET RESPIRATION OCCURRED AT 20 - 30 M.

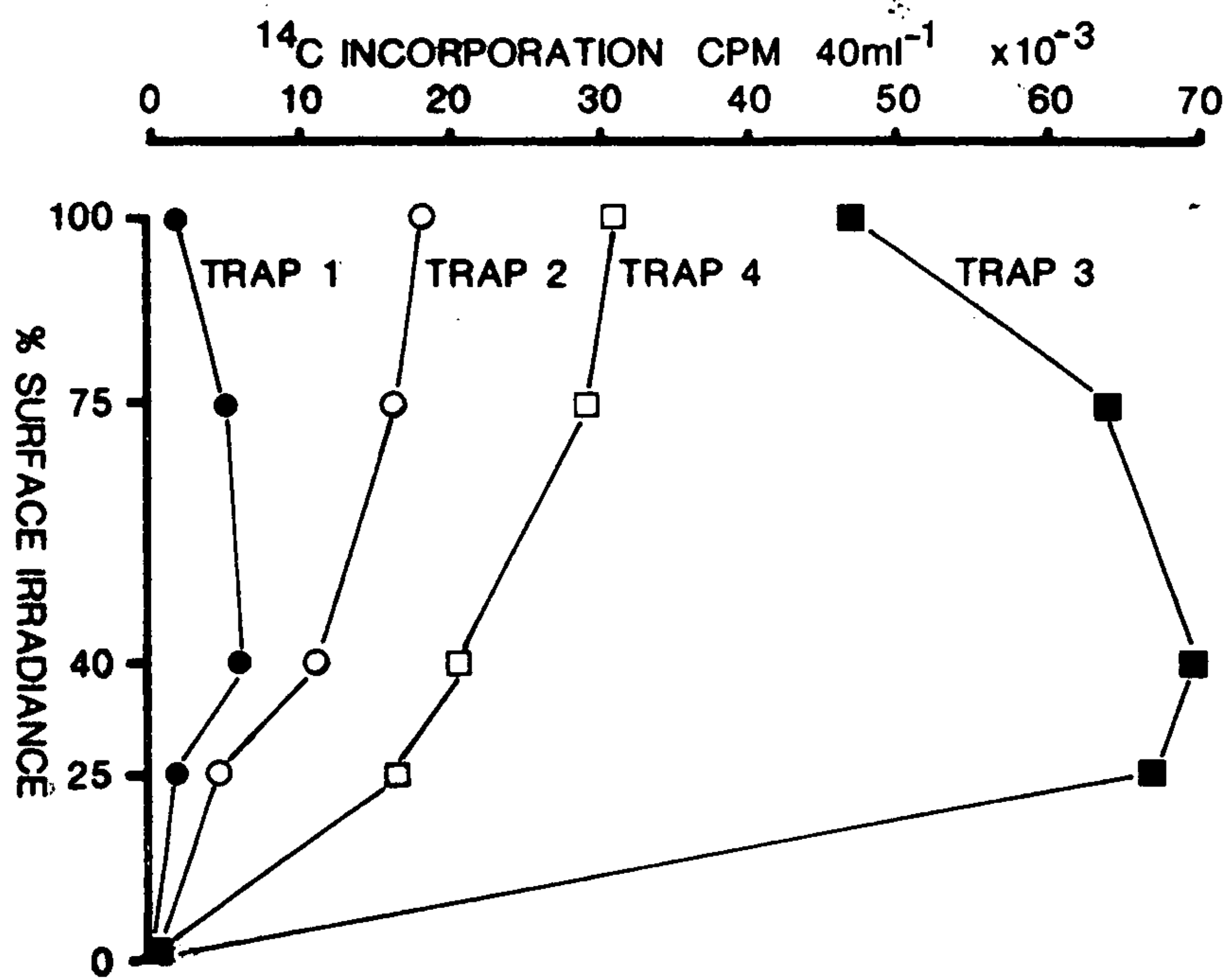
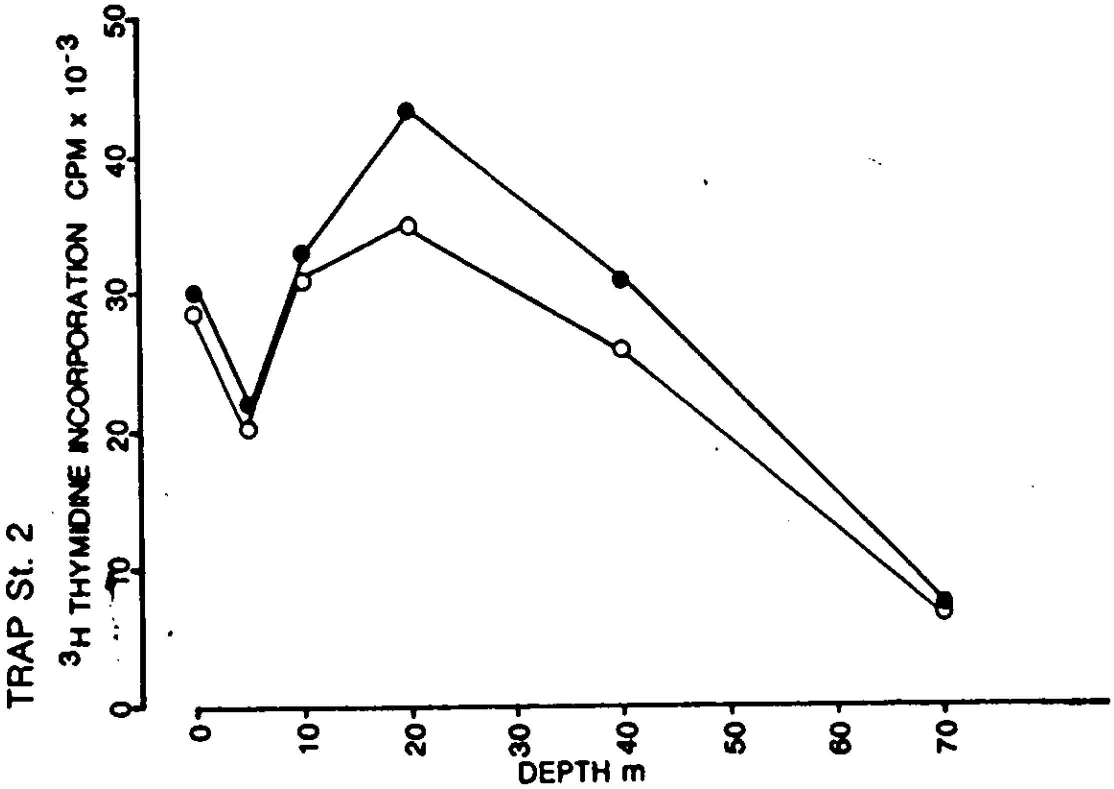


