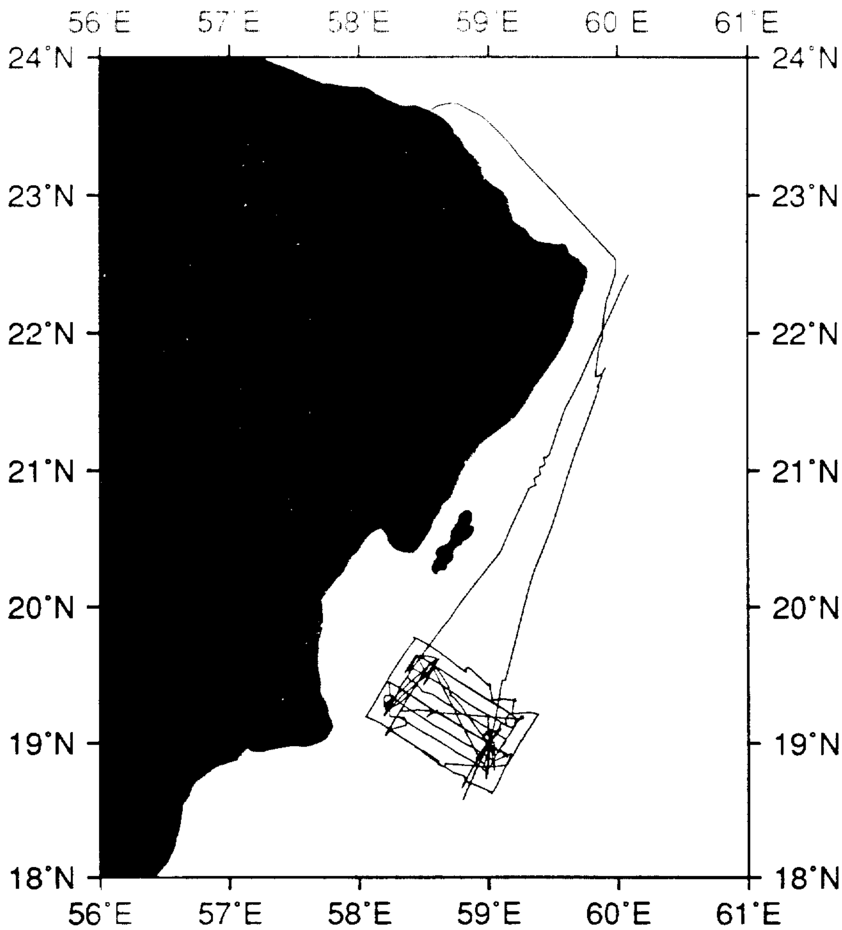
Institute of
Oceanographic Sciences
Deacon Laboratory

RRS *Discovery* Cruise 209

03 Aug - 22 Aug 1994

Biological and physical studies of the oxygen minimum and other hydrographic features of the Arabian Sea at 19°N 59°W during the south west monsoon

Cruise Report No 244 1994



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INSTITUTE OF OCEANOGRAPHIC SCIENCES

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CRUISE REPORT NO. 244

RRS *DISCOVERY* CRUISE 209
03 AUG - 22 AUG 1994

Biological and physical studies of the oxygen minimum and other hydrographic features of the Arabian Sea at 19°N 59°W during the south west monsoon

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ABSTRACT

Discovery Cruise 209 had two main objectives. The first was to relate the biological distributions in the area around 19°N 59°E, and extending from deep water to the shelf, to the physical and chemical oceanography of the area. Particular attention was to be given to the effects of the oxygen minimum layer and to acoustic assessment of the populations.

The second objective was to undertake a sampling programme consisting of a "box" of CTD profiles to the bottom, again extending from the shelf into deep water. This would allow a nutrient budget to be calculated for the area.

The sampling programme successfully achieved both objectives. It involved the use of the CTD and rosette sampler for physical and chemical data at specific positions and two SeaSoar surveys (within the main CTD box) for detailed spatial information on the upper ocean physical structure. Longhurst-Hardy Plankton Recorder tows, together with a day/night series of rectangular midwater trawls to 1000m, provided the distributional data on macroplankton and nekton. The Acoustic Doppler Current Profiler was used for simultaneous measurements of acoustic backscatter in the upper 300m.

Profiles of stimulable bioluminescence in the upper 600m were obtained with a self-contained pumped CTD system. Samples for the assessment of bioluminescent bacterial and dinoflagellate populations were also taken and the bioluminescence chemistry of selected midwater animals was investigated.

KEYWORDS

ACOUSTIC SURVEY, ADCP, ARABESQUE REFERENCE STATION, ARABIAN SEA, BATHYPHOTOMETER, BIOLOGY, BIOLUMINESCENCE, CHLOROPHYLL, CTD OBSERVATIONS, *DISCOVERY*/RRS - CRUISE(1994)(209), FLUORESCENCE, INDNWARA, LIGHTFISH, NUTRIENTS, OMAN WATERS, OPTICAL PROPERTIES, OXYGEN MINIMUM LAYER, RECTANGULAR MIDWATER TRAWL, RMT, SEASOAR, UPPER OCEAN, VERTICAL PROFILES, WOCE

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SHIELDS, S.	Steward
ORSBORN, J.	Steward
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AL-WAILI, Mohamed	Omani Officer Trainee

ITINERARY

Depart Muscat, Oman, 3rd August 1994

Arrive Muscat, Oman, 23rd August 1994

OBJECTIVES

Cruise 209 was a commissioned research cruise supported equally by the Defence Research Agency (DRA) and the World Ocean Circulation Experiment (WOCE). An earlier commissioning agency, the US Office of Naval Research, withdrew for financial reasons in February 1994.

Overall objective

To determine the influence of the oxygen minimum layer, across the shelf and slope of Oman, on the production, distribution, migrations and bioluminescence of the fauna and flora of the water column.

Specific scientific objectives

1. To investigate the physicochemical features of the upper ocean with a 10x50km SeaSoar survey, with particular reference to the oxygen minimum.

2. To study the distribution patterns of zooplankton and micronekton using the ADCP with LHPR and RMT sampling.

3. To determine a nutrient budget for the region by means of CTD profiles from the surface to the bottom, in a box of stations surrounding the SeaSoar survey.

4. To collect data on the optical characteristics of the upper water column, using instruments mounted on the CTD, SeaSoar and Lightfish.

5. To investigate the vertical distribution of bioluminescence in pumped profiles, and the biochemical characteristics of some of the bioluminescent organisms.

6. To carry out a predetermined suite of measurements at the Arabesque reference station (19°N 59°E) at the start and end of the cruise.

NARRATIVE

Problems with the RVS container shipments to Muscat imposed a last minute delay on the cruise which had been scheduled to start on August 1st (Julian day 213). It was rescheduled for August 3rd - 23rd with a resulting half day loss of working time. Ten of the scientific party (Herring, Pugh, Boorman, Keene, Wallace, Crisp, Hemmings, Holley, Megann and Bellerby) joined the ship late on Saturday July 30th in anticipation of unloading the two containers of equipment which had been sent out. In fact problems with the ships refrigeration system, which resulted in the urgent need to use the refrigerated container that had been shipped out full of scientific equipment, meant that it had already been unloaded by the ships personnel into the laboratory spaces. The equipment was sorted and stowed on July 31st, when the soft top container was also part unloaded.

The following day (August 1st) the French participants (Geistdorfer and Vincendeau) arrived with their equipment which was also loaded on board. The remaining scientific party of nine (Angel, Roe, Edge, Weeks, Ballestero, Hill, Whitaker, Moat and Thomson) arrived around midday. A third (RVS) container (with some essential deck winches) had been delayed and was due to arrive on the 1st but in practice did not arrive until August 3rd, the day of sailing.

A brief scientific meeting was held to discuss watchkeeping and the outline scientific programme. Medical problems left Richard Phipps (RVS) unfit to sail and he had to return to the UK, leaving only two winch drivers to provide 24hr cover.

On August 3rd the missing container finally arrived and was unloaded. One deck winch (for the Lightfish) had been held up during shipment and its cable had to be airfreighted out for winding on an existing (but less satisfactory) winch. It was also discovered that the cadmium wire essential for the nitrate analyses had been left behind. It was therefore necessary to freeze all the samples for analysis on the next cruise.

The vessel finally sailed at 1530Z (1930 local time) into a 35kt wind and light rain with spectacular lightning. The sea temperature of 31.5°C reduced speed to 5kt.

The PES fish was deployed in the morning of August 4th (J day 216) and the first station (12660) took place in the afternoon, en route to the Arabesque reference station at 19°N 59°E. This station comprised a trial CTD cast to 150m, following a morning teach-in on the sampling protocols, and was used as a practice exercise for the scientific personnel to familiarise themselves with the procedures.

The Arabesque station (stn 12661#1-5) was reached on August 5th. It had previously been decided to complete a full suite of samples at the start and end of the cruise, in order to provide the maximum temporal cover of the station to compare with similar sample suites during the three subsequent Discovery cruises in the area. Initial operation of the zooplankton net, bioluminescence profiler and CTD was prevented by problems with the winch. These were finally resolved and a complete sample set (CTD, nutrients, oxygens, salinities, bacteria, zooplankton, bioluminescence, phytoplankton) was achieved early next morning.

The next part of the programme was the deployment of a series of CTDs for a nutrient budget analysis, the core of the WOCE interest. 15 stations were planned, in a box some 120 x 70km enclosing the intended SeaSoar survey and extending from deep water (3500m) to the shelf (Fig. 2). These stations (stn 12662 #1-#22) included several bathyphotometer profiles alongside certain CTD casts. The box was completed by midmorning on August 9th.

In the first cast (and at the previous Arabesque station) the fluorometer failed to work properly due to power incompatibility between the IOS CTD and the RVS fluorometer. This was resolved for the second and all subsequent casts. One sample set (#6) was abandoned because of confusion over a misalignment of bottles on the rosette sampler. It was repeated as #7. The rolling induced by the SW monsoon winds was excessive when on passage between stations on the NW-SE sides of the box. It was reduced by steaming a dog-leg course between stations.

Very low oxygen levels were encountered at depths below about 100m (Fig. 3) at all stations, even those over the shelf.

A seamount reported at 385m on the chart was confirmed during the passage between stations and required further delineation before the planned SeaSoar survey could be undertaken with safety.

The ADCP was run throughout the box survey and the vessel steamed back to the first CTD position of the box to complete the ADCP continuity.

Once the CTD box had been completed an attempt was made to achieve a vertical light profile by lowering the sensor over the stern. The temporary framework proved too insubstantial to deploy in this way, but midships deployment was effective, so long as a large weight was slung beneath. Unfortunately the only one available was bright orange, which jeopardized the upward irradiance measurements.

The SeaSoar survey was the next scientific priority. This was planned as a grid of six 100km legs at 10km intervals, running at right angles to the shelf edge and thus covering the range from the shelf to deep water. The start point was in the NW corner of the CTD box and on passage to this position Lightfish was deployed and a detour made to investigate the region of the seamount, as well as a dubious 16.5m datum point on the chart. The latter was not confirmed.

After a CTD calibration cast to 500m (12663 #1) the first SeaSoar deployment began at 0525Z on August 10th in about 500m water depth, with Lightfish run at the same time. Problems with the SeaSoar termination required the vehicle to be recovered at 1430h. One conductivity sensor also turned out to be broken (perhaps during recovery). Comparative day and night bathyphotometer profiles were taken during the repair period (12663 #2-4) on the last of which the salinity and temperature data on the profiler were corrupted, a problem that could not be rectified. Subsequent profiles had to be matched with IOS CTDs for these data.

SeaSoar and Lightfish were redeployed at 1647Z. SeaSoar provided excellent data for the remainder of the survey, but Lightfish failed during the night and was recovered 0545Z 11 August at the offshore end of the third leg. The second section came inshore to a water depth of 300m while the fourth section (going through the Arabesque station position) reached a minimum water depth of 95m.

The survey would normally have finished early a.m. 12 August, but the data from the first section were erratic and it was decided to run SeaSoar back to the start of this leg and repeat it (Fig. 4). At the turn to the NE at the end of leg 6 Lightfish took a turn round the SeaSoar cable, stripping some of the fairing. SeaSoar was successfully recovered, the lines disentangled, and SeaSoar redeployed to complete the survey about 1300Z with a subsequent calibration CTD to 500m (12663 #5).

Having completed the main physical programme, the biological sampling began. A first deployment of the LHPR was made to 290m (12664 #1) from which recovery was complicated by two winch power failures. The RMT multinet system was then deployed at the Arabesque position for a day/night series of horizontal tows between the surface and 1000m, interspersed with three bathyphotometer profiles, a shallow CTD for bacteria around the oxycline and two LHPRs, the last of which (12664 #37) completed the work at the reference position but jammed after 6min when it engulfed a large swimming crab (16th August). The RMTs demonstrated a greatly impoverished fauna in the low oxygen layer, with a major migration into the oxygenated near-surface waters at night. Swimming crabs were numerous and myctophids were the main component of the fish catches. One set of tows (12664 #34-36) was taken at the bottom of the oxygen minimum zone (1200-1785m) and provided much larger catches, with a greater variety, than any of those above.

A second SeaSoar survey was then undertaken, with appropriate CTD calibrations (12665 #1 & 2), incorporating the Satlantic irradiance sensors, with a cross track which repeated both the short ends of the previous survey and leg 4 through the reference position (Fig. 5). Dangerously high wire tensions caused the system to be brought back inboard but it was found that the strain gauge had a large offset, giving erroneous readings, and SeaSoar was redeployed. The light sensors reduced the effective Seasoar depth to 250m and resulted in additional electrical noise on the signals, but neither were severely limiting. The survey was completed at 0500Z 18 August, having coped with Force 7 winds and heavy seas most of the time.

"Discovery" now moved inshore on to the slope so that the scientific party could carry out an LHPR (12666 #1), bathyphotometer profiles (12666 #2 & 3) and a further day/night set of RMTs to 400m (12667 #1-12). Very clear stratification was observed in the day samples and very little in the deeper night ones. Crabs were abundant in the top 100m.

A final series (19-20 August) of RMT tows, bathyphotometer profiles and CTDs were taken on the shelf (12668 #1-16) where large numbers of a small medusa were encountered. A single RMT tow was then made at 400-500m at the position of 12667#10, adding this horizon to the top 400m previously sampled.

Broadband ADCP tests on a vertical wire were carried out late on August 20th (following a barbeque) and passage was then made to the Arabesque position. A second complete suite of samples was achieved here (12670 #1-6) and a last LHPR (12670 #7) which (typically) jammed on a crab.

Passage was then made back to Muscat with a diversion along one previous Seasoar line, to compare data from the on-board surface sampler. The PES fish was brought inboard, and an ADCP calibration run made a.m. August 22nd. Frenetic packing occupied this final day at sea and was largely completed by arrival on the morning of August 23rd. Two containers were packed that day and most of the scientific party flew out very early a.m on 24th August.

GEAR AND SCIENCE REPORTS

CTD and SeaSoar Operations

CTD and multisampler system

Instruments used for the CTD/multisampler set-up were:

Neil Brown MKIIIB CTD (Deep01) and oxygen sensor,
General Oceanics 24 bottle multisampler,
Chelsea Instruments Fluorometer (RVS instrument),
Sea Tech 100cm transmissometer,
EG&G 10 litre water bottles,
FSI 10 litre water bottles,
3 SIS digital reversing thermometers (RVS instruments),
2 SIS digital reversing pressure meters.

An altimeter was to be included for accurate near bottom sampling, but the CTD power supply could not provide enough current and an IOSDL pinger was used instead.

