RRS Charles Darwin

Cruise 114
Report

29 July 1998 – 24 August 1998

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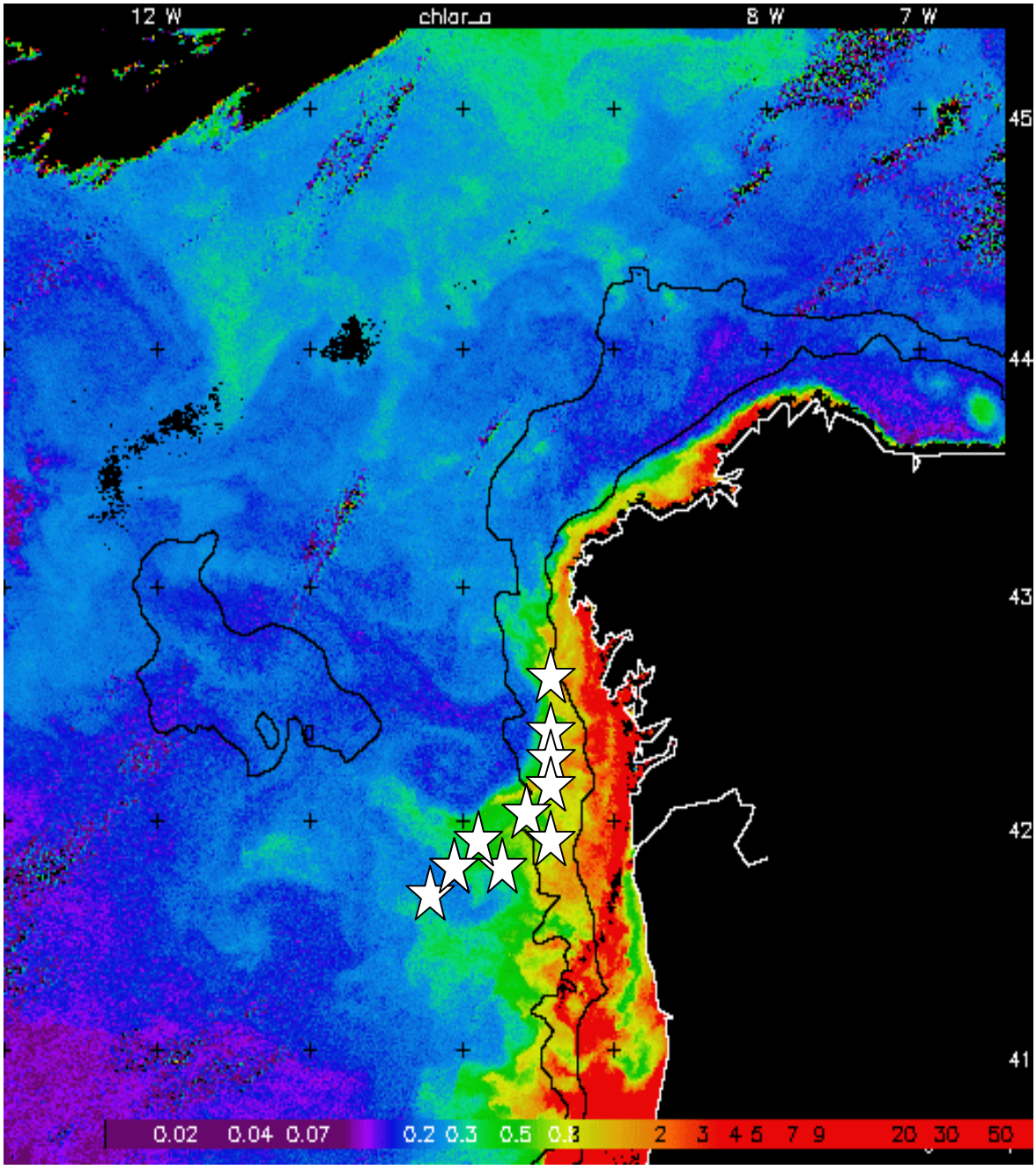
Prepared by:
Dr Ian Joint
CCMS
Plymouth Marine Laboratory
Prospect Place, Plymouth
PL1 3DH, UK
Tel: +44 (0)1752 633100
Fax: +44 (0) 1752 633101
E-Mail: I.Joint@CCMS.ac.uk