FIGURE 8 DEPTH PROFILES OF ^{14}C INCORPORATION (PRIMARY PRODUCTION).

FIGURE 9 DEPTH PROFILES OF ^{3}H-THYMIDINE INCORPORATION (BACTERIAL PRODUCTION) - FILLED CIRCLES - TOTAL ACTIVITY. OPEN CIRCLES - ACTIVITY ASSOCIATED WITH FREE LIVING BACTERIA.



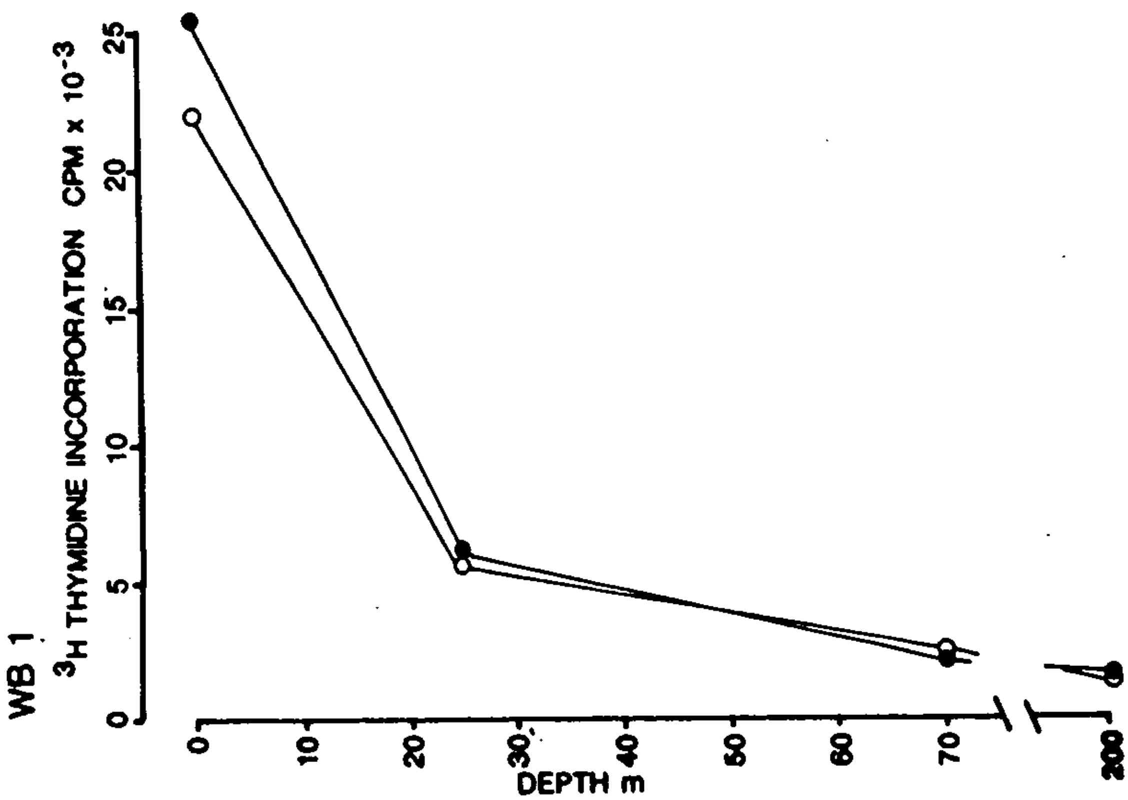


FIGURE 10 PRODUCTION OF N_2O (DENITRIFICATION) IN SEDIMENT CORES AMENDED WITH ACETYLENE. PRESENCE OF N_2O AT T_o INDICATES THAT N_2O IS PRODUCED <u>IN SITU</u>.