Twenty four bottles were used at the test station (12660 #1) to check the multisampler and the new FSI bottles. The multisampler functioned fully and the FSI bottles, after analysis of the samples, seemed to have functioned satisfactorily.

Only four misfires occurred in twenty five stations and no misfire occurred twice at the same bottle position. The multisampler modifications, made prior to the cruise, have therefore been successful.

The CTD cable termination survived the whole cruise without fault. The cable from the fluorometer to the CTD was changed once when it developed a leak, resulting in bad data. The CTD and transmissometer both operated well.

SeaSoar

The instruments used for the first survey on the IOSDL SeaSoar survey were:

Neil Brown MKIIIB CTD (Shallow 01) and oxygen sensor,
FSI Ocean Conductivity Module (OCM),
Chelsea Instruments Fluorometer (IOSDL instrument),
2 _ PAR irradiance sensor (IOSDL instrument).
Oxygen sensor

For the second survey the Satlantic light sensor package was added.

On the first survey (Fig. 4) the SeaSoar had to be recovered after about five hours due to bad conductivity readings from the OCM and to the breakdown of the cable termination. Once on board it was clear that the top of the OCM had snapped, perhaps caused by the drogue used for the recovery. Once reterminated, the SeaSoar was deployed without an OCM. There was a heavy swell and it was thought the drogue might be required for recovery, which would have entailed putting another OCM at risk.

Except for a period in shallow waters the SeaSoar was flown with the depth limited to approximately 350m at a towing speed of 8 kt, due to the strain peaking at 1500kg. On reaching the shelf the cable out was shortened to 180m, to ensure that if the ship stopped the SeaSoar would not drop on to the sea bed.

On August 12th (J day 224) the Lightfish cable became wrapped around the SeaSoar cable, leading to some loss of fairing but no damage to the cable itself. SeaSoaring continued, after the portion of cable with damaged fairing had been hauled in. Later the cable connecting the fluorometer to the CTD became partially disconnected at the fluorometer end; this led to sea water corrupting the fluorometer data. Both the bulkhead connector and cable were replaced on recovery at the end of the survey.

For the second survey (Fig. 5) the Satlantic light sensor package was installed. The CTD data were very noisy, but after use of a software filter (J. Smithers) the bad pressure points were discarded, allowing continued operation. Several hours after deployment, the SeaSoar was recovered as a precaution in the face of apparent large strains, even at the surface. On inspection it was found that the strain gauge had a 982kg offset, thus the strain readings were not as bad as first feared. After redeployment the SeaSoar operation continued successfully until the planned end of the second survey.

This was the first time a Satlantic light sensor package had been used with a SeaSoar and, except for the bad data frames, which require filtering, the SeaSoar responded favourably. The depth reached was approximately 250m with strains peaking at the maximum of 1500kg. This could be improved in calmer conditions. Flying was not quite as smooth as with the bomb weight on the vehicle but it is thought this could be improved by having slightly less cable out.

The SeaSoar surveys covered the survey area twice. The first survey took about 3 days and was a finer grid than the second. Subsequent processing has shown that critical changes occurred in the upper 400m over the survey area in the week between the two surveys.

SBK, RFW, SW

SeaSoar Processing

SeaSoar data were logged via the RVS ABC computer system, then transferred into the IOSDL PStar system. Data were split into 4-hourly sections, and initial calibrations and editing of the data were carried out. The four hourly sections were plotted as time series and as TS profiles, so that an assessment could be made of the data quality. While the conductivity cell was noisy, the other data were of good quality. The four hourly sections were appended and contoured for each leg of the survey (Figs 6-8). Although a start was made on de-spiking the data, more work is required. The manufacturers calibrations for the temperature, salinity, depth, fluorescence and downwelling PAR sensors have been applied.

A programme of surface sampling was carried out when the SeaSoar was deployed, with samples being taken from the non-toxic supply at 2 hourly intervals. The sampling was timed to coincide with the time at which SeaSoar would sample the water at the surface. Samples were taken for salinity, chlorophyll "a" and oxygen. These samples will be compared with the surface SeaSoar measurements and calibration algorithms will be developed and applied to the SeaSoar data.

The rapid processing and contouring of the data showed some indication of a high density layer of water being upwelled on to the shelf in the north of the survey during the first survey. This was less apparent during the second survey, which did not extend on to the shelf. During the second survey the temperature and density difference in the top 100m metres was considerably more intense than during the first survey.

NC, JCPH, AM, BIM, AW

CTD Processing

Data from the CTD were brought into the Pexec software package via the RVS level ABC system. The level A is a dedicted unit, and, in addition to some de-spiking, generates 1s averages of the raw CTD data.

After each CTD cast, the data were read in and archived. The manufacturer's calibrations for the sensors were then applied and 10s averaged files produced. Downcast data were extracted, sorted on pressure and averaged to 2 deci-bar intervals. The laboratory calibration of the pressure sensor was adjusted by -2.6 dbar after noting the deck pressure offset during the first few casts. This remained consistent (within +/- 1 dbar) for the duration of the cruise.

Calibration of the salinity data from the CTD was achieved with the aid of the salinity samples drawn from the rosette bottles in addition to cable-out data from the winch system, and bottle firing times which are logged with the RVS level ABC system. Casts were calibrated on an individual basis, but the general offset applied to the sensor data did not change by more than about 0.003 psu. The worst differences between upcast and downcast data after being matched on pressure, except for a few outliers, were 0.006 psu (+/- 0.002 psu in the more stable deep water).

A one-time comparison of oxygen data from the CTD and measurements from bottle samples showed poor agreement which varied significantly with depth. Lack of experience in calibrating CTD oxygen data, which is known to be often a trying task, has meant that this will be attempted back at the laboratory where useful experience can be called upon.

The fluorescence data will be calibrated back at the laboratory using extracted chlorophyll data from bottle samples. Reworking of the nominal calibration will also be required for the earlier stations as this was applied incorrectly at first.

Plots of Potential temperature, Salinity, Fluorescence, and Oxygen against Pressure on scales of 0-600db and 0-4000db were generated for each cast enabling a first look at the performance of the instrument and quality of data. In order to produce contour plots of Temperature, Salinity, and Density, cast data were gridded to form the four sides of the CTD survey box.

NC, AM, AW

Chlorophyll "a" and Particulate Sampling

Chlorophyll "a"

Discrete samples were taken for the measurement of chlorophyll "a" from the non-toxic supply, and from bottles on the rosette multisampler, for the purpose of calibrating the fluorometers used during the cruise to measure in-vivo fluorescence. Chelsea Instruments "Aquatracka" MkII fluorometers were mounted on to the CTD frame and the SeaSoar. A Turner Designs model 10-000R fluorometer fitted with a flow-through cell was connected to the de-bubbled non-toxic supply. A second surface sampling fluorometer, also a MkII "Aquatracka", provided in vivo fluorescence and was sited in a rapidly flushing tank in the hangar, along with a transmissometer. Both the surface sampling fluorometers were fed from header tanks above the hangar. The depth of the seawater intake through the hull of the ship was approximately 4m. Both the surface sampling fluorometers sampled continuously throughout the cruise and the data was logged via separate Level As on to the ships computer system.

About 200 discrete samples were taken for chlorophyll "a" and phaeophytin determinations, Samples were taken from the non-toxic supply at 2 hourly intervals during the SeaSoar surveys. At CTD stations samples were normally taken at 6 depths (to 500m) but at the Arabesque station samples were taken at 12 depths. Triplicate samples were taken: two were placed immediately in acetone for analysis at least 15 hours later. The third was frozen as a backup.

Analysis of chlorophyll "a" and phaeopigments was carried out by filtering 100ml (sometimes 200ml) of seawater onto 25mm GFF glassfibre filters and extracting the pigments by adding 20ml 90% Analar acetone for a minimum of 15 hours. Analysis was carried out on a Turner Designs Model 10-000R fluorometer. The chlorophyll fluorescence was measured before and after adding 0.1M hydrochloric acid. Fluorometer calibration was carried out with pure chlorophyll "a" standard; the concentration of the standard had been determined by spectrophotometry before leaving the UK. Calibration checks were made during the cruise. The results are reported as mg m^{-3} chlorophyll "a"' and phaeopigments.

All the samples were measured during the cruise. The results have been entered into Excel spreadsheets and with the rest of the sample data will be used to develop the fluorometer calibrations.

Photosynthetic pigments

Samples were taken during the cruise for the identification of the major light absorbing pigments, including chlorophyll "a". These are to be measured by Dr. Mantoura and his colleagues on the following cruise, D210. Samples were taken from 12 depths at the reference station for the Arabesque cruises (59°N, 19°W). In addition surface samples were taken at 2 hourly intervals along the transect from the reference station to the coast. Samples were also taken at the four corners of the survey box, from the surface only. These extra samples were taken in order to evaluate the variability of the pigment distribution over a wide area, and to assess whether the samples taken from the reference station were representative of the area.

Water volumes of 1 or 2 litres were filtered through 25mm Whatman glass fibre filters and stored in cryovials at -50°C. Some 30 samples were taken.

Particulate Organic Carbon.

Samples were taken from 12 depths from the 2 CTD stations at the reference station for the Arabesque series of cruises. 1l of water was filtered though a 25cm Whatman glass fibre filter paper and stored in cryovials at -50°C. 24 samples were taken.

Phytoplankton Species

Samples were taken for the analysis of phytoplankton species at the reference station at 12 depths. At the corners of the CTD survey box six depths were sampled, and at regular intervals from the non-toxic supply during the Seasoar survey. Two samples were taken, one into Lugols iodine and one in borax-buffered formaldehyde. Analysis of the samples will be invaluable in identifying the phytoplankton species distribution in the survey area.

JCPH, AW

Optical Oceanography

Multispectral measurements of irradiance and radiance were made using two towed instruments. They were both deployed to provide sub-surface measurements of reflectance for comparing ocean colour with phytoplankton biomass, and for development of an Arabian sea algorithm for use with SeaWiFS. Lightfish, towed at a fixed depth of 4m below the surface, can be used to compare horizontal scales of variation of ocean colour, phytoplankton biomass and physical structure. Since Lightfish data are logged along with other underway parameters such as temperature, salinity and fluorescence, the data set can be used to compare these spatial scales. Downwelling irradiance and upwelling radiance sensors were mounted on to SeaSoar to provide data from a depth profile. As well providing data for the development of spectral reflectance algorithms for phytoplankton biomass, the Satlantic sensors on SeaSoar will allow investigation of the relationship between the optical properties of the ocean and the mixed layer depth (from the spectral diffuse attenuation coefficient, Kd, derived from the Satlantic/SeaSoar data).

Lightfish was fitted with 6 upwelling and downwelling irradiance sensors; the wavelengths of the sensors were 410, 450, 490, 510, 554 and 670nm. A pressure sensor was mounted in the towing body to provide depth measurements. The data were logged via the Level ABC, averaging in the order of 6 frames and recording all the channels every 30s, and then transferred to PStar for calibration and further processing.

A number of problems were encountered with the deployment of Lightfish. The portable winch with slip ring which was to have been shipped from RVS did not arrive in Muscat in time for the cruise and so a winch was used which did not have the capability of conveying data via the winch during its operation to the computer on the ship. It was necessary to disconnect the sensor system every time the wire length was altered. It curtailed plans to use the Satlantic sensors in a profiling mode. In general it made the deployment of the optical sensors on board awkward and tiresome as the method of deployment was not the one chosen for this experiment.

Despite these problems Lightfish was deployed successfully, providing four transects of data covering most of the area of the survey. The data were of very high quality, since the system has been redesigned since its last oceanic deployment in the Southern Ocean in late 1992. Comparisons of the reflectance ratio (R450/R560) with the uncalibrated fluorescence show a promising inverse relationship which should provide a biomass algorithm based on ocean colour for the Arabian Sea.

The Satlantic sensors, recently purchased from Canada, were tested by deploying them on a profiling rig at the side of the ship. The data looked to be of high quality and so the sensors were mounted on to SeaSoar for the second survey. The downwelling sensor was mounted flush with the uppermost surface of the tailfin and in front of it; the upwelling radiance sensor was mounted below the body of the system, with the data acquisition unit mounted below and forward of the SeaSoar body. Two cores of the SeaSoar cable were used for power and data transmission. The data were sampled by a fast Level A and averaged every second. The system provided very high quality data, which have the advantage of being calibrated and providing radiometric units. The wavelengths for irradiance and radiance were the SeaWiFS wavelengths 412, 443, 490, 510, 555, 670 and 683nm. The system provided about 30 hours of data, measuring to about 50m below the surface. Initial data screening suggests that the deployment system on SeaSoar provides very stable data. The depth of SeaSoar during the deployment of the Satlantic sensors was 300m, shallower than for the previous survey and caused by the deterioration of the weather. There did not seem to be any adverse effects on the performance and control of SeaSoar with the change in payload. The data were noisier than usual, but the spikes were removed by software after acquisition, resulting in fewer data frames being acquired every second. The data from the SeaSoar CTD were compared with that from the first survey and were found to be of the same high quality.

DB,AW

Oxygen analyses

Sampling

Bottle oxygen samples were the first samples taken from the Niskin bottles at each CTD cast; a total of 287 samples was measured. Duplicate samples were taken on each cast, usually from the first two bottles, with full duplicates on the Arabeasque reference station. Overall some 25% of the samples were measured in duplicate. Discrete samples were also taken, in duplicate, from the non-toxic supply at two hourly intervals on the SeaSoar legs. Samples were drawn into clear, wide necked calibrated glass bottles and fixed immediately with reagents dispensed using Anachem dispensers. Samples were shaken on deck for half a minute then again in the laboratory, thirty minutes after collection. The first (test) CTD station (12660 #1) was used for training in sampling techniques and as a check on the oxygen bottle calibrations. Bottle temperatures were taken, following sampling for oxygen, using a hand held electronic thermometer probe. The temperatures were used to calculate any temperature dependent changes in the sample bottle volumes and will also be used in the calculation of density for conversion of µmol/l to µmol/kg units.

Analysis

Samples were analysed in the constant temperature laboratory, starting two hours after sample collection, following the Winkler whole bottle titration with an amperometric method of endpoint detection, as described by Culberson and Huang (1987). The equipment used was supplied by Metrohm and included the Titrino unit and control pad, exchange unit with 5ml burette to dispense the thiosulphate in increments of 1µl, with an electrode for amperometric end point detection. A second 5 ml exchange unit, driven by a Metrohm Dosimat, was used to dispense the potassium iodate standard. Initial problems on the test station were resolved by slowing down the fill rate on the burette and changing the electrode and aspirator tip. This improved the reproducibility. The Anachem bottle top dispenser, used to dispense acid before titration, had to be replaced at station 12662 #17, otherwise the equipment appeared to work well.

Reproducibility

The absolute mean difference between duplicate samples on the CTD casts was 0.73µmol/l, about 0.3% full scale. The oxygen concentrations ranged from 0-225 µmol/l. The mean duplicate difference, as a % full scale, was 0.55% for samples with concentrations less than 50 µmol/l improving to 0.09% for a set of samples over 50µmol/l. The precision on samples from the non-toxic supply was not as good, with duplicate differences of up to 3% full scale. A distinct yellow colour remained in some of the non toxic supply samples following analysis; many of these samples also had bubbles in at analysis as the method of sampling from the non-toxic supply was not ideal. Thiosulphate normality was checked on every station against potassium iodate. The exact weight of this standard along with the calibration of the 5 ml exchange unit and the 1 l glass volumetic flask used to dispense and prepare the standard, were accounted for in the worksheet used to calculate the oxygen values. One batch of iodate standard lasted for the whole cruise - it was checked at the start of the cruise against a commercial standard obtained from the Sagami chemical company in Japan. The thiosulphate normality changed when the reservoir was topped up, on station 12665 #1, and also at station 12662 #11. A conversion factor of 44.66 was used to convert from ml/l to µmol/l. The introduction of oxygen with the reagents and impurities in the manganese chloride were corrected for by blank measurements made on each station, as described in the WOCE Manual of Operations and Methods (Culberson, 1991).