THE REGION OF STUDY



SeaWiFS image of 3 August showing surface chlorophyll concentrations

Data received by the NERC Dundee Receiving Station were processed by the CCMS Plymouth Marine Laboratory Remote Sensing Group and transmitted to the *RRS Charles Darwin*. The image shows surface chlorophyll concentrations (the scale, in mg chlorophyll m^{-3}, is along the bottom of the image). Also shown (☆) are the station positions occupied on the two Legs of the cruise.

Scientific Programme

Background

This cruise is part of the OMEX (*Ocean Margin Exchange*) Project, funded by the Marine Science and Technology (MAST III) Programme of the European Commission. The OMEX project is organised into a series of 4 Work Packages. The research on this cruise related to Work Package 1 (WP1) – "the Temporal Evolution of Surface Production and the Fate of Organic Matter". Participants on the cruise came from Spain, Portugal, Belgium, Norway, Estonia, and the UK.

The region of study was the continental shelf and slope off the Northwest of the Iberian Peninsular. This is an area of intense periodic upwelling in the summer months. The upwelled water is cold and has high concentrations of nutrients which fertilise the coastal waters and enable the phytoplankton (microscopic plants) to grow. The cold water is clearly seen from space and satellite images of sea surface temperature were sent daily to the ship; this allowed detailed planning of research activities and identified where to take samples.

The objectives of the cruise (and of OMEX WP1) were:

- To study the production and fate of organic carbon on the narrow shelf and along/across its margin.
- Estimate the flux of new nitrogen from oceanic deep water into the surface ocean and onto the shelf and analyse the temporal variability of primary and new production as well as recycling.
- Examine the role of a narrow shelf for the production and development of zooplankton, the microbial loop and vertical flux.
- Evaluate to what extent shelf production is exported to the ocean interior and if this transport is balanced by oceanic nutrient fluxes.

The cruise was divided into 2 Legs, with different scientific emphases. Leg 1 followed the movement of a patch of newly upwelled water southward on the shelf. On each day, samples were taken to assess how the plankton community was changing in response to the introduction of nutrient-rich water on the shelf. Leg 2 concentrated on a filament which extended off the shelf into the ocean. These filaments are composed of cooler water which appears to be travelling offshore in response to upwelling events. The filament was tracked by following 5 Argos drifting buoys and, as on Leg 1, measurements were made to following the changes in the plankton community as the filament moved away from the shelf.

The individual tasks performed by each of the participants, which relate to WP1, were as follows.

1. Inorganic carbon biogeochemistry and atmospheric exchanges *(Université de Liege - ULg*)
2. Lagrangian observations, filament transport and budgets *(University of Wales Bangor-UWBa*)
3. Vertical mixing and turbulence measurements *(University of Wales, Bangor – UWBb*)
4. Remote sensing – continuous data processing of AVHRR and SeaWiFS data *(PML*)
5. Nutrients, DOC, phytoplankton assemblages, suspended organic matter, bio-optical properties and primary production. *(Instituto de Investigacións Mariñas –IIM)*
6. Pigment biomarkers *(Plymouth Marine Laboratory – PMLa)*
7. Phytoplankton production and nutrient uptake *(Plymouth Marine Laboratory – PMLc)*
8. Bacterioplankton biomass and activity in Iberian shelf waters *(Universidade do Algarve, UAL)*

9. Microzooplankton dynamics and constraint of microzooplankton on vertical flux of phytogenic carbon at the ocean margin of NE Spain. *(Plymouth Marine Laboratory – PMLb)*
10. The role of zooplankton in the flux of carbon at the NW shelf of Spain *(University of Tromsø – UITOb)*
11. The CPR survey of the Iberian Margin *(Sir Alister Hardy Foundation for Ocean Sciences – SAHFOS)*
12. Short-term vertical flux measurements and faecal pellet production. *(University of Tromsø – UITOa).*

In addition, a number of measurements were made to fulfil the requirements of OMEX Work Package II – "Spatial and seasonal fluxes and biogeochemical processes in the water column". These include the deployment for 19 days of the bottom mounted current meter and instrument array (STABLE).