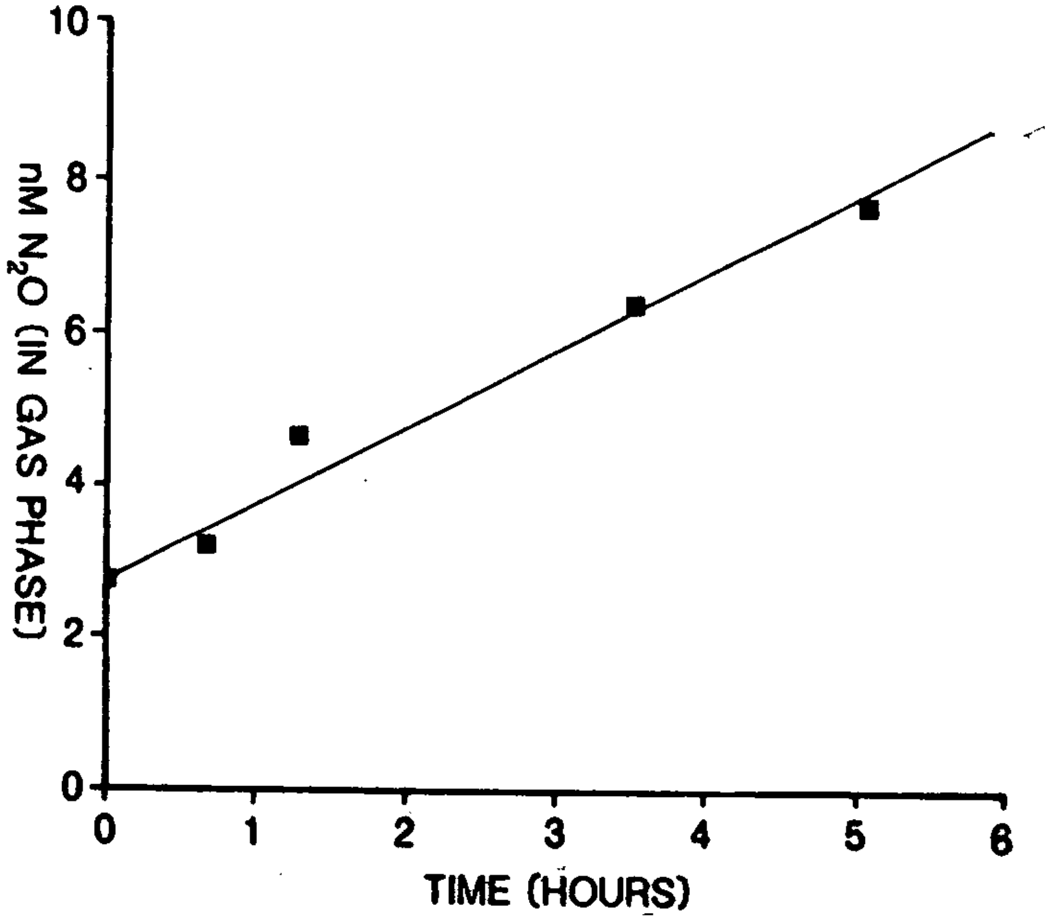


FIGURE 11   LOCATION OF UOR TOWS

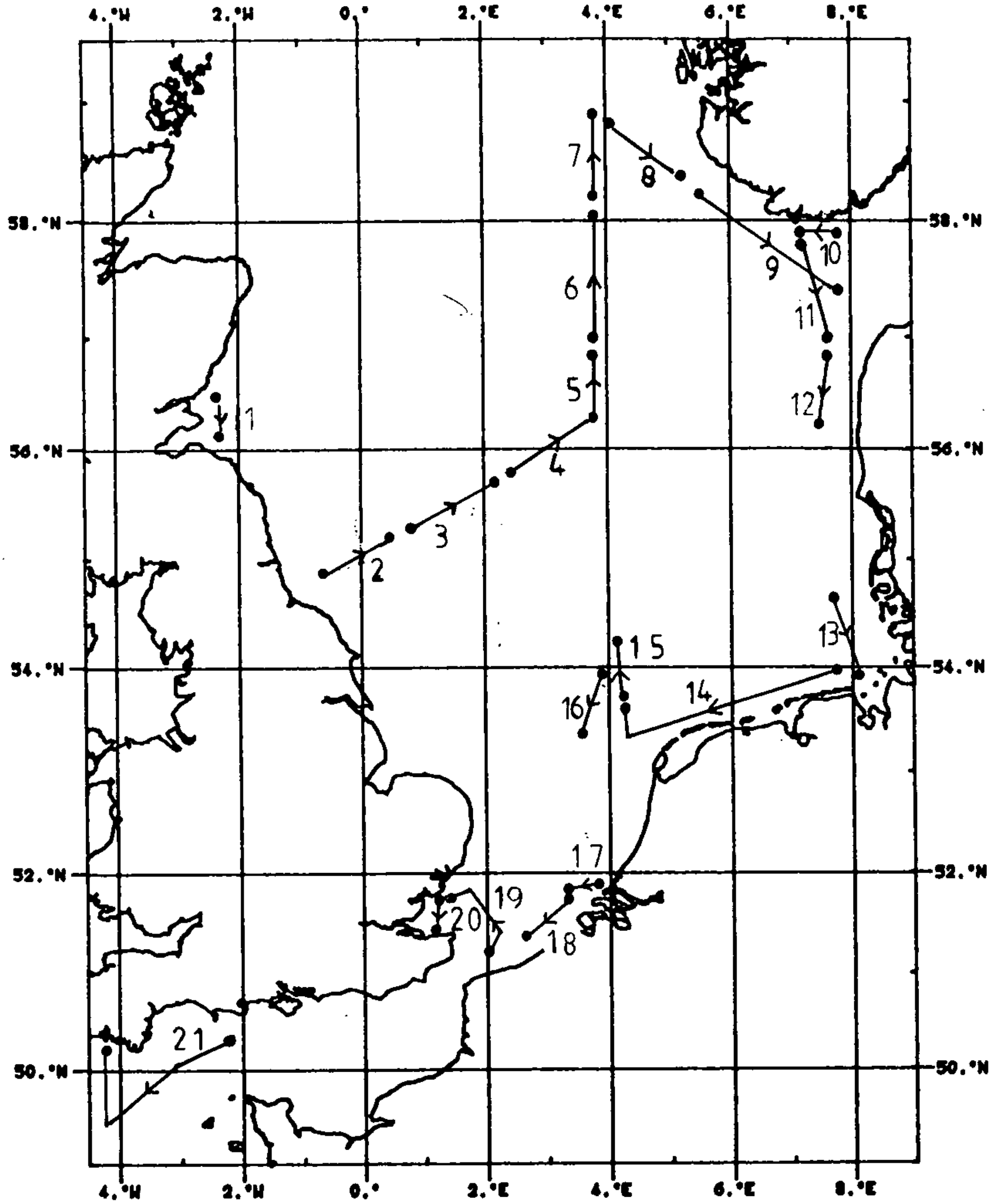


Figure 12(a) UOR TOW 2 - TEMPERATURE PROFILE (°C)