References:

Culberson, C.H. and S.Huang, 1987. Automated amperometric oxygen titration. Deep Sea Research, **34**, 875-880

Culberson, C.H. 1991. 15pp in the WOCE Operations Manual (WHP Operations and Methods) WHPO 91/1, Woods Hole.

SH

Nutrient Analysis

Nutrient analyses were carried out using a Technicon AA II system further developed at PML and set up to measure silicate, phosphate, nitrate and nitrite. However, it was not possible to measure nitrate as an oversight at PML, during packing, led to the cadmium wire being forgotten! Measures were taken to obtain a replacement, but complications with communications in Muscat defeated the attempt and we sailed without it. (Frozen samples were taken for later nitrate analysis -- see below).

Two methods of introducing the water samples to the autoanalyser were employed: discrete samples and continuous on-line analysis. During the CTD survey discrete samples were taken from the CTD rosette (following the protocol described elsewhere). Storage of the samples is not encouraged so analysis was carried out as soon as possible after sampling; however, during the interim, samples were kept in the refrigerator. On analysis the samples were carefully placed in an autosampler, following a rigourous cleaning and rinsing procedure. Samples were always run in duplicate, although some triplicates were measured for comparison.

Continuous on-line analysis was employed during the SeaSoar surveys. Water supplied to the laboratory from the ship's own non-toxic system was used. Upon reaching the autoanalyser water was on-line filtered by a continuous filter block, which contained a pre-rinsed (10% HCl) 0.45µm Millipore filter.

By using this continuous system the water sample was never exposed to the atmosphere, hence avoiding contamination both by the laboratory atmosphere and from any contamination problems arising from sampling water from the CTD rosette bottles. However, it is not appropriate for sampling depth profiles. Where samples are collected from the CTD great care must be taken to avoid contamination; this also applies to the use of the autosampler during analysis.

Nutrient calibration was effected by running standards made up in low nutrient seawater (Ocean Science International - OSI). For discrete samples standards were run at the beginning and end of each set of CTD cast samples. Daily standards were run for the on-line analysis. Milli-Q water was used as a reagent blank. Working standards used for the CTD stations were as follows: phosphate 1, 2, 3, 4microµol, silicate 10, 20, 30, 40µmol and nitrite 0.1, 0.2, 0.3, 0.4µmol. During on-line surface analysis only half these concentrations were necessary.

In addition to the calibration standards several others were used as monitors of precision throughout the cruise. These included an 'internal' reference seawater standard (QC2) collected at depth (1000m) at the beginning of the cruise and bottled in separate Dilu-vials, an OSI (Ocean Scientific Instruments) nutrient inter-comparison standard (QC1) and Sagami Chemical Co. of Japan certified nutrient standard solutions.

During the initial part of the cruise several problems were encountered with the NO_2/NO_3 channels. These proved to be unusual electrical faults (perhaps a result of the local humidity) and time consuming to solve. Therefore during the CTD survey and first SeaSoar survey only phosphate and silicate were measured. During the second SeaSoar survey and final visit to the Arabesque station phosphate, silicate and nitrite were measured.

The above problems coupled with the inability to measure nitrate gave rise to an extra duplicate set of samples being taken for nutrients from all CTDs and two hourly during the SeaSoar surveys. These were immediately frozen, for analysis during the inter-cruise change over in Muscat. As the nitrite was measured at the second visit to the Arabesque reference station an interesting comparison with the frozen samples will be possible.

Maximum silicate concentrations of approx. 160µmol were found in waters below about 1000-1200m and minimum concentrations at the surface of approx. 2µmol. Corresponding phosphate concentrations of 3µmol and 1.5µmol were found.

BB

Discrete salinity and underway measurements

The IOS Autosal salinometer (Model 53718) was used routinely throughout the cruise to measure the salinity of samples drawn every four hours from the thermosalinograph and from all CTD casts. Standard seawater ampoules (batch P124) were used as reference samples at the beginning and end of each crate of 24 samples. We used the "salinity master" Excel spreadsheet to generate the salinities from hand-recorded conductivity ratios.

Underway measurements

Data were taken from four RVS logging systems:

1) Thermosalinograph (TSG) data (surflog)
2) Meteorological data (metloggr)
3) Nutrient data (nutri2)
4) Fluorescence data (t_fluor).

Tsgexec0 was used to convert the TSG data from RVS format into Pstar format and then tsgexec1_209 was used to calculate salinity, de-spike the salinity data, average the data every two minutes and merge with navigation data. Tsgexec3_209 was then used to calibrate the TSG with salinity sample measurements. The TSG performed well all cruise apart from two occasions. A few hours of data were lost on August 6 (Jday 218) when the header tank ran dry and bubbles where found in the system midday on August 12th (Jday 224). Meteorological data were taken from the RVS system using metexec0, and metexec1_209 was used to convert raw multimet data into physical Pstar data. The met data were then merged with navigation data using metexec2. The nutrient and fluorescence data were taken from the RVS system and converted into Pstar format using nutexec0 and tflexec0. The data were then averaged every two minutes and merged with navigation data using nutexec1_209 and tflexec1_209.

NC, BIM

Acoustic Doppler Current Profilers

Shipboard ADCP

The use of the ADCP on this cruise was geared more towards the measurement of acoustic backscatter from zooplankton than the measurement of currents, although of course, the latter will be very useful data for validation (and comparison with), the SeaSoar and CTD data. The R.D. Instruments 150 kHz shipboard ADCP was, therefore, set up with 120 bins of length 4m giving a total maximum range of 480m and fine horizontal resolution (the standard IOSDL setup being 8m bins in deep water).

The ADCP hardware (Firmware version 17.10) and PC (running DAS v2.48) operated smoothly throughout the cruise. Data from the ADCP were processed using the IOSDL Pexec software. Four main processing steps were carried out using C-shell scripts:

1. Conversion of the data from RVS data format to Pstar format
2. Correction for the drift of the ADCP clock against GMT
3. Merging smoothed navigation data to enable subtraction of the ship's velocity and, therefore, calculation of absolute current velocity.
4. Calculation of relative backscatter by observing the deviation from the mean amplitude value at each bin depth over daily periods.

An ADCP calibration run, using the technique described by Pollard and Read (1989), was carried out at the end of the cruise on the way back to Muscat in about 80m of water. For this purpose, the ADCP was set up with 30 x 4m bins and with the bottom tracking enabled. GPS coverage during the period of the calibration (which had been chosen after observing the previous day's coverage) was excellent. There was insufficient time to work up the calibration data at sea, and so, for the purpose of generating plots of absolute current, the calibration values from a previous cruise were used for misalignment angle and scaling factor.

ADCP/ Longhurst sampling

Plots of relative backscatter were generated throughout the cruise, and showed several interesting features. The upper 350m (during the day) and 200m (at night) were highly stratified, on some occasions as many as 12 distinct layers of backscatter could be seen. This is far more than has been observed in our previous data sets. Depth penetration by the ADCP was consistently poorer by night, presumably due to the enormous biomass migration into the top 10m, effectively blanking the ADCP transducers.

Efforts to biologically validate the backscatter with the LHPR were largely unsuccessful. Six hauls were made, but only 2 were totally trouble free, the others failing due to equipment problams and/or catching swimming crabs which jammed the rollers. We should, however, have sufficient material to combine with the midwater trawls to resolve the various layers and link these with the CTD and SeaSoar data.

BroadBand ADCP

A 150kHz RDI BroadBand ADCP installed with the latest Firmware version (4.18) was used in a downward looking configuration in a profiling experiment. The unit was left at 15m depth for a period of approximately 2 hours for an intercomparison with the shipboard ADCP, and then lowered at 25m min^{-1} to 950m and back. This is the second deployment of this kind by IOS and will provide an additional data set giving some confidence in current and amplitude data from an ADCP used in this way. An Aanderaa RCM8 current meter was installed 2m above the ADCP to provide additional current and pressure data.

NC, HSJR

MACSAT Operation

Installation

The Mac, MacSat receiver and the antenna interface were installed on Sunday 31/7, and there seemed to be nothing missing. Although an antenna was packed in the MacSat crate, the dome antenna already installed on the rail was the one used for MacSat in the last cruise (as confirmed by Dave Cotton's notes), so the other one was stowed and connections routed to the one already in place. Dave Cotton's description of the antenna as "vibrating considerably under moderate to high wind conditions" was confirmed by the Bridge after the first night at sea! The only other hardware problem at this stage was a short, tracked to the co-ax plug in the back of the MacSat receiver, which was quickly sorted out. In general the equipment proved to be in good working condition.

The equipment, despite initial doubts of the security of the antenna's dome, proved capable of producing good images from the three NOAA (National Oceanographic and Aeronautic Administration) satellites, and for passes of over 13 min or so noise levels were acceptably low in about 60% of cases. The salient features in the images were mostly clouds and landmasses, although the latter were not always clear. In a few cases some sea-surface features were visible, but the 8-bit (0-255) resolution of the images meant that little useful information could be extracted fom these, especially in the absence of proper calibration of the infra-red images. The predictions for NOAA satellite passes proved to be reliable and accurate.

The Sub-Satellite projection (SSP) was found to be quite useful, allowing the ship's position and the coastlines to be seen simultaneously with the tracks of all three NOAA satellites. This was used successfully on cloudier days to locate the image when the coastlines were not clearly visible. Overlays proper, however, were found to be worse than useless in most cases: the resolution of the Aden-Muscat coastline is two straight lines, and MacSat does not even seem able to place these reliably over the image. The same goes for the lat-long lines - for some reason the Arabesque region seemed to roam apparently at random around the globe, with the South Pole occasionally appearing off the Omani coast!.

With the hardware as installed on D209, it was not possible to print images directly using MacSat, as none of the Macs on the network had MacSat installed. Thanks to Martin Beney, a complex procedure was found which allowed images to be printed, but this required image files to be transferred onto the UNIX system via a floppy, another Mac and Telnet, and then using GRABGRID and ALV utilities to get the pictures into postscript form so they could be sent to a laser printer. The better images were saved to floppy disc; we hope to be able to print them more conveniently on return to JRC. It is a pity the MacSat Mac could not be networked, because it was a significant disadvantage not to have immediate access to a printer. This was not only because of the inconvenience of having to transfer daily prediction formats to Word format and on to another Mac via floppy disk for printing but more crucially the inability to compare printed images of successive cloud images rendered the setup near useless for any meteorological analysis.

AM

Micronekton and Microplankton samples

No processing of the catches was carried out onboard, so these comments are very much first impressions. The catches, in general, appeared to contain a relatively small variety of species. The samples from the top 100m were massive and RMT1 samples contained substantial amounts of aggregated phytoplankton. Small quantities of similar aggregates were common in some of the deeper samples, which may either have been contamination or aggregates sedimenting down through the oxygen minimum. The oxygen minimum had a clear influence on all samples collected from below 100m. By night catches were extremely small below 100m, whereas by day there were small catches of vertical migrants, myctophids (*Diaphus* and *Benthosema*), a photichthyid fish, small euphausiids, and small decapods (mostly sergestids and pasiphaeids). The migrants were mostly caught in the surface 50m haul by night but in lower numbers, possibly because by day when in the oxygen minimum they are lethargic and so more easily caught. This is in contast to the normal pattern in the North Atlantic where catches of migrants tend to be larger at night than by day. There was a clear depth zonation of the various migrant species in the daytime catches which may well correlate with the multiple scattering layers displayed by the ADCP. There were one or two species which appeared to be specially adapted to life within the oxygen minimum, which included a polychaete (possibly a terebellid) with bright red tentacles and gills, and morids (Physiculus) which also had large, bright red gills. The single set of samples taken from below the oxygen minimum at 1400m provided relatively rich catches in terms of both biomass and in variety of species. This suggests that future work on the populations inhabiting the water beneath the minimum will be very rewarding.

The samples collected on the shelf tended to catch massive swarms of a medusa akin to *Pelagia*, which appeared to exclude most of the other species. The one set of nighttime samples that missed the jellyfish contained huge numbers of euphausiids. Although relatively few speimens of fish were caught over the shelf, there was quite a variety of species, few of which had been taken offshore. Perhaps the greatest disappointment was the comparative scarcity of cypridinid ostracods, which during the International Indian Ocean Expedition (Discovery cruise 1) had often dominated catches in the near-surface waters and providing spectacular displays of bioluminescence at night. Another group which proved to be unexpectedly rare was the Siphonophora, possibly because oxygen minimum excludes these gelatinous species from the depths of 200-400m, at which they are dominant in the North Atlantic. The low oxygen water extended over the shelf, and so may have accounted for the catches of small flatfishes at 50-100m.

MVA

Bacterial sampling

10 or 20ml samples were drawn from all Niskin bottles from the following CTD casts: Arabesque reference station (at the beginning and end of the cruise), 12662 #4, 12662 #11, 12662 #14, 12662 #22, 12664 #19 and 12668 #2.

Serial dilutions of the samples were made down to 1 in 1000; 100 microl of each dilution (and of neat sample) were plated on to nutrient seawater (NSW) agar plates made with 60% seawater. In addition 1ml and 5ml samples of the original sample were filtered through sterile 45µm nitrocellulose filters which were then placed on nutrient agar plates. Plates were incubated at 20°C for 24-48hrs until colonies were clearly visible.

Following incubation, all aerobic bacteria were enumerated and the bioluminescent colonies counted, picked off the original plates and streaked on to fresh NSW plates to ensure that the picked colonies were not mixed. Pure cultures of all bioluminescent bacteria obtained were immediately placed in stab culture for transport back to UK. In addition a number of tests were performed on these organisms to assist with preliminary identification. Tests used were: Oxidase, utilisation of propionate, utilisation of citrate and growth on low salt medium. These tests should allow for distinction between *Vibrio fischeri*, *V. harveyi* and *V. cholerae* but are not a good basis for the identification of *Photobacterium* spp. or of other potentially bioluminescent Vibrios such as *V. logei*, *V. vulnificus* etc.

In addition all secondary cultures, even those which no longer appeared bioluminescent, were picked on to charge-modified nylon membrane. Picked bacteria were then lysed and their DNA bound to the membrane. Back in the UK these membranes can be probed for the presence of bioluminescence associated genes (eg *lux*AB) and for species specific genes (eg *lux*R) to assist with identification of the organisms. This will also establish whether bacteria not displaying a bioluminescent phenotype nevertheless have the genetic capacity for bioluminescence but were down-regulated for bioluminescence under the culture conditions used.

PH, SW

Bioluminescence profiles

The bathyphotometer profiling system

This consists of:

1. A SeaBird CTD SBE25 with modular SBE3 thermometer, SBE4 conductivity sensor, SBE5 submersible pump and a pressure sensor. The CTD is battery powered and is used to record data in solid state memory.

2. A SeaTech fluorometer. The excitation filter has a 425 nm peak response and the emission peak response is 685 nm. It is connected to the CTD.

3. A bathyphotometer, built in the Laboratoire d'Océanographie de l'Ecole Navale, which has been designed to measure stimulated bioluminescence in the water column to a maximum depth of 600m by day and night. It is battery powered and the data are recorded on the CTD's memory.