CD 114 Cruise Participants

(see Appendix A for postal and E-mail addresses)

Transit 1 – 29 July–1 August 1998 - Fairlie to Vigo

	Name	*Nationality*		*Name*	*Nationality*
1	**Ian Joint**	UK	2	**Alberto Borges**	Portugal
3	**Denise Cummings**	UK	4	**Elaine Fileman**	UK
5	**Elizabeth Halvorsen**	Norway	6	**John Humphrey**	UK
7	**Andrew Rees**	UK	8	**Jason Scott**	UK
9	**Alan Taylor**	UK	10	**Paul Howarth**	UK
11	**Alan Sherring**	UK			

Leg 1 – 1-11 August 1998

	Name	*Nationality*		*Name*	*Nationality*
1	**Ian Joint**	UK	2	**Anna Barbosa**	Portugal
3	**Alberto Borges**	Portugal	4	**Denise Cummings**	UK
5	**Franciscus Figueiras**	Spain	6	**Elaine Fileman**	UK
7	**Elizabeth Halvorsen**	Norway	8	**Mark Inall**	UK
9	**Kalle Olli**	Estonia	10	**Andrew Rees**	UK
11	**Xose A. Salgado**	Spain	12	**Gavin Tilstone**	UK
13	**Ricardo Torres**	Spain	14	**Ray Wilton**	UK
15	**Alan Taylor**	UK	16	**Jason Scott**	UK
17	**Alan Sherring**	UK	18	**Paul Howarth**	UK

Leg 2 – 11-21 August 1998

	Name	*Nationality*		*Name*	*Nationality*
1	**Ian Joint**	UK	2	**Des Barton**	UK
3	**Sonia Batten**	UK	4	**Alberto Borges**	Portugal
5	**Elaine Fileman**	UK	6	**Elizabeth Halvorsen**	Norway
7	**Andrew Hirst**	UK	8	**Pedro Mendes**	Portugal
9	**Kalle Olli**	Estonia	10	**Andrew Rees**	UK
11	**Christian Riser**	Norway	12	**Ricardo Torres**	UK
13	**Ray Wilton**	UK	14	**Malcolm Woodward**	UK
15	**Alan Taylor**	UK	16	**Jason Scott**	UK
17	**Alan Sherring**	UK	18	**Paul Howarth**	UK

Transit 2 –21-24 August 1998 - Vigo to Southampton

	Name	*Nationality*		*Name*	*Nationality*
1	**Ian Joint**	UK	2	**Sonia Batten**	UK
3	**Alberto Borges**	Portugal	4	**Elaine Fileman**	UK
5	**Elizabeth Halvorsen**	Norway	6	**Andrew Hirst**	UK
7	**Andrew Rees**	UK	8	**Malcolm Woodward**	UK
9	**Alan Taylor**	UK	10	**Jason Scott**	UK
11	**Alan Sherring**	UK	12	**Paul Howarth**	UK

***RRS Charles Darwin* Crew**

Geoff Long	Captain	**Derrick Noden**	Chief Officer
Richard Hawse	2nd Officer	**Maureen Deevaney**	3rd Officer
Ian Bennett	Chief Engineer	**Alex Greenhorn**	2nd Engineer
Jim Crosbie	3rd Engineer	**Keith Conner**	3rd Engineer
Bernie Rant	Radio Officer	**Mick Drayton**	Bosun
Greg Lewis	Bosun's Mate	**Bob Johnson**	Seaman
Phil Allison	Seaman	**Marc Squibb**	Seaman
Steve Day	Seaman	**Ray Bell**	Catering Manager
Jay Swenson	Chef	**Carol Dillon**	Stewardess
Andy Duncan	Steward	**Sheila Link**	Stewardess
John Smyth	Motorman		

Acknowledgement
We wish to thank the Officers and Crew of the *RRS Charles Darwin* for their help and assistance during this cruise. Without their positive attitude, we would not have been able to achieve the objectives of the cruise.