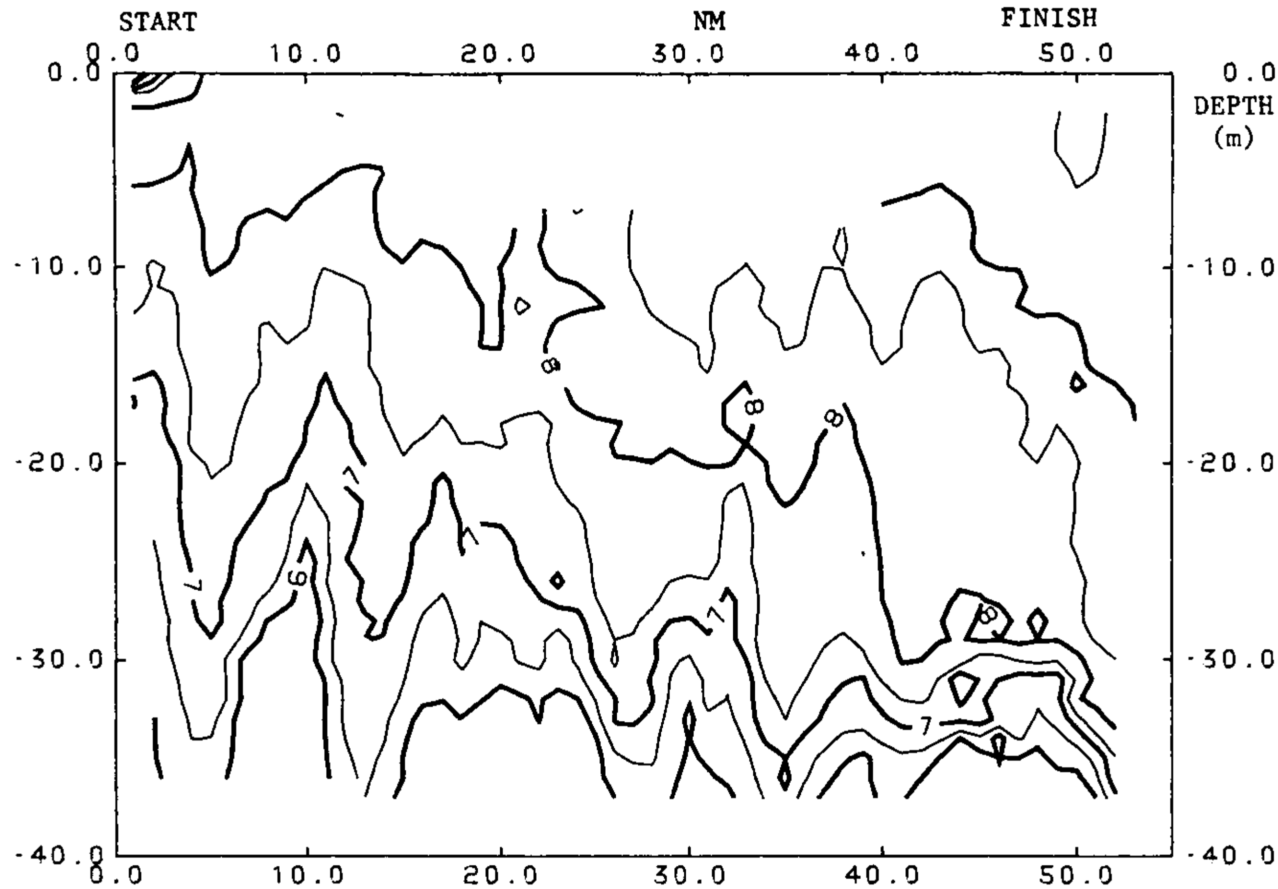
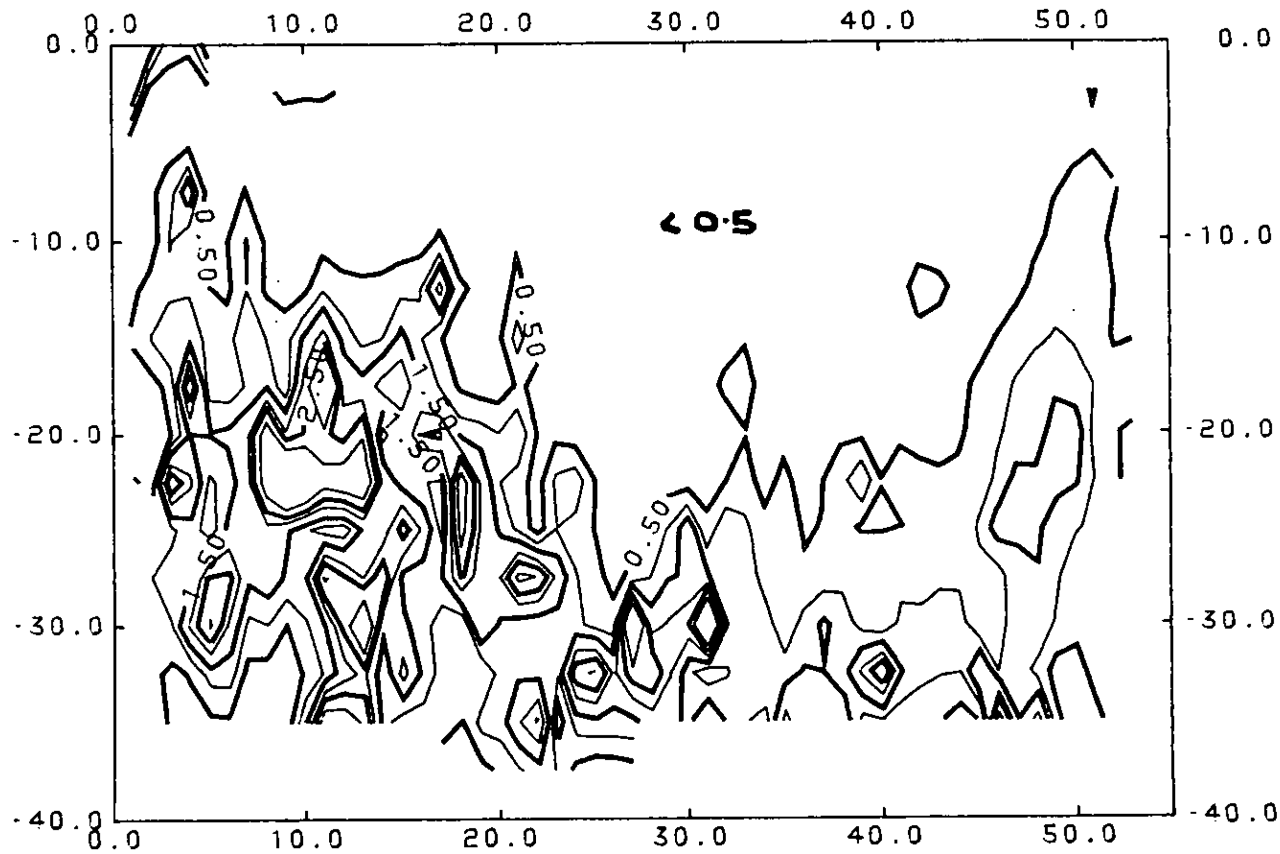
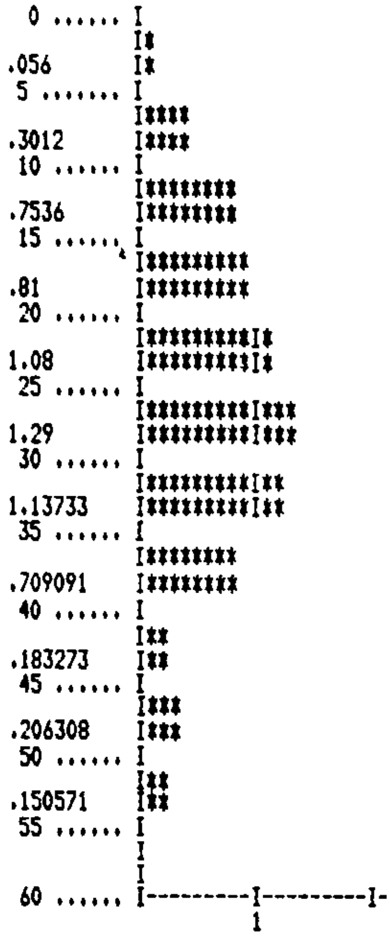