4. A Challenger Oceanic submersible pump. The centrifugal pump is mounted on the bathyphotometer. It is used to pull seawater through the dark chamber of the bathyphotometer at a flow rate of 0.4-0.5ls^{-1}, giving a residence time in the chamber of approx 0.45s. The flow rate is recorded by a mechanical displacement flow meter at the pump output.

Bathyphotometer characteristics

A dark hose (1.44m length and 0.17m diameter) leading to the dark chamber excludes ambient light. A grid of 2 mm mesh across the chamber's input aperture stimulates the bioluminescent plankton.

A photomultiplier tube (PMT) Philips XP2081 integrates the light signal over 0.5 s. Its spectral sensitivity is 450-570nm so that it is possible to detect light at 10^{-4} to 10^{-9} $W.m^{-2}$ and its gain is 10^6. The PMT has a dark current of less than 1 nA.

Between the PMT and the dark chamber, light passes through a neutral density filter (transmission 40%) and a window (transmission 90%). Different filters can be inserted in place of the neutral density one but this is a difficult operation at sea.

Operation

In situ stimulated bioluminescence was measured in Arabian Sea in August 1994 with the system described above.

The bathyphotometer and the SeaTech fluorometer were connected to the SeaBird SBE25 CTD where bioluminescence, fluorescence, temperature and salinity data were recorded at a rate of 2 or 4 scans per second. The system could only be used for vertical profiles and recorded data as it went down and up at a speed of about 0.5 $m.s^{-1}$, to a maximum depth of 600m. The PMT was not calibrated; the results could only be expressed in current units (amps).

Results

Twelve stations between 58°-59°30'E and 18°30'-20°N were investigated and 57 bioluminescence profiles were recorded at 10 different station positions during 22 profiling periods. The first 19 were accompanied by a full CTD data set (Fig. 9), but the remainder lacked the temperature and salinity data (as a result of SeaBird sensor failure) and were accompanied by parallel reference casts of the IOSDL CTD. Measurements were conducted by night and by day as well as at dawn and dusk.

Bioluminescence was observed at all depths to 600m but it was greatest in the top 100m. At a few stations, two or three consecutive profiles were recorded. The depth of the bioluminescence peak was the same on each profile but there were some differences in the level of bioluminescence. This was similar to the variation between up and down profiles taken at the same position.

During the day the maximum of bioluminescence was located between 40 and 60m depth. At night, the bioluminescence was mainly between the surface and 50m depth (Fig. 10). Bioluminescence was not necessarily correlated with *in vivo* fluorescence or oxygen profiles and some bioluminescence was measured within the oxygen minimum layer. Correlations with temperature and salinity were not obvious. Future work will look at the relationship between bioluminescence and the other biological and chemical parameters. The distribution of bioluminescence, especially between the shelf and deep water stations, is being analysed.

Dinoflagellate samples were concentrated from 1l samples from CTD bottles in the top 50m by filtration through 8μm filters, to correlate with the bioluminescence profiles. These samples will be analysed for their species compositions on return.

PG, M-AV

The biochemistry and distribution of imidazolopyrazine bioluminescence

Bioluminescence is a widespread phenomenon in the deep sea. Imidazolopyrazine is known to be the most common class of luciferin found in marine bioluminescent organisms. Two types of this class of luciferin are found: coelenterazine and a *Vargula*-type (ostracod) luciferin. However, coelenterazine occurs more widely than the *Vargula*-type luciferin.

Our main aim has been to identify how widespread coelenterazine bioluminescence is in marine organisms and to compare data for the Arabian Sea species with those from the Atlantic obtained in 1993. The basis for the assay has been the coelenterazine reactivation of the calcium-activated photoprotein aequorin. A standard curve is established and coelenterazine quantified in tissue extracts. A variety of decapods, copepods, ostracods, some fish and squid have been assayed in this way.

In order to make predictions about the role of particular tissues in bioluminescence we have examined the tissue distribution of coelenterazine in some of these animals. A *Vargula*-type luciferin assay has also been employed, using the reaction with *Vargula* luciferase.

New species and genera using coelenterazine have been identified and the prevalence of this luciferin type further highlighted. *Vargula*-type luciferin has been found only in the ostracod *Cypridina dentata*. Tissue distribution studies of coelenterazine have shown consistent differences in some species. The midwater shrimp *Systellaspis debilis* has previously shown higher levels of luciferin in the stomach than the liver. This has now been demonstrated in *Systellaspis braueri* and may reflect the key role of the stomach in the ejection of the luminous secretion in this genus. High levels of coelenterazine have also been found in some fish photophores and this may indicate the enhanced role of the photophores in coelenterazine storage.

CMT

COMPUTING CONFIGURATION AND DATA COLLECTION

The following list shows the hardware configuration during the cruise.

Discovery1 (Level C)

Sun SPARCstation IPC
Hard Disks:
    200Mb Internal
    2800Mb HAMCOM External
Floppy disk: 3.5" 1.44Mb/720K PC or Unix format.
Tape Units:
    150Mb Sun Quarter Inch Cartridge (QIC) drive
    Resolv Exabyte 8mm drive
Sun CD-ROM drive.

Discovery2

Sun SPARCstation IPC
Hard Disks:
    200Mb Internal
    327Mb External
    1340Mb External
Floppy disk: 3.5" 1.44Mb/720K PC or Unix format.
Tape Unit:
    150Mb Sun Quarter Inch Cartridge (QIC) drive

Discovery3

Sun SPARCstation 1
Hard Disks:
    327Mb External
    327Mb External
Floppy disk: 3.5" 1.44Mb/720K PC or Unix format.

Discovery4

Sun SPARCstation 1
Hard Disks:
    327Mb External
No floppy disk.

Output Devices (permanently on ship)

Dot matrix printer	NEC Pinwriter P5 (132 column)
Laser printer	Hewlett-Packard Laserjet III with Turboscript Postscript cartridge
Screen dump plotter	Tektronix 4693RGB Wax Transfer
Drum Plotter	Nicolet-Zeta A0, GML + HPGL
Flatbed plotter	Advance-Bryans Colourwriter A3/A4 HPGL

Level B

Custom built fault-tolerant data logger, comprising:

Philips PG2111 Single board computer featuring:
- 68030 25Mhz CPU with 68882 Floating-point Co-processor
- 4Mb RAM
- 1Mb ROM
- 4 Serial ports
- 1 Parallel port
- SCSI port

Mirrored 150Mb SCSI Hard disks
150Mb Viper QIC tape drives x 2
Radstone PME-SIO4 Intelligent Serial Cards x 2 featuring:
- 68020 12.5Mhz CPU
- 1Mb RAM
- 128K ROM
- 8 x 68681 DUART giving a total of 32 serial ports

Level A computers

There were three types of Level A used during cruise 209.

Mk 1 Level A based on an RVS designed board utilising an Intel 8085 processor.

BOTTLES	CTD bottle firing
MX1107	Transit satellite navigation
NUTRI2	Nutrient and foremast lightmeter
T_FLUOR	Turner Fluorometer

Mk II Level A based on the Syntel CP-68 board using a Motorola 68000 processor.

GPS_ASH	Ashtek Differential GPS Receiver
GPS_TRIM	Trimble GPS Surveyor
GYRO_RVS	Ships gyro
LITEFISH	Towed Light sensors
LOG_CHF	Chernikeeff log
SIM500	Simrad EA-500 Hydrographic Echosounder

MK II Level A based on the same processor board used in the Level B.

CTD_17D2	IOS CTD
CTD_19	IOS Seasoar
SATLANT	Towed light sensors, also on Seasoar

PC Based Level A's

SURFLOG	Thermosalinograph, fluorometer, transmissometer
METLOGGR	Wind speed/direction, wet/dry temperature, barometric, pressure, long wave radiation, port/starboard light sensors.
WINCH	Seametrix winch monitoring system.

Data collection

The following list shows the start and end times, together with their source, for data file names and their variables.

adcp	94 215 16:56:01	94 234 10:24:01	PC
	bindepth, roll, pitch, heading, temp, velew, velns, velvert, velerr, ampl, good, bottomew, bottomns, depth		
adcp_raw	94 215 16:56:01	94 234 10:24:01	PC
	rawdopp, rawampl, rawspecw, rawgood, rawstdv, beamno, bindepth		
avgdepth	94 216 07:55:30	94 234 12:03:30	(derived)
	depth		
bestdrf	94 213 14:09:00	94 234 16:25:30	(derived)
	vn, ve, kvn, kve		
bestnav	94 213 14:09:00	94 234 16:25:30	(derived)
	lat, lon, vn, ve, cmg, smg, dist_run, heading		
bottles	94 216 09:52:27	94 233 10:59:22	Mk1levela
	code		
ctd_17d2	94 216 13:27:00	94 233 04:03:49	Mk2levela (VME)
	press, temp, cond, trans, fluor, alt, oxyc, oxyt, deltat, nframes		
ctd_19	94 221 07:35:12	94 230 05:05:32	Mk2levela (VME)
	press, temp, cond, trans, fluor, light, oxyc, oxyt, cond2, deltat, nframes		
gps_ash	94 218 14:56:54	94 234 16:25:59	Mk2levela
	sec, lat, lon, hdg, pitch, roll, mrms, brms, attf		
gps_trim	94 213 14:08:52	94 234 16:26:04	Mk2levela
	lat, lon, pdop, hvel, hdg, svc, s1, s2, s3, s4, s5		
gyro_rvs	94 213 14:08:54	94 234 16:26:09	Mk2levela
	heading		
litefish	94 217 15:10:00	94 224 05:28:00	Mk2levela
	ch1, ch2, ch3, ch4, ch5, ch6, ch7, ch8, ch9, ch10, ch11, ch12, pres		
log_chf	94 213 15:03:46	94 234 16:26:08	Mk2levela
	speedfa, speedps		
metloggr	94 213 17:58:36	94 234 12:10:53	PC

	windspd, winddir, pairtemp, sairtemp, seatemp, humid, ppar, ptir, spar, stir, baro		
mx1107	94 213 15:08:24	94 234 14:38:24	Mk1levela
	lat, lon, slt, sln, el, it, ct, dist, dir, sat, r, status		
nutri2	94 217 08:31:45	94 234 12:22:15	Mk1levela
	ch1, silicate, ch3, nitrite, fosphate, nitrate, ch7, light		
proctd	94 216 13:27:00	94 233 04:03:49	(derived)
	press temp, cond, trans, oxyc, oxyt, salin, sigmat, atten, potemp, sigmap, fluor, oxygen, oxypc, dyhigh		
prodep	94 216 07:55:30	94 234 10:57:00	(derived)
	uncdepth, cordepth, cartarea		
pross	94 221 07:35:12	94 230 05:05:32	(derived)
	press, temp, cond, cond2, oxyc, oxyt, salin, salin2, sigmat, trans, potemp, sigmap, fluor, oxygen, oxypc, dyhigh, light		
psatlant	94 220 17:19:22	94 230 04:33:01	(derived)
	press, ed1, ed2, ed3, ed4, ed5, ed6, ed7, lu1, lu2, lu3, lu4, lu5, lu6, lu7		
relmov	94 213 15:04:00	94 234 16:25:30	(derived)
	vn, ve, pfa, pps, pgyro		
satlant	94 220 17:19:22	94 230 04:33:01	Mk2levela (VME)
	press, ed1, ed2, ed3, ed4, ed5, ed6, ed7, lu1, lu2, lu3, lu4, lu5, lu6, lu7, nframes		
seabird	94 217 08:58:00	94 233 11:57:13	Ascii file
	depth, biolumen, salin, temp, fluor, flag		
sim500	94 216 07:51:42	94 234 12:09:44	Mk2levela
	depth, rpow, angfa, angps		
surflog	94 215 19:29:46	94 234 12:12:51	PC
	temph, tempr, cond, trans, fluor, spr30v, spr12v		
t_fluor	94 217 14:22:12	94 234 12:20:23	Mk1levela
	fluor, range		
winch	94 216 04:50:41	94 233 13:28:13	PC
	cabltype, cablout, rate, tension, btension, comp, angle		

MB

SUMMARY AND CONCLUSIONS

Despite the earlier uncertainties about its funding (and the last minute ones about its timing) this cruise demonstrated the effectiveness of a multidisciplinary biological and physical programme focused on a restricted region of great oceanographic interest. The monsoon conditions, although testing at times, did not limit the sampling operations and in the event no time was lost to bad weather.

The SeaSoar surveys provided evidence of some upwelling but this appeared considerably less dynamic than had been anticipated. Chlorophyll levels were not very high to start with but increased markedly during the cruise. The oxygen minimum layer encroached over the shelf and had a dramatic effect on the zooplankton and micronekton distributions, greatly limiting the populations within it and enhancing the nocturnal migrations out of it into the surface layers. The remarkable increase in the pelagic populations at its lower margin was a particularly interesting feature.

Analysis of the results, combined with the longer term sampling of the Arabesque station on subsequent cruises, will provide a unique data set for interpreting the seasonal events in this region.

ACKNOWLEDGEMENTS

The cruise participants gratefully acknowledge the financial support of the Defence Research Agency and of the World Ocean Circulation Experiment, without which this cruise would not have taken place.

It is a tribute to the RVS technical support and to the ships company that despite poor weather conditions and technical failures all the scientific objectives were achieved. The unfailing and cheerful assistance provided at all times by Capt Avery and the ships personnel made it a pleasure to be involved in the cruise.

ACRONYMS AND GEAR CODES

ADCP	Acoustic Doppler Current Profiler
BPCTD	Bathyphotometer with Seabird CTD
CTD	Conductivity, Temperature and Depth probe
IOSDL	Institute of Oceanographic Sciences, Deacon Laboratory
LHPR	Longhurst Hardy Plankton Recorder
MS	Multisampler
PES	Precision Echo Sounder
JRC	James Rennell Centre
RMT1M	Rectangular Midwater Trawl 1m^2 Multinet
RMT8M	Rectangular Midwater Trawl 8m^2 Multinet
RVS	Research Vessel Services
TRANSM	Transmissometer
TS	Temperature/Salinity
UFL	Fluorometer
WB	Water Bottle (10l)
WP2	Vertical zooplankton net

STN.	DATE 1994	POSITION LAT	POSITION LONG	GEAR	DEPTH (M)	TIMES GMT*	COMMENT	MEAN SOUND (M)
12660 # 1	4/ 8	21 36.6N 21 37.4N	59 51.0E 59 51.5E	CTD MS TRANSM UFL	0- 151	1254-1320 Day	Test dip. All bottles fired at 59.7m.	2239
12661 # 1	5/ 8	19 00.1N 19 00.1N	59 00.1E 59 00.2E	WP2	0- 112	1127-1139 Day	Arabesque St. Vertical haul @ 0.5m/sec.	
12661 # 2	5/ 8	19 00.0N 18 59.9N	59 00.3E 59 00.7E	BPCTD	0- 600	1200-1305 Day	Arabesque St.	
12661 # 3	5/ 8	18 59.7N 18 59.9N	59 00.9E 59 00.8E	CTD MS TRANSM UFL	0-3372	1627-1926 Night	Arabesque St. WB @ standard depths.	3392
12661 # 4	5/ 8	18 59.9N 18 59.9N	59 00.6E 59 00.6E	WP2	0- 100	2009-2020 Night	Arabesque St. Vertical haul @ 0.5m/sec	
12661 # 5	5/ 8	18 59.7N 19 00.1N	59 00.2E 59 00.6E	BPCTD	0- 600	2035-2127 Night	Arabesque St.	
12662 # 1	6/ 8	18 50.3N 18 50.6N	59 08.3E 59 08.7E	CTD MS TRANSM UFL	0-3436	0220-0503 Day	Box St.1. WB @ standard depths.	3456
12662 # 2	6/ 8	19 01.3N 19 01.0N	59 15.3E 59 15.2E	CTD MS TRANSM UFL	0-3395	0641-0918 Day	Box St.2. WB @ standard depths.	3423
12662 # 3	6/ 8	19 13.1N 19 13.0N	59 23.2E 59 23.2E	BPCTD	0- 600	1155-1300 Day	Box St.3.	