Timetable of Activities

Transit

Tuesday 28 July 1998	Loaded equipment on board ship in Fairlie, Scotland
Wednesday 29 July 1998	Sailed from Fairlie – on passage
Thursday 30 July 1998	On Passage
Friday 31 July 1998	On Passage
Saturday 1 August 1998	On Passage. STABLE deployed at 1700h

Leg 1

Sunday 2 August 1998	Boat transfer in Vigo harbour of participants in Leg 1. CTD survey began
Monday 3 August 1998	Beginning of Lagrangian experiment on the continental shelf; samples taken in vicinity of a drifting buoy
Tuesday 4 August 1998	Continuation of Lagrangian experiment
Wednesday 5 August 1998	Continuation of Lagrangian experiment
Thursday 6 August 1998	Continuation of Lagrangian experiment
Friday 7 August 1998	Continuation of Lagrangian experiment
Saturday 8 August 1998	Anchor station CTD series
Sunday 9 August 1998	Continuation of Lagrangian experiment
Monday 10 August 1998	CTD survey
Tuesday 11 August 1998	Boat transfer in Vigo harbour. End of Leg 1 and cruise participants left ship at 0800

Leg 2

Tuesday 11 August 1998	Boat transfer in Vigo harbour. Leg 2 participants joined ship at 0800 and Leg 2 commenced with a CTD survey.
Wednesday 12 August 1998	Hove to due to bad weather
Thursday 13 August 1998	CTD and plankton survey
Friday 14 August 1998	Deployment of 5 Argos drifting buoys (one instrumented) and beginning of 2nd Lagrangian experiment to track filament off shelf
Saturday 15 August 1998	Continuation of Lagrangian experiment
Sunday 16 August 1998	Continuation of Lagrangian experiment
Monday 17 August 1998	Continuation of Lagrangian experiment
Tuesday 18 August 1998	Continuation of Lagrangian experiment
Wednesday 19 August 1998	Recovery of instrumented Argos buoy (0900h)
Thursday 20 August 1998	Recovery of STABLE (0750h)
Friday 21 August 1998	Boat transfer in Vigo harbour. Leg 2 participants left ship.

Transit

Friday 21 August 1998	Set course for UK 0900.
Saturday 22 August 1998	On Passage
Sunday 23 August 1998	On Passage
Monday 24 August 1998	Dock in Southampton 0900h; unloaded equipment.