Figure 12(b) UOR TOW 2 - FLUORESCENCE PROFILE (mgm^{-3})





XBT # 2 T- 7 PROBE

TIME 19 03 GMT DAY 2

LAT: 55 DEG 11 MIN 0 SEC (N)

LON: 0 DEG 21 MIN 0 SEC (E)

SA-810 serial # 60

TAPE FILE NAME 72A

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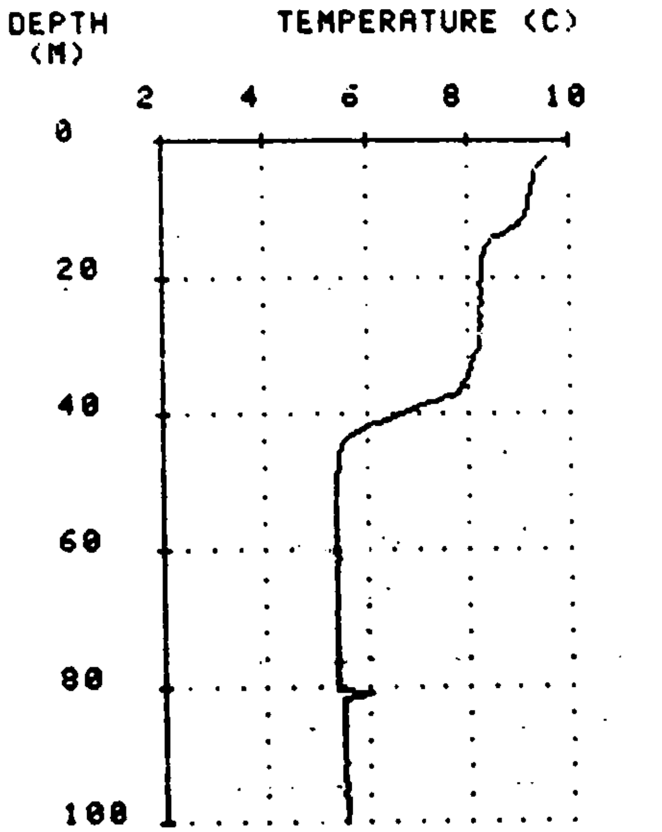

FIGURE 13 DEPTH PROFILES OF CHLOROPHYLL FLUORESCENCE AND TEMPERATURE. STATION WB 1.