* Local = GMT + 4

STN.	DATE 1994	POSITION LAT	POSITION LONG	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND (M)
12662 # 4	6/ 8	19 13.1N 19 13.5N	59 23.2E 59 23.1E	CTD MS TRANSM UFL	0-3384	1315-1558 Dusk	Box St.3. WB @ standard depths.	3405
12662 # 5	6/ 8	19 13.4N 19 13.2N	59 23.0E 59 22.8E	BPCTD	0- 600	1651-1753 Night	Box St.3.	
12662 # 6	6/ 8	19 19.5N 19 19.0N	59 12.0E 59 12.6E	CTD MS TRANSM UFL	0-3264	2020-2255 Night	Box St.4. WBs misaligned.	3279
12662 # 7	7/ 8	19 19.7N 19 19.2N	59 11.8E 59 11.6E	CTD MS TRANSM UFL	0-3263	0008-0242 Dawn	Box St.4. WB @ standard depths.	3284
12662 # 8	7/ 8	19 26.2N 19 25.7N	59 00.6E 59 00.3E	CTD MS TRANSM UFL	0-2779	0517-0744 Day	Box St.5. WB @ standard depths.	2815
12662 # 9	7/ 8	19 32.6N 19 32.0N	58 49.2E 58 49.7E	CTD MS TRANSM UFL	0-2896	0956-1214 Day	Box St.6. WB @ standard depths.	2915
12662 #10	7/ 8	19 39.5N 19 39.5N	58 38.1E 58 38.1E	CTD MS TRANSM UFL	0-1078	1429-1503 Dusk	Box St.7. WB @ standard depths.	1100

STN.	DATE 1994	POSITION LAT	LONG	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND (M)
12662 #11	7/ 8	19 46.7N 19 46.7N	58 25.6E 58 25.8E	CTD MS TRANSM UFL	0- 91	1820-1850 Night	Box St.8. WB @ standard depths.	105
12662 #12	7/ 8	19 46.5N 19 46.4N	58 26.0E 58 26.1E	BPCTD	0- 85	1942-2015 Night	Box St.9. 3 profiles to 85,65 & 58m.	105
12662 #13	7/ 8	19 30.1N 19 30.1N	58 14.5E 58 14.4E	CTD MS TRANSM UFL	0- 113	2245-2315 Night	Box St.9. WB @ standard depths.	125
12662 #14	8/ 8	19 12.1N 19 12.2N	58 03.0E 58 03.0E	CTD MS TRANSM UFL	0- 78	0222-0246 Dawn	Box St.10. WB @ standard depths.	80
12662 #15	8/ 8	19 12.0N 19 12.1N	58 03.0E 58 02.9E	BPCTD	0- 70	0333-0449 Day	3 dips to various depths.	80
12662 #16	8/ 8	19 05.3N 19 05.3N	58 14.4E 58 14.8E	CTD MS TRANSM UFL	0- 922	0634-0742 Day	Box St.11. WB @ standard depths.	940
12662 #17	8/ 8	18 58.6N 18 58.4N	58 25.6E 58 26.0E	CTD MS TRANSM UFL	0-3142	0938-1205 Day	Box St.12. WB @ standard depths.	3160
12662 #18	8/ 8	18 51.8N 18 51.4N	58 37.0E 58 36.7E	CTD MS TRANSM UFL	0-3266	1418-1651 Night	Box St.13. WB @ standard depths.	3280

STN.	DATE 1994	POSITION LAT	LONG	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND (M)
12662 #19	8/ 8	18 51.7N 18 51.5N	58 37.0E 58 37.0E	BPCTD	0- 500	1733-1826 Night	Box St.13.	3288
12662 #20	8/ 8	18 51.4N 18 51.3N	58 36.9E 58 36.9E	BPCTD	0- 100	1833-1856 Night	Box St.13.	3288
12662 #21	8/ 8	18 45.1N 18 44.2N	58 48.4E 58 49.1E	CTD MS TRANSM UFL	0-3105	2040-2305 Night	Box St.14. WB @ standard depths.	3127
12662 #22	9/ 8	18 38.4N 18 38.3N	59 00.1E 59 00.2E	CTD MS TRANSM UFL	0-3462	0109-0357 Dawn	Box St.15. WB @ standard depths.	3480
12662 #23	9/ 8	18 38.4N 18 38.0N	59 00.7E 59 01.2E	BPCTD	0- 600	0454-0600 Day	Box St. 15	
12663 # 1	10/ 8	19 36.9N 19 36.9N	58 30.9E 58 31.0E	CTD MS TRANSM UFL	0- 489	0315-0400 Day	WB @ standard depths. SeaSoar Survey	509
12663 # 2	10/ 8	19 10.1N 19 09.9N	59 07.8E 59 07.9E	BPCTD	0- 400	1228-1309 Day		
12663 # 3	10/ 8	19 09.9N 19 09.6N	59 07.9E 59 07.9E	BPCTD	0- 400	1312-1355 Dusk		
12663 # 4	10/ 8	19 09.2N 19 09.2N	59 08.3E 59 08.4E	BPCTD	0- 400	1536-1622 Night		

STN.	DATE 1994	POSITION LAT	LONG	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND (M)
12663	12/ 8	19 08.9N	59 05.5E	CTD	0- 505	1344-1428	WB@ standard depths. End SeaSoar Survey	3313
# 5		19 08.3N	59 05.3E	MS		Day		
				TRANSM				
				UFL				
12664	12/ 8	19 07.1N	59 04.8E	LHPR	0- 290	1552-1819	Winch problems during recovery.	
# 1		18 58.3N	58 58.5E			Night		
12664	12/ 8	18 55.5N	58 56.9E	RMT1M/1	400- 505	2120-2220		3406
# 2		18 52.9N	58 55.3E	RMT8M/1		Night	FLOW DIST. 5.013 KM.	
12664	12/ 8	18 52.9N	58 55.3E	RMT1M/2	505- 595	2220-2320		3406
# 3		18 50.6N	58 53.7E	RMT8M/2		Night	FLOW DIST. 4.630 KM.	
12664	12/ 8	18 50.6N	58 53.7E	RMT1M/3	560- 700	2320-0029	Winch failure prevented proper fishing.	3406
# 4	13/ 8	18 48.2N	58 52.1E	RMT8M/3		Night	FLOW DIST. 4.803 KM.	
12664	13/ 8	18 56.9N	59 00.1E	RMT1M/1	390- 500	0854-0954		
# 5		18 54.5N	58 59.9E	RMT8M/1		Day	FLOW DIST. 3.955 KM.	
12664	13/ 8	18 54.5N	58 59.9E	RMT1M/2	500- 600	0954-1054		
# 6		18 51.9N	58 59.8E	RMT8M/2		Day	FLOW DIST. 4.090 KM.	
12664	13/ 8	18 51.9N	58 59.8E	RMT1M/3	600- 705	1054-1154		
# 7		18 49.2N	58 59.8E	RMT8M/3		Day	FLOW DIST. 4.203 KM.	
12664	13/ 8	18 46.4N	58 59.7E	RMT1M/1	0- 715	1415-1526	Net appeared to have opened at surface.	
# 8		18 49.4N	58 59.8E	RMT8M/1		Night		
12664	13/ 8	18 49.4N	58 59.8E	RMT1M/2	715- 800	1526-1626		3402
# 9		18 52.1N	58 60.0E	RMT8M/2		Night	FLOW DIST. 4.000 KM.	
12664	13/ 8	18 52.1N	58 60.0E	RMT1M/3	798- 900	1626-1726		3402
#10		18 54.3N	59 00.1E	RMT8M/3		Night	FLOW DIST. 3.865 KM.	

STN.	DATE 1994	POSITION LAT	LONG	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND (M)
12664 #11	13/ 8	18 53.6N 18 54.7N	58 59.1E 58 59.2E	RMT1M/1 RMT8M/1	150- 200	1933-2003 Night	Cod end lost on recovery. FLOW DIST. 1.910 KM.	
12664 #12	13/ 8	18 54.7N 18 56.8N	58 59.2E 58 59.5E	RMT1M/2 RMT8M/2	200- 300	2003-2103 Night	FLOW DIST. 3.415 KM.	
12664 #13	13/ 8	18 56.8N 18 58.7N	58 59.5E 58 59.8E	RMT1M/3 RMT8M/3	300- 400	2103-2203 Night	FLOW DIST. 3.280 KM.	
12664 #14	14/ 8	19 06.4N 19 06.1N	59 00.9E 59 00.9E	BPCTD	0- 600	0054-0153 Night		3333
12664 #15	14/ 8	19 01.4N 18 58.2N	59 01.3E 59 00.9E	RMT1M/1 RMT8M/1	700- 795	0626-0726 Day	FLOW DIST. 5.350 KM.	
12664 #16	14/ 8	18 58.2N 18 54.8N	59 00.9E 59 00.4E	RMT1M/2 RMT8M/2	795- 900	0726-0826 Day	FLOW DIST. 5.665 KM.	
12664 #17	14/ 8	18 54.8N 18 51.8N	59 00.4E 59 00.0E	RMT1M/3 RMT8M/3	900-1000	0826-0926 Day	FLOW DIST. 5.305 KM.	
12664 #18	14/ 8	18 59.6N 18 45.3N	59 00.4E 58 59.0E	LHPR	0- 210	1208-1516 Dusk	Not all silk used.	
12664 #19	14/ 8	19 01.6N 19 01.1N	59 00.7E 59 01.3E	CTD MS TRANSM UFL	0- 153	1836-1914 Night	WB for bacteria & dinoflagellates.	3377
12664 #20	14/ 8	19 01.0N 19 00.3N	59 01.5E 59 02.4E	BPCTD	0- 600	1937-2048 Night		3385
12664 #21	14/ 8	18 57.8N 18 54.2N	59 02.8E 59 02.7E	RMT1M/1 RMT8M/1	100- 150	2146-2249 Night	FLOW DIST. 6.045 KM.	

STN.	DATE 1994	POSITION LAT	LONG	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND (M)
12664	14/ 8	18 54.2N	59 02.7E	RMT1M/2	52- 100	2249-2349		
#22		18 51.3N	59 02.8E	RMT8M/2		Night	FLOW DIST. 4.698 KM.	
12664	14/ 8	19 05.2N	59 04.9E	RMT1M/3	0- 52	2349-0019		
#23	15/ 8	18 50.0N	59 02.8E	RMT8M/3		Night	FLOW DIST. 1.955 KM.	
12664	15/ 8	19 01.1N	59 00.7E	BPCTD	0- 600	0302-0409		
#24		19 00.5N	59 01.2E			Day		
12664	15/ 8	18 58.8N	59 00.8E	RMT1M/1	150- 205	0453-0554	RMT1 cod end torn off - no sample.	
#25		18 56.0N	58 59.6E	RMT8M/1		Day	FLOW DIST. 4.990 KM.	
12664	15/ 8	18 56.0N	58 59.6E	RMT1M/2	205- 300	0554-0654		
#26		18 53.6N	58 58.8E	RMT8M/2		Day	FLOW DIST. 4.540 KM.	
12664	15/ 8	18 53.6N	58 58.8E	RMT1M/3	300- 400	0654-0754		
#27		18 51.3N	58 58.1E	RMT8M/3		Day	FLOW DIST. 4.000 KM.	
12664	15/ 8	19 02.1N	59 01.0E	RMT1M/1	90- 150	1023-1123		
#28		18 59.9N	59 00.5E	RMT8M/1		Day	FLOW DIST. 4.090 KM.	
12664	15/ 8	18 59.9N	59 00.5E	RMT1M/2	45- 95	1123-1222		
#29		18 57.7N	59 00.2E	RMT8M/2		Day	FLOW DIST. 3.505 KM.	
12664	15/ 8	18 57.7N	59 00.2E	RMT8M/3	0- 45	1222-1322	No RMT1 net fished.	
#30		18 55.6N	59 00.0E			Day	FLOW DIST. 3.595 KM.	
12664	15/ 8	19 11.1N	58 59.8E	RMT1M/1	400- 505	1819-1919		
#31		19 08.6N	58 59.8E	RMT8M/1		Night	FLOW DIST. 4.180 KM.	
12664	15/ 8	19 08.6N	58 59.8E	RMT1M/2	505- 600	1919-2023		
#32		19 06.1N	58 59.8E	RMT8M/2		Night	FLOW DIST. 4.585 KM.	

STN.	DATE 1994	POSITION LAT	LONG	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND (M)
12664 #33	15/ 8	19 06.1N 19 04.2N	58 59.8E 58 58.0E	RMT8M/3	600- 700	2023-2123 Night	No RMT1 net fished. FLOW DIST. 3.820 KM.	
12664 #34	16/ 8	19 02.6N 19 00.2N	59 02.7E 59 00.3E	RMT1M/1 RMT8M/1	1200-1400	0109-0242 Dawn	FLOW DIST. 5.278 KM.	
12664 #35	16/ 8	19 00.2N 18 57.9N	59 00.3E 58 57.9E	RMT1M/2 RMT8M/2	1400-1600	0242-0412 Day	FLOW DIST. 4.920 KM.	
12664 #36	16/ 8	18 57.9N 18 55.4N	58 57.9E 58 55.6E	RMT8M/3	1580-1785	0412-0542 Day	No RMT1 net fished. FLOW DIST. 4.965 KM.	
12664 #37	16/ 8	19 07.0N 18 57.4N	59 05.9E 58 58.0E	LHPR	0- 270	0909-1208 Day	Swimming crab jammed up works!	
12665 # 1	16/ 8	18 57.0N 18 56.9N	59 05.1E 59 05.6E	CTD MS TRANSM UFL	0- 503	1847-1945 Night	Start of second SeaSoar survey	3407
12665 # 2	18/ 8	19 03.5N 19 03.5N	58 12.2E 58 12.2E	CTD MS TRANSM UFL	0- 503	0535-0625 Day	End of second SeaSoar survey	743
12666 # 1	18/ 8	19 21.5N 19 14.5N	58 22.7E 58 13.0E	LHPR	0- 335	0927-1210 Day		
12666 # 2	18/ 8	19 14.7N 19 14.8N	58 12.9E 58 12.8E	BPCTD	0- 280	1227-1252 Day		
12666 # 3	18/ 8	19 14.7N 19 14.5N	58 12.8E 58 12.6E	BPCTD	0- 220	1257-1326 Day		

STN.	DATE 1994	POSITION LAT	POSITION LONG	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND (M)
12667 # 1	18/ 8	19 33.2N 19 31.3N	58 33.9E 58 32.4E	RMT1M/1 RMT8M/1	95- 152	1700-1800 Night	FLOW DIST. 3.505 KM.	
12667 # 2	18/ 8	19 31.3N 19 29.6N	58 32.4E 58 30.6E	RMT1M/2 RMT8M/2	50- 95	1800-1900 Night	FLOW DIST. 4.248 KM.	
12667 # 3	18/ 8	19 29.6N 19 28.3N	58 30.6E 58 29.2E	RMT8M/3	0- 50	1900-1950 Night	No flow. No RMT1 net.	
12667 # 4	18/ 8	19 34.0N 19 31.9N	58 34.8E 58 33.6E	RMT1M/1 RMT8M/1	145- 200	2141-2241 Night	FLOW DIST. 3.640 KM.	
12667 # 5	18/ 8	19 31.9N 19 29.8N	58 33.6E 58 32.1E	RMT1M/2 RMT8M/2	200- 305	2241-2338 Night	FLOW DIST. 3.913 KM.	
12667 # 6	18/ 8 19/ 8	19 29.8N 19 27.7N	58 32.1E 58 30.9E	RMT8M/3	305- 400	2338-0038 Night	No RMT1 net. FLOW DIST. 3.865 KM.	
12667 # 7	19/ 8	19 33.0N 19 30.9N	58 34.6E 58 33.3E	RMT1M/1 RMT8M/1	100- 150	0252-0352 Day	FLOW DIST. 3.730 KM.	
12667 # 8	19/ 8	19 30.9N 19 28.7N	58 33.3E 58 32.0E	RMT1M/2 RMT8M/2	45- 100	0352-0452 Day	FLOW DIST. 4.180 KM.	
12667 # 9	19/ 8	19 28.7N 19 26.3N	58 32.0E 58 30.3E	RMT8M/3	0- 70	0452-0603 Day	No flow. No RMT1 net.	
12667 #10	19/ 8	19 36.6N 19 34.6N	58 36.5E 58 35.2E	RMT1M/1 RMT8M/1	155- 205	0821-0921 Day	FLOW DIST. 3.910 KM.	
12667 #11	19/ 8	19 34.6N 19 32.8N	58 35.2E 58 33.9E	RMT1M/2 RMT8M/2	200- 305	0921-1021 Day	FLOW DIST. 3.370 KM.	