Satellite Remote Sensing

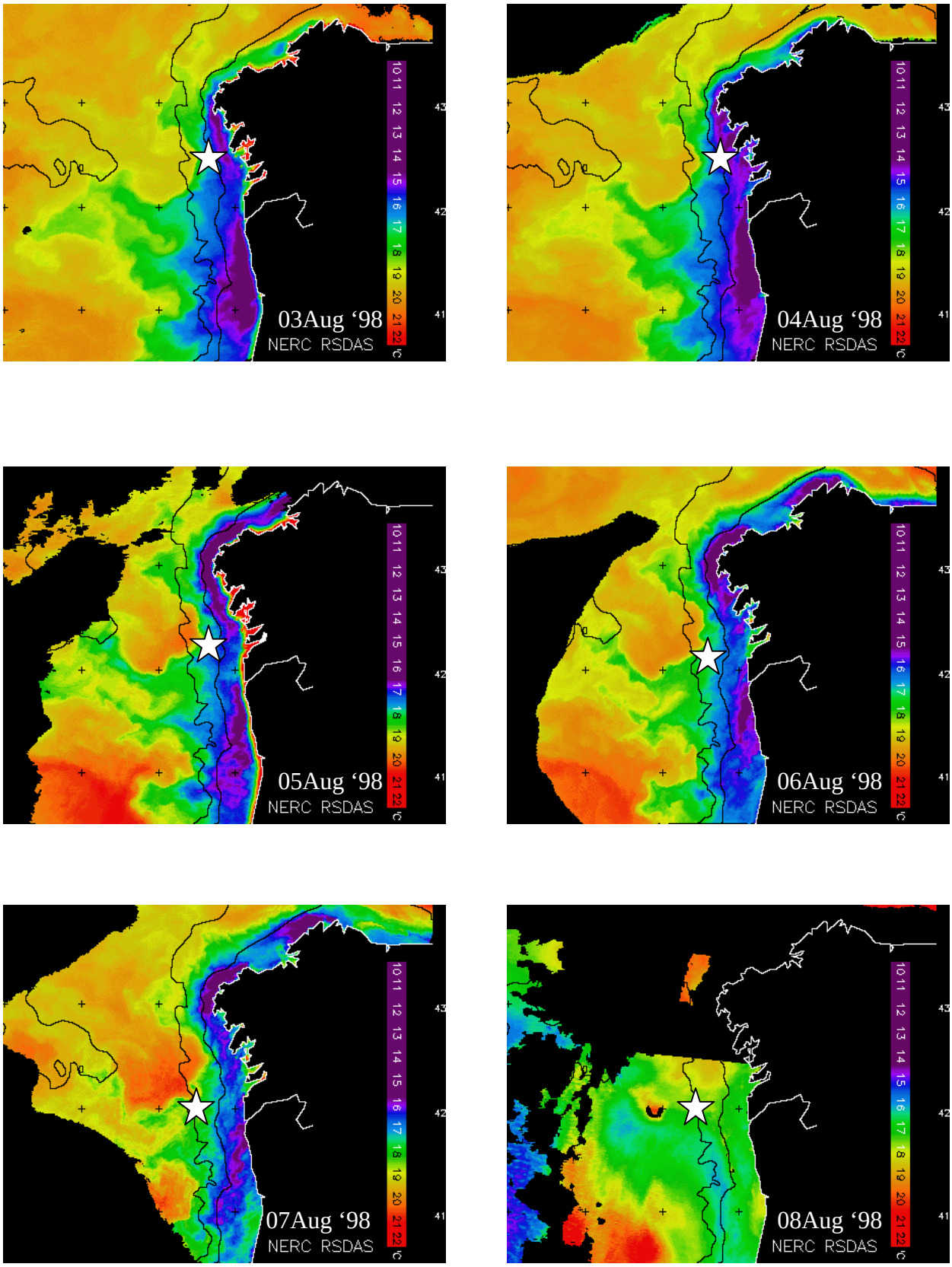
Steve Groom, Peter Miller, Tim Smyth – CCMS Plymouth Marine Laboratory, UK

Satellite remote sensing played an important part in the operation of the cruise. Images from the Advanced Very High Resolution Radiometer (AVHRR) were received several times a day at the NERC Receiving Station at Dundee. The data were transferred to the Plymouth Marine Laboratory and processed to give sea surface temperature (SST) values. The images were then E-mailed to the ship and printed by RVS Computer Support. Hence images of sea surface temperature were usually available by the end of the day on which they were received from the satellite. These data were a great help in planning the sampling activities and in placing the measurements made on board into a wider context. In addition to AVHRR images, surface chlorophyll values were obtained from the SeaWiFS sensor. These data were also processed by the PML Remote Sensing Group and transmitted to the ship at the same time as the sea surface temperature images.