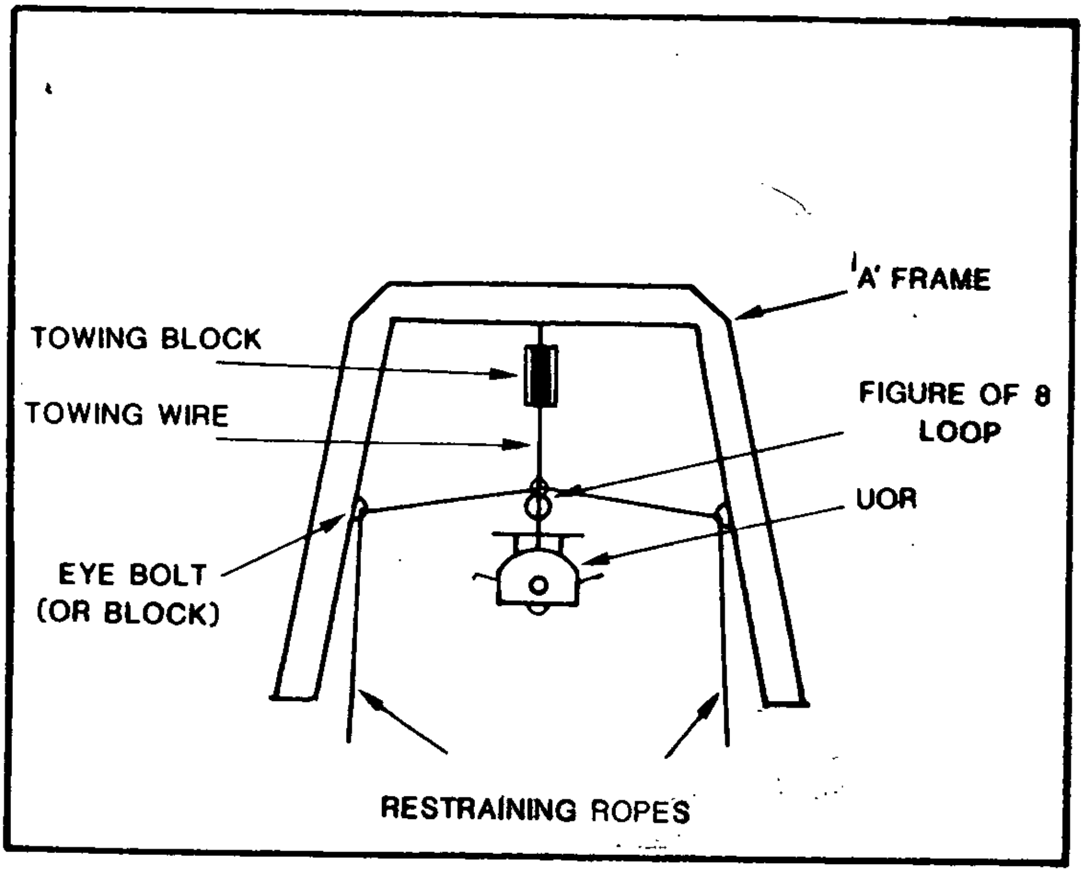

FIGURE 14 ARRANGEMENT OF RESTRAINING ROPES USED IN MODIFIED DEPLOYMENT AND RECOVERY OF UOR.

TABLE 1 PERCENTAGE CARBON ASSIMILATED IN THREE SIZE CLASSES OF PHYTOPLANKTON

	SIZE CLASS		
STATION	0.2 - 0.8 µm	0.8 - 5 µm	> 5 µm
TRAP 1	13	71	16
TRAP 2	21	43	36
TRAP 3	2	5	93
TRAP 4	3	17	80

TABLE 2 INCORPORATION OF ^{3}H - THYMIDINE INTO FREE AND ATTACHED BACTERIA

SITE	DEPTH [m]	TOTAL ACTIVITY [CPM]	% FREE	% ATTACHED
WB 1	SURF	3095	92	8
[STRATIFIED]	5	2108	95	5
	10	3377	93	7
	20	4358	81	19
	40	3119	86	14
	70	672	97	3
TRAP 1	SURF	4185	64	36
[STRATIFIED]	5	3488	87	13
	10	6005	88	12
	20	3175	77	23
	30	2026	89	11
	50	1108	100	0
TRAP 2	SURF	25504	86	14
[WELL MIXED]	25	6269	95	5
	70	2028	100	0
	200	1329	100	0
WB 4	SURF	NO DATA		
[STRATIFIED]	10	14129	67	33
	25	1478	100	0
	256	1087	100	0

TABLE 3 DENITRIFICATION RATE (as N_2O)
NORTH SEA - MAY/JUNE 1986

SITE	nmol N_2O m^{-2} sediment h^{-1}
TEES MOUTH	217.9
WB 4	311.2
TRAP 2	0
TRAP 3	870.9
WB 6	435.4
TRAP 4	1385.2
WB 8	10 (detection limit)

APPENDIX 1

CRUISE TRACK AND STATION POSITIONS

For cruise track see chart 1.
Total distance of track ~ 1500 NM

STATION	POSITION	DEPTH (M)	STATION TYPE
TEES	54° 48' N; 01° 00' W	50	SEDIMENT CORING
WB 1	55° 11' N; 00° 22' E		VERTICAL PROFILES
TRAP 1	55° 15' N; 03° 45' E		VERTICAL PROFILES SEDIMENT TRAP
WB 2	57° 07' N; 03° 44' E		VERTICAL PROFILES
WB 3	58° 44' N; 03° 44' E		VERTICAL PROFILES
TRAP 2	59° 00' N; 03° 45' E	267	VERTICAL PROFILES SEDIMENT TRAP SEDIMENT CORING
WB 4	58° 22' N; 05° 11.4' E	308	VERTICAL PROFILES SEDIMENT CORING
TRAP 3	58° 08' N; 08° 31' E	280	VERTICAL PROFILES SEDIMENT TRAP SEDIMENT CORING
WB 5	56° 33' N; 07° 31' E	35	VERTICAL PROFILES
WB 6	54° 02' N; 07° 56' E	27	VERTICAL PROFILES SEDIMENT CORING
TRAP 4	54° 09' N; 04° 09' E	42	VERTICAL PROFILES SEDIMENT TRAP SEDIMENT CORING
WB 7	51° 57' N; 03° 52' E	17	VERTICAL PROFILES
OUTER THAMES	51° 43' N; 01° 47' E	15	SEDIMENT CORES
WB 8	51° 31' N; 01° 24' E	12	VERTICAL PROFILES