STN.	DATE 1994	POSITION LAT	LONG	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND (M)
12667 #12	19/ 8	19 32.8N 19 31.0N	58 33.9E 58 32.3E	RMT8M/3	305- 405	1021-1121 Day	No RMT1 net. FLOW DIST. 3.550 KM.	
12668 # 1	19/ 8	19 38.0N 19 38.1N	58 27.4E 58 27.2E	BPCTD	0- 200	1312-1354 Day	2 profiles.	250
12668 # 2	19/ 8	19 38.3N 19 38.6N	58 27.1E 58 26.9E	CTD MS TRANSM UFL	0- 211	1416-1456 Dusk	WBs for dinoflagellates.	231
12668 # 3	19/ 8	19 38.1N 19 35.7N	58 26.5E 58 25.2E	RMT1M/1 RMT8M/1	100- 170	1526-1626 Night	FLOW DIST. 3.865 KM.	195
12668 # 4	19/ 8	19 35.7N 19 33.7N	58 25.2E 58 24.0E	RMT1M/2 RMT8M/2	50- 100	1626-1726 Night	FLOW DIST. 3.640 KM.	
12668 # 5	19/ 8	19 33.7N 19 32.2N	58 24.0E 58 23.2E	RMT8M/3	0- 50	1726-1805 Night	FLOW DIST. 3.388 KM.	
12668 # 6	19/ 8	19 38.7N 19 39.0N	58 26.9E 58 26.7E	CTD MS TRANSM UFL	0- 197	1923-1955 Night	WBs for dinoflagellates.	210
12668 # 7	19/ 8	19 39.0N 19 39.1N	58 26.6E 58 26.5E	BPCTD	0- 150	2015-2051 Night	2 profiles.	200
12668 # 8	19/ 8	19 38.3N 19 35.9N	58 26.0E 58 24.7E	RMT8M/1	100- 170	2124-2224 Night	No RMT1 net. Fished to 25 mob. FLOW DIST. 3.370 KM.	195
12668 # 9	19/ 8	19 35.9N 19 33.4N	58 24.7E 58 23.3E	RMT1M/2 RMT8M/2	50- 100	2224-2324 Night	FLOW DIST. 4.405 KM.	332

STN.	DATE 1994	POSITION LAT	LONG	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND (M)
12668	19/ 8	19 33.4N	58 23.3E	RMT1M/3	0- 50	2324-2352		
#10		19 32.4N	58 22.7E	RMT8M/3		Night	FLOW DIST. 1.957 KM.	
12668	20/ 8	19 33.8N	58 24.9E	CTD	0- 310	0056-0135	WBs for dinoflagellates.	318
#11		19 33.9N	58 24.5E	MS		Night		
				TRANSM				
				UFL				
12668	20/ 8	19 33.9N	58 24.3E	BPCTD	0- 250	0155-0250	2 profiles.	300
#12		19 34.0N	58 23.9E			Dawn		
12668	20/ 8	19 38.0N	58 26.5E	RMT8M/1	98- 150	0449-0549	No RMT1 net.	
#13		19 35.9N	58 24.7E			Day	FLOW DIST. 3.685 KM.	
12668	20/ 8	19 35.9N	58 24.7E	RMT1M/2	50- 100	0549-0656		
#14		19 33.6N	58 22.9E	RMT8M/2		Day	FLOW DIST. 4.045 KM.	
12668	20/ 8	19 33.6N	58 22.9E	RMT1M/3	0- 60	0656-0756		
#15		19 31.6N	58 21.5E	RMT8M/3		Day	FLOW DIST. 4.439 KM.	
12668	20/ 8	19 38.6N	58 26.5E	BPCTD	0- 150	0917-1010	4 profiles.	205
#16		19 38.6N	58 26.6E			Day		
12669	20/ 8	19 36.4N	58 35.8E	RMT1M/2	400- 500	1141-1226		
# 1		19 34.8N	58 35.4E	RMT8M/2		Day	FLOW DIST. 2.393 KM.	
12670	20/ 8	18 60.0N	59 00.2E	WP2	0- 100	2305-2318	Arabesque St. Vertical haul.	
# 1		18 59.9N	59 00.3E			Night		
12670	20/ 8	18 59.7N	59 00.3E	BPCTD	0- 600	2335-0034		3390
# 2	21/ 8	18 59.3N	59 00.4E			Night		

STN.	DATE 1994	POSITION LAT	LONG	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND (M)
12670 # 3	21/ 8	18 60.0N 18 59.0N	58 59.9E 58 59.6E	CTD MS TRANSM UFL	0-3371	0102-0404 Dawn	Arabesque St. WB @ standard depths.	3392
12670 # 4	21/ 8	18 58.1N 18 46.6N	58 59.2E 58 53.2E	LHPR	0- 300	0507-0759 Day		
12670 # 5	21/ 8	18 46.0N 18 45.9N	58 52.9E 58 53.0E	BPCTD	0- 600	0854-0954 Day		3400
12670 # 6	21/ 8	18 45.9N 18 45.9N	58 53.0E 58 53.1E	WP2	0- 100	1000-1010 Day		
12670 # 7	21/ 8	18 45.5N 18 35.1N	58 53.0E 58 48.2E	LHPR	0- 310	1030-1312 Day	Swimming Crab jammed works!	

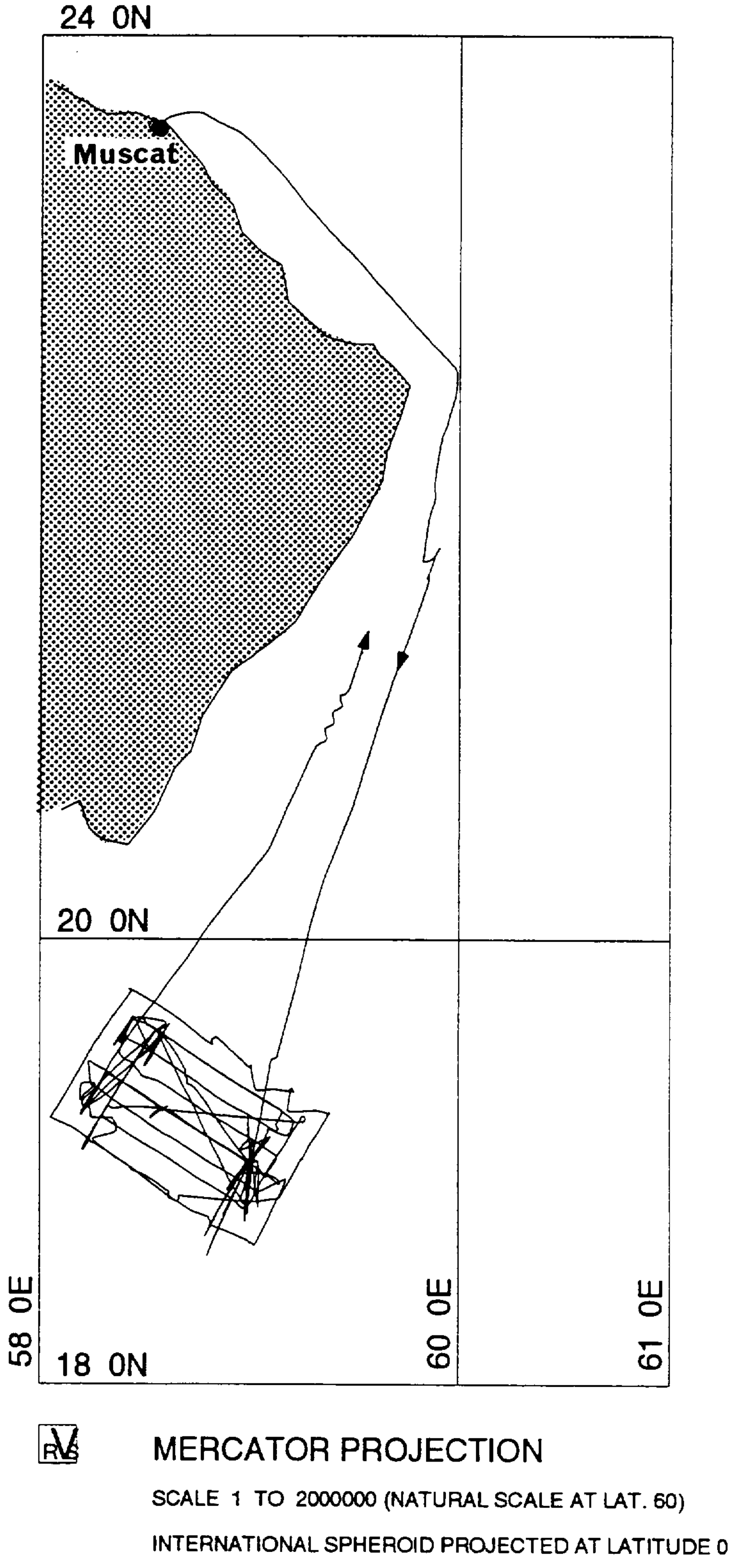
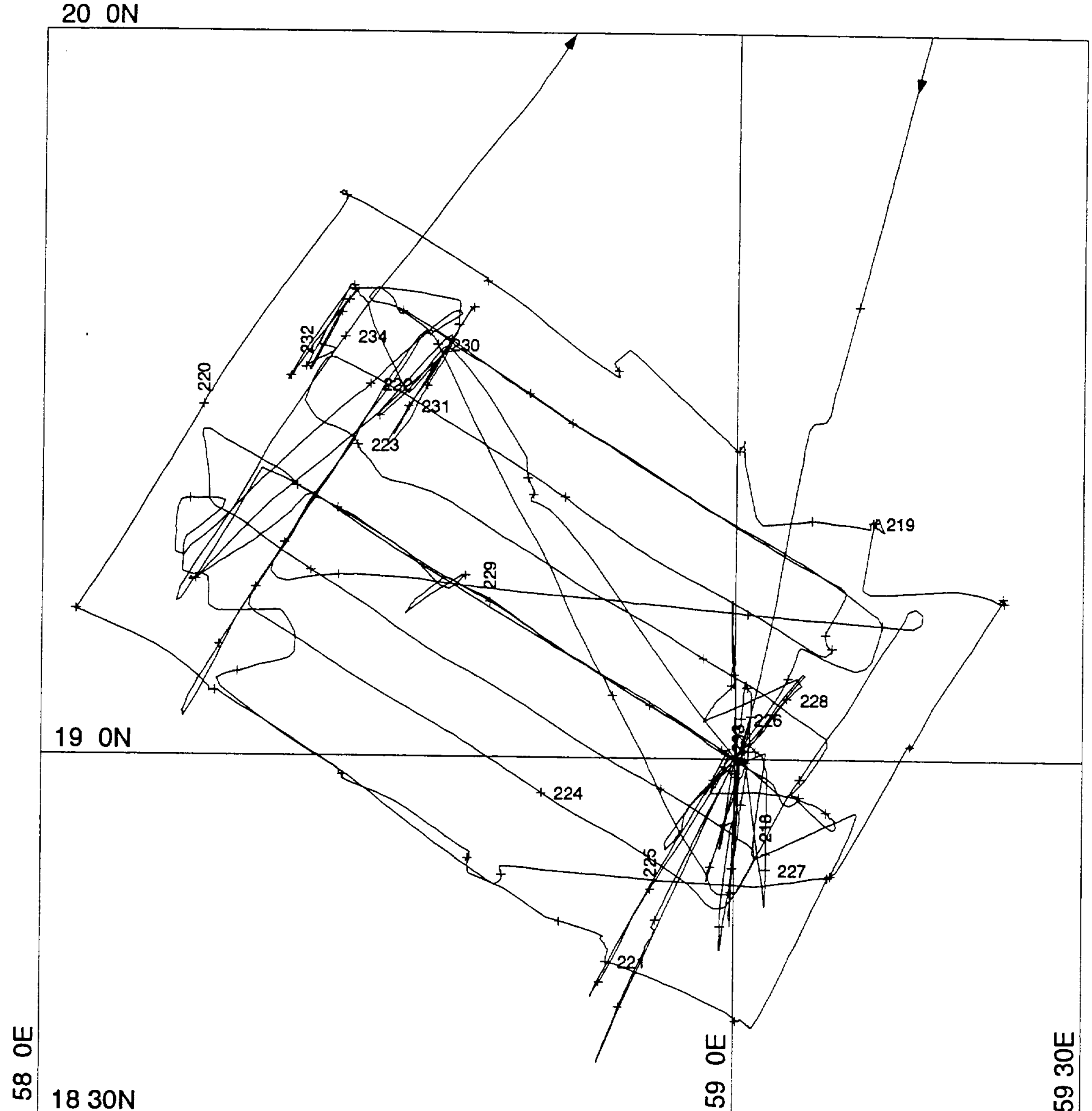


Fig. 1. Track chart, RRS *Discovery* Cruise 209 3 Aug - 22 Aug 1994, showing the main working area.



MERCATOR PROJECTION

SCALE 1 TO 1000000 (NATURAL SCALE AT LAT. 0)

INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0

GRID NO. 1

Fig. 2. Track plot of operations within the working area. The position at the start of each day is marked with the Julian day number.

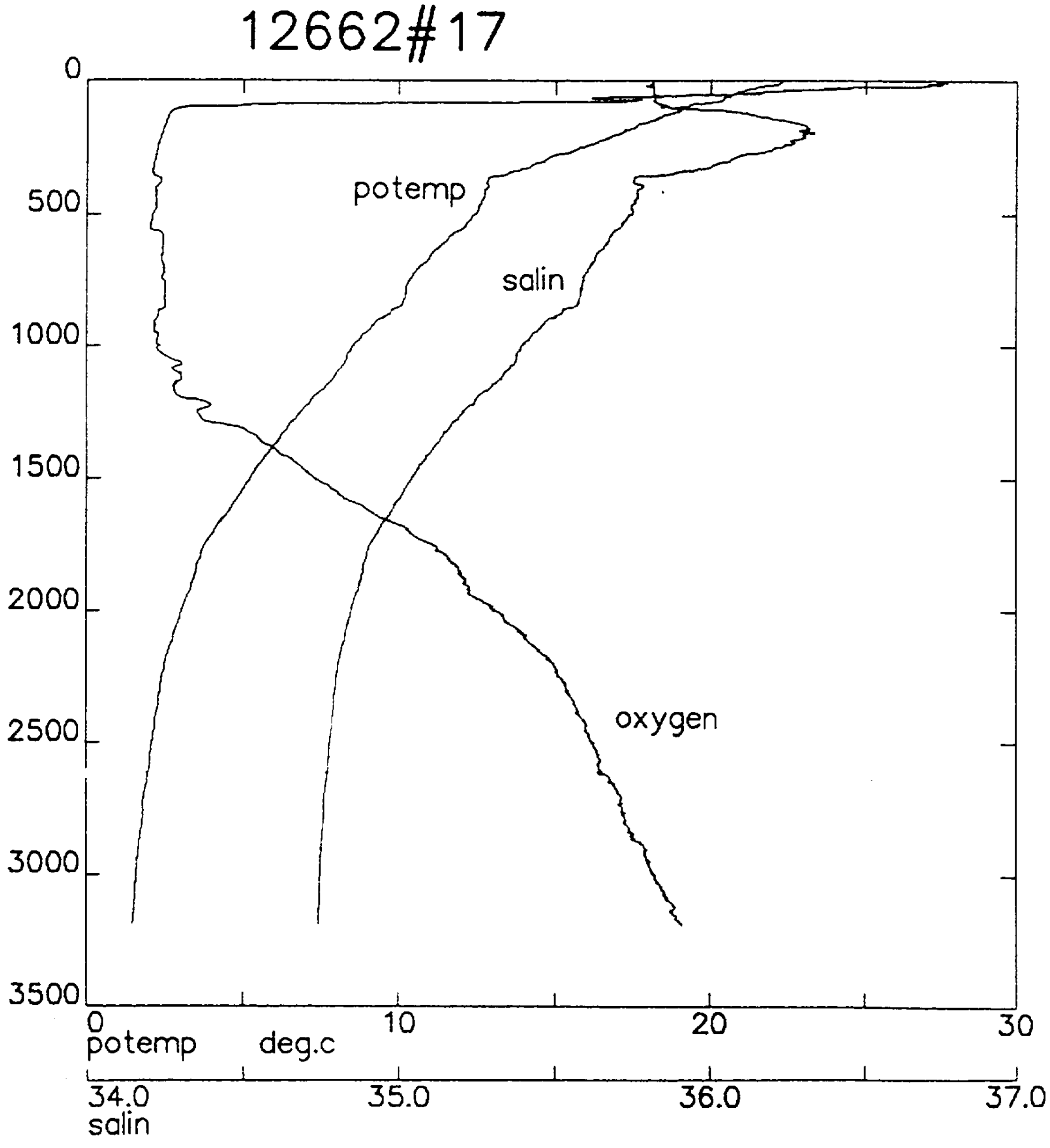


Fig. 3 CTD profile at Station 12662 #17.

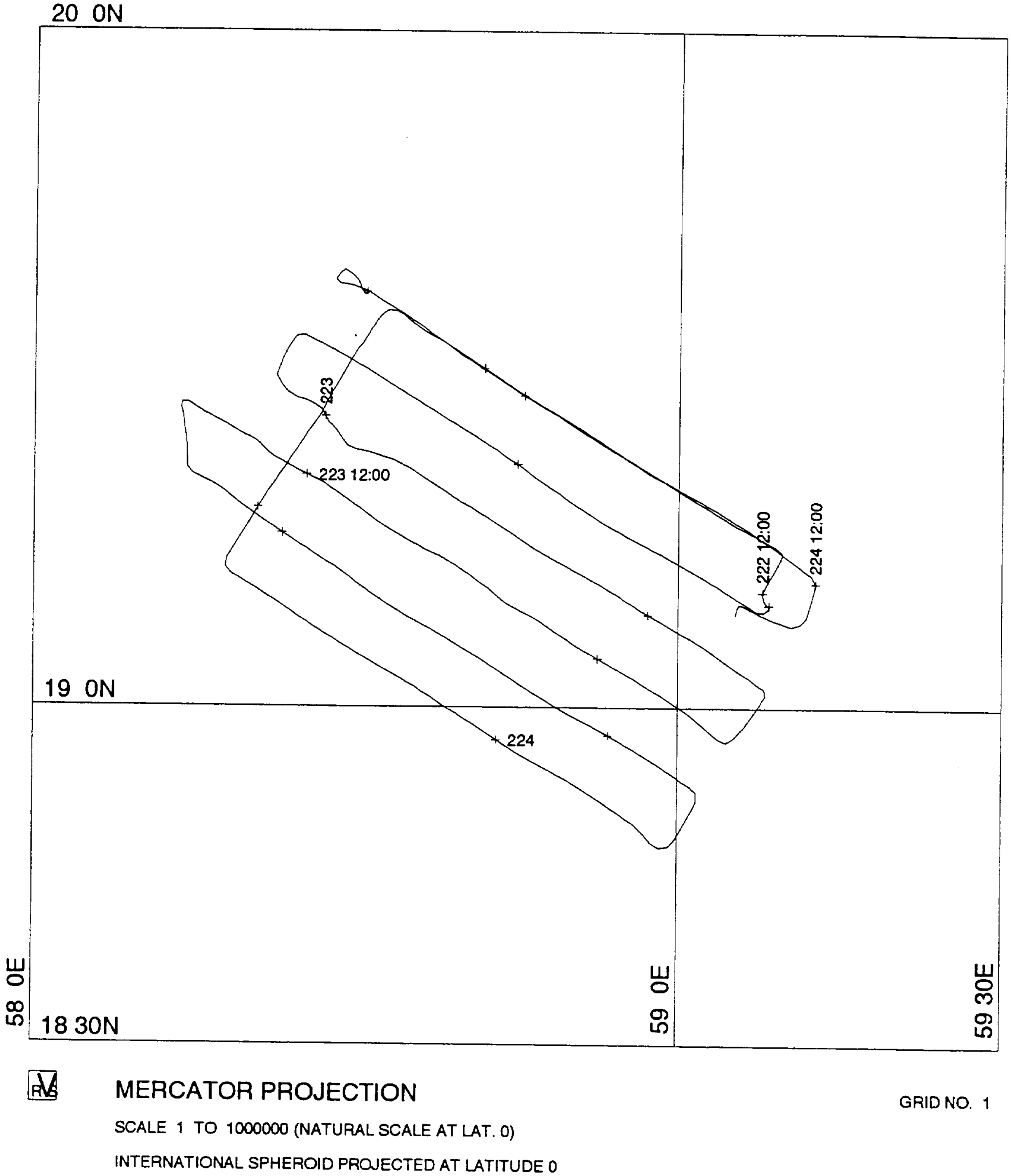


Fig. 4. SeaSoar survey 1 track plot.

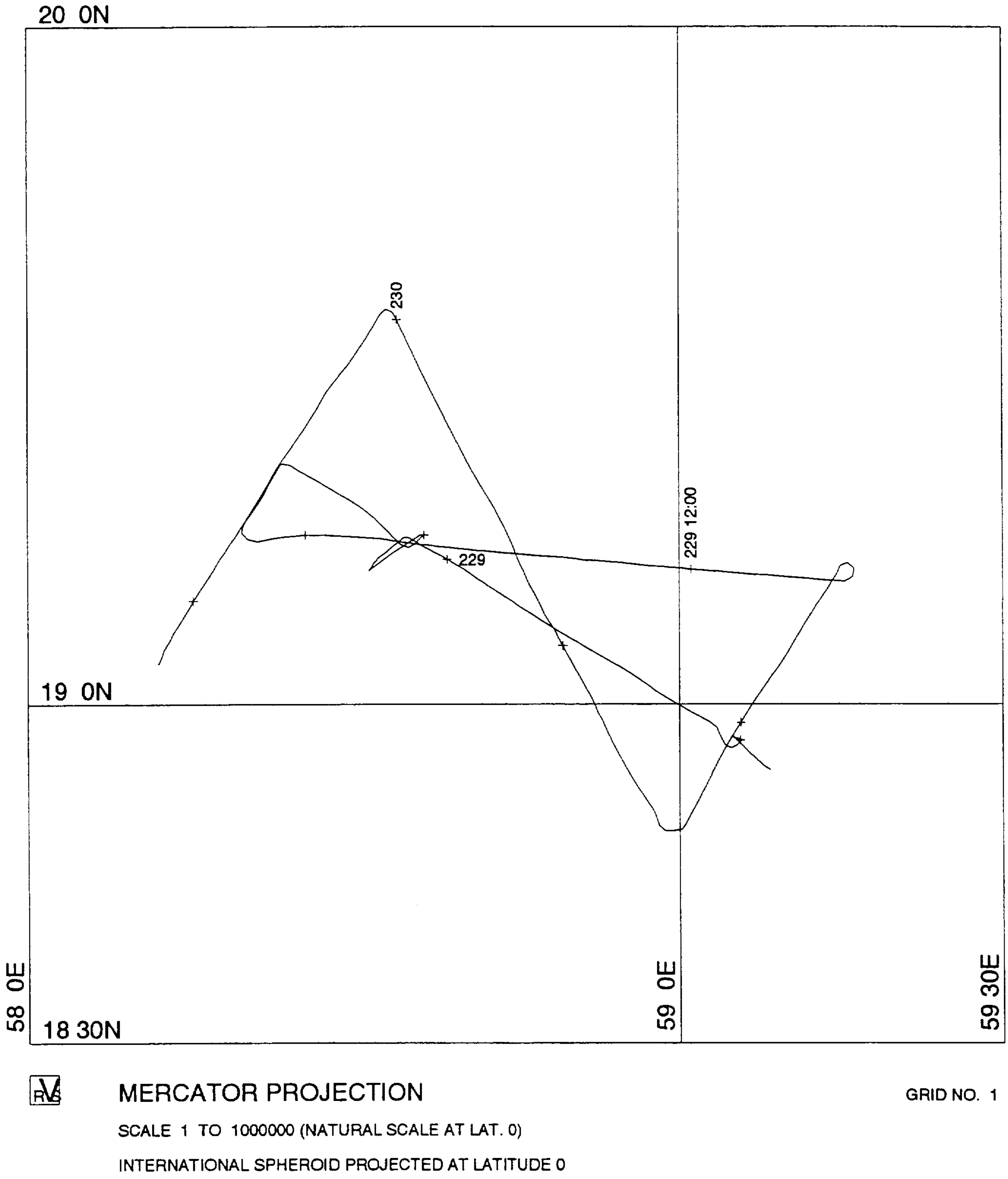


Fig. 5. SeaSoar survey 2 track plot.

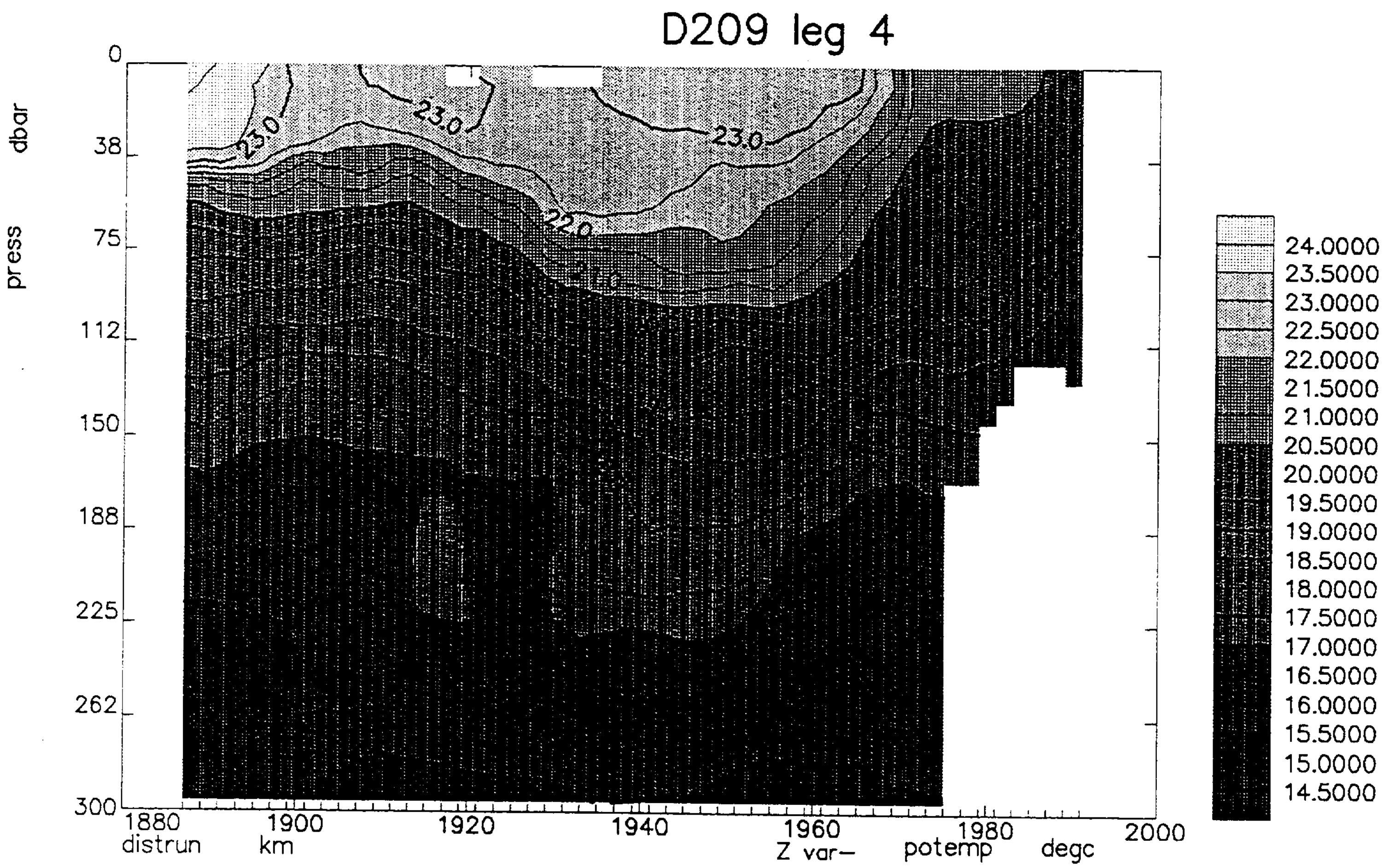


Fig. 6. SeaSoar survey 1: Section 4, Potential Temperature.