APPENDIX 2

DETAILS OF VERTICAL PROFILES

VERTICAL PROFILE No	STATION	DATE	TIME	DEPTHS (M)
I	WB 1	31/5	1945	0*, 5, 10, 20, 40, 70, XBT
II	TRAP 1	1/6	1815	0, 15, 30, 50, XBT
VII	TRAP 1	2/6	0630	0*, 5, 10, 20*, 30, 50, XBT
IV	WB 2	2/6	2040	0, 30, 50, XBT
V	WB 3	3/6	0817	0, 25, 50, XBT
VI	TRAP 2	3/6	1530	0, 10, 25, 40, 70, 100, 150, 200, XBT
VII	TRAP 2	4/6	0630	0*, 10, 25, 40, 70, 100, 150, 200, 250*
VIII	WB 4	5/6	1340	0, 10, 25, 80, 110, 166, 240, 256, XBT
IX	TRAP 3	6/6	1425	0*, 10, 15, 20*, 50, 100, 150, XBT
X	WB 5	9/6	0100	0, 20, XBT
XI	WB 6	9/6	2340	0, 20, XBT
XII	TRAP 4	10/6	0630	5, 30, XBT
XIII	WB 7	11/6	1230	0, 20, XBT
XIV	WB 8	12/6	1615	0, 10, XBT

All water bottles 7.1ℓ. In addition, 30ℓ bottles used at positions marked with an asterix.

APPENDIX 3

POSITIONS OF UOR TOWS

TOW	DATE		TIME	LAT	LONG	DISTANCE (NM)
1	30/5/86		1805	56° 20'.5 N	02° 20' W	
			1950	56° 04' N	02° 19' W	16
2	31/5/86		1420	54° 49' N	00° 58' W	
			1930	55° 11' N	00° 22' E	53
3	31/5-1/6/86		2220	55° 12' N	00° 35' E	
			0515	55° 47' N	02° 21' E	60
4	1/6/86		0650	55° 50' N	02° 33' E	
			1145	56° 15' N	03° 45' E	52
5	2/6/86		1605	56° 15' N	03° 45' E	
			2030	57° 07' N	03° 44' E	55
6	2-3/6/86		2305	57° 10' N	03° 33' E	
			0810	58° 22' N	03° 44' E	77
7	3/6/86		1110	58° 27' N	03° 44' E	
			1430	59° 05' N	03° 45' E	43
8	5/6/86		0700	59° 02' N	03° 50' E	
			1200	58° 21' N	05° 10' E	60
9	5-6/6/86		1835	58° 14' N	05° 53' E	
			0235	57° 30' N	08° 09' E	94
10	7/6/86		1445	57° 54' N	07° 48' E	
			1545	57° 54' N	07° 38' E	8
11	7/6/86		1655	57° 50' N	07° 35' E	
			1955	57° 19' N	07° 44' E	31
12	7/6/86		2135	57° 01' N	07° 48' E	
			2330	56° 45' N	07° 38' E	19
13	8/6/86		1900	54° 46' N	07° 38' E	
			2300	54° 04' N	07° 52' E	45
14	9/6/86		0305	53° 52' N	07° 33' E	
		(A/C)	1245	52° 24' N	04° 50' E	
			1410	53° 35' N	04° 34' E	114
15	9/6/86		1440	53° 40' N	04° 30' E	
			1650	54° 02' N	04° 13' E	27
16	10/6/86		2140	53° 53' N	04° 01' E	
			2355	53° 3' N	03° 49' E	25
17	11/6/86		1035	51° 53' N	03° 26' E	
			1115	51° 55' N	03° 37' E	9
18	11/6/86		1700	51° 52' N	03° 26' E	
			2120	51° 23' N	02° 29' E	42
19	11-12/6/86		2305	51° 26' N	02° 12' E	
		(A/C)	0130	51° 38' N	02° 24' E	
		(A/C)	0305	51° 51' N	02° 00' E	
		(A/C)	0345	51° 51' N	01° 53' E	
			0410	51° 51' N	01° 48' E	45
20	12/6/86		1300	51° 55' N	01° 48' E	
			1500	51° 33' N	01° 35' E	24
21	13/6/86		0915	50° 19' N	02° 05' W	
		(A/C)	1300	50° 10' N	03° 00' W	
		(A/C)	1800	49° 31' N	04° 02' W	
			2220	51° 16' N	04° 12' W	137

TOTAL DISTANCE TOWED 1036 NM