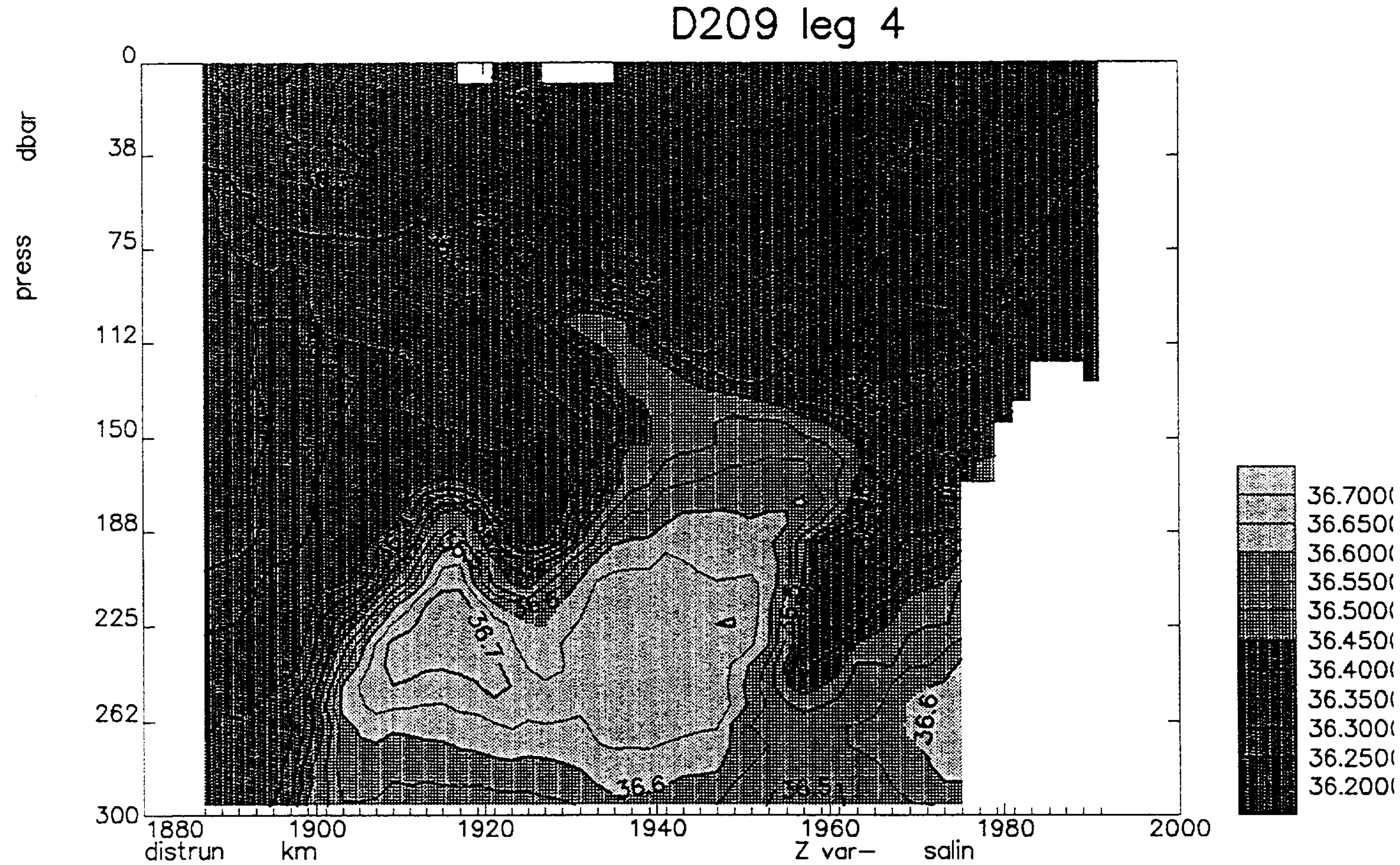


Fig. 7. SeaSoar survey 1: Section 4, Salinity.

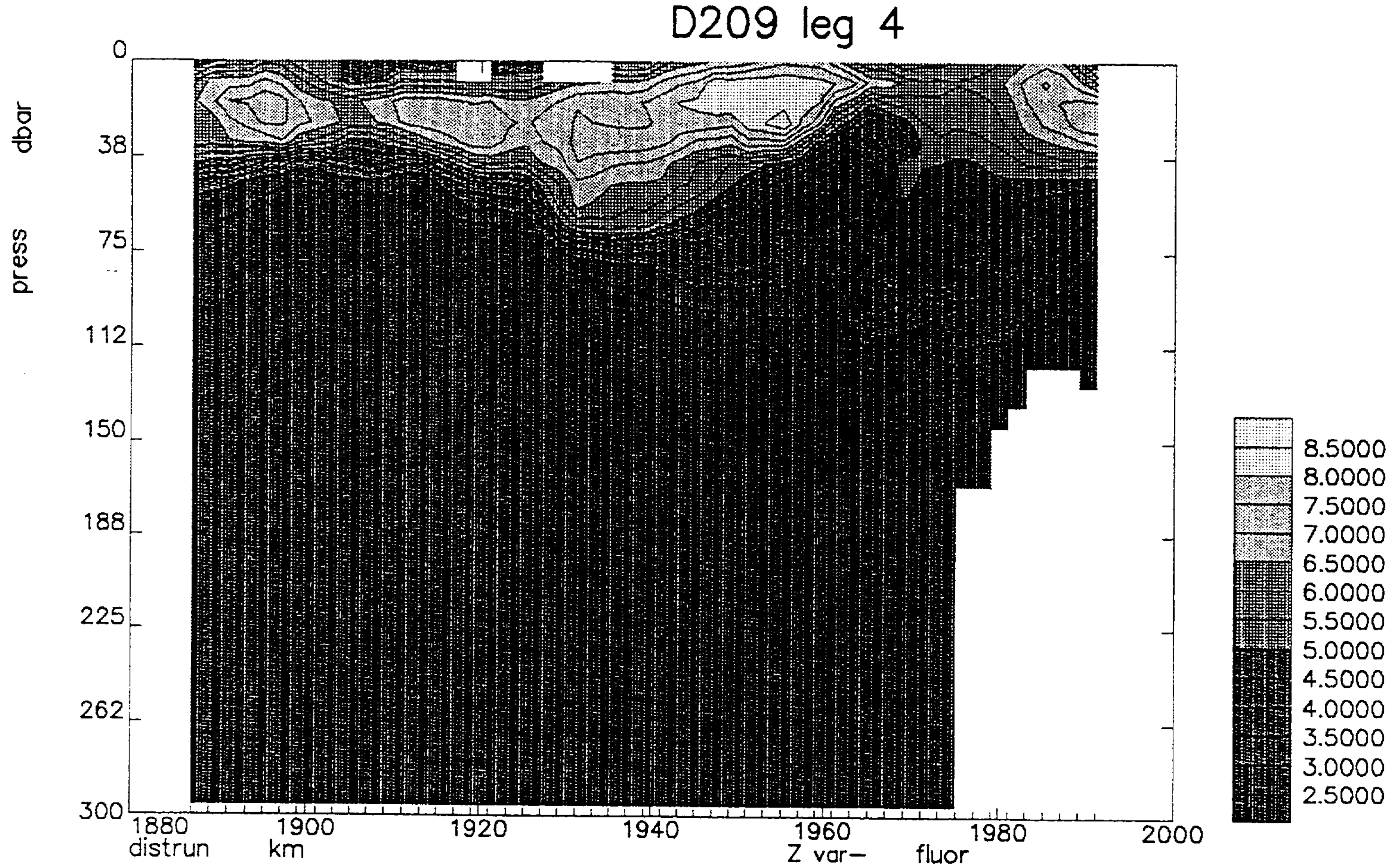


Fig. 8. SeaSoar survey 1: Section 4, Fluorescence.

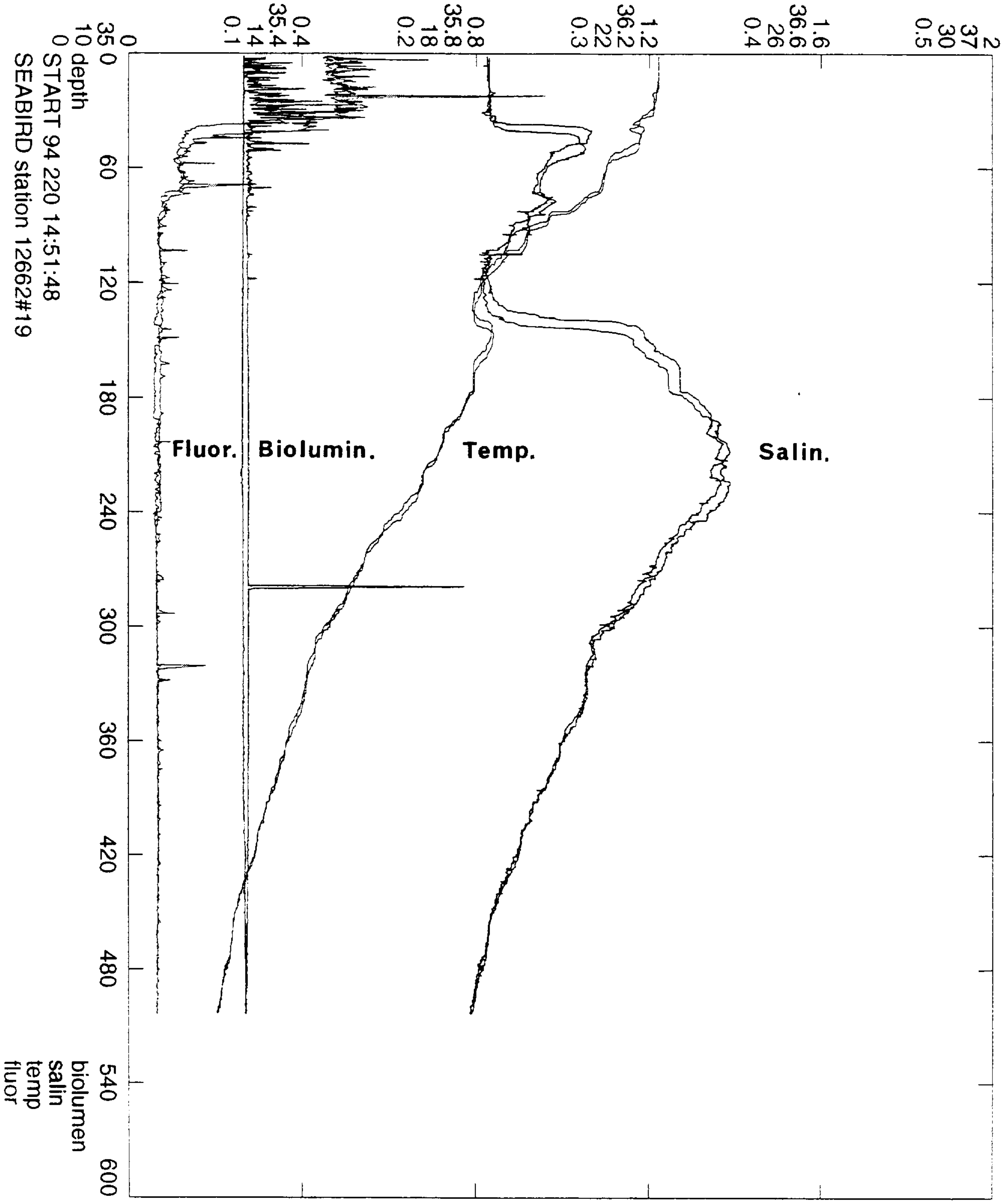
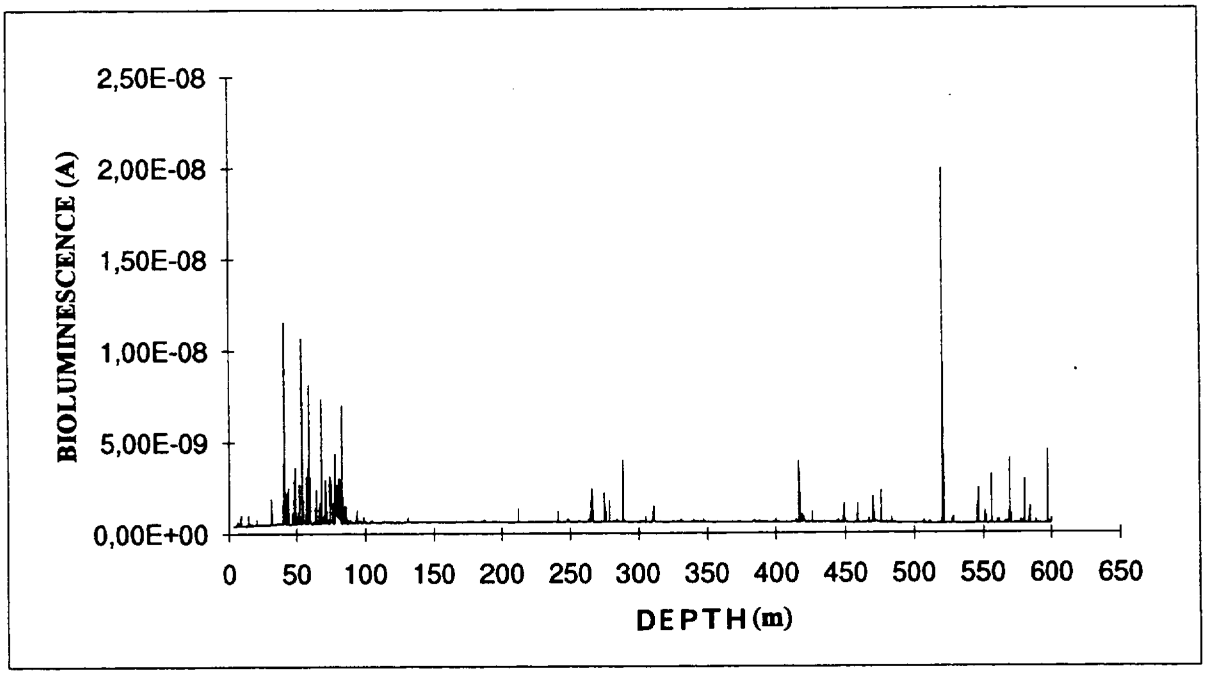


Fig. 9. Bathyphotometer/SeaBird profile at Station 12662 #19

12661a by DAY



12661b by NIGHT

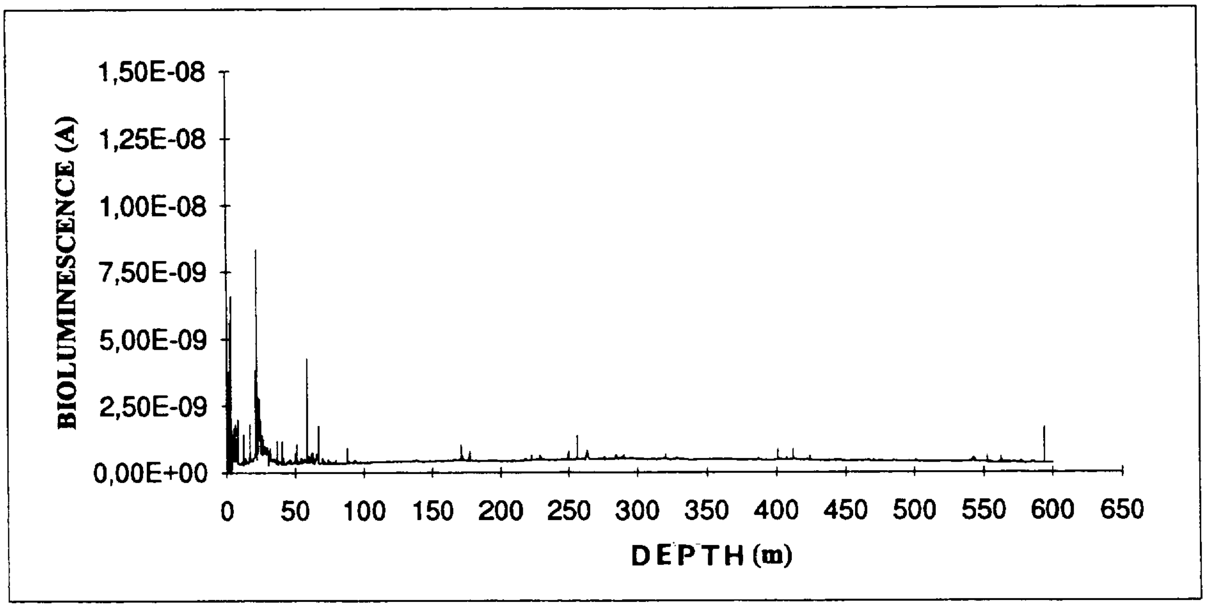


Fig. 10. Day/night bathyphotometer profiles at the Arabesque Station (12661).