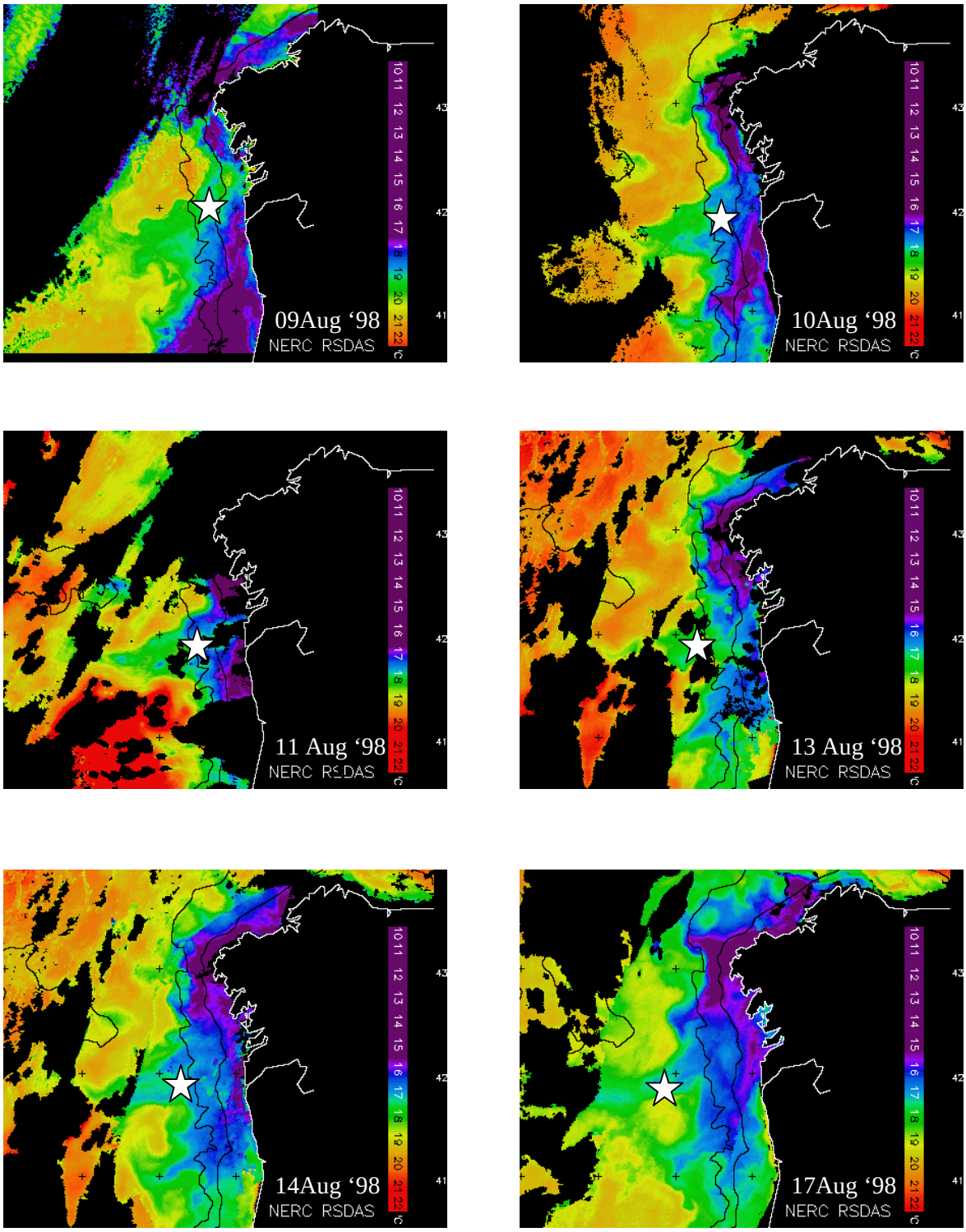
Images from both sensors confirmed that there was strong upwelling at the beginning of Leg 1. SST images showed an area of colder water at the shelf break and on the shelf. These cooler waters also had higher chlorophyll concentrations, suggesting that they were nutrient rich and that the phytoplankton assemblage was growing and achieving a higher biomass in response to the elevated nutrient supply. The SST images also showed a number of filaments which appeared to be transporting cooler surface waters off the shelf and into deeper waters. At the beginning of Leg 2, the SST images helped to define the position for the start of the second Lagrangian experiment.

Unfortunately, there were severe problems in the transmission of images to the ship during Leg 2. The problem was caused by the exclusion of the University of Southampton from the Joint Academic Network (JANET) as a result of infiltration by Hackers. Whilst the University was off-line, no data could be sent from PML and nothing could be sent to the ship. During this time, the PML Remote Sensing Group kept the ship informed of changes in SST by faxing contour diagrams of surface temperatures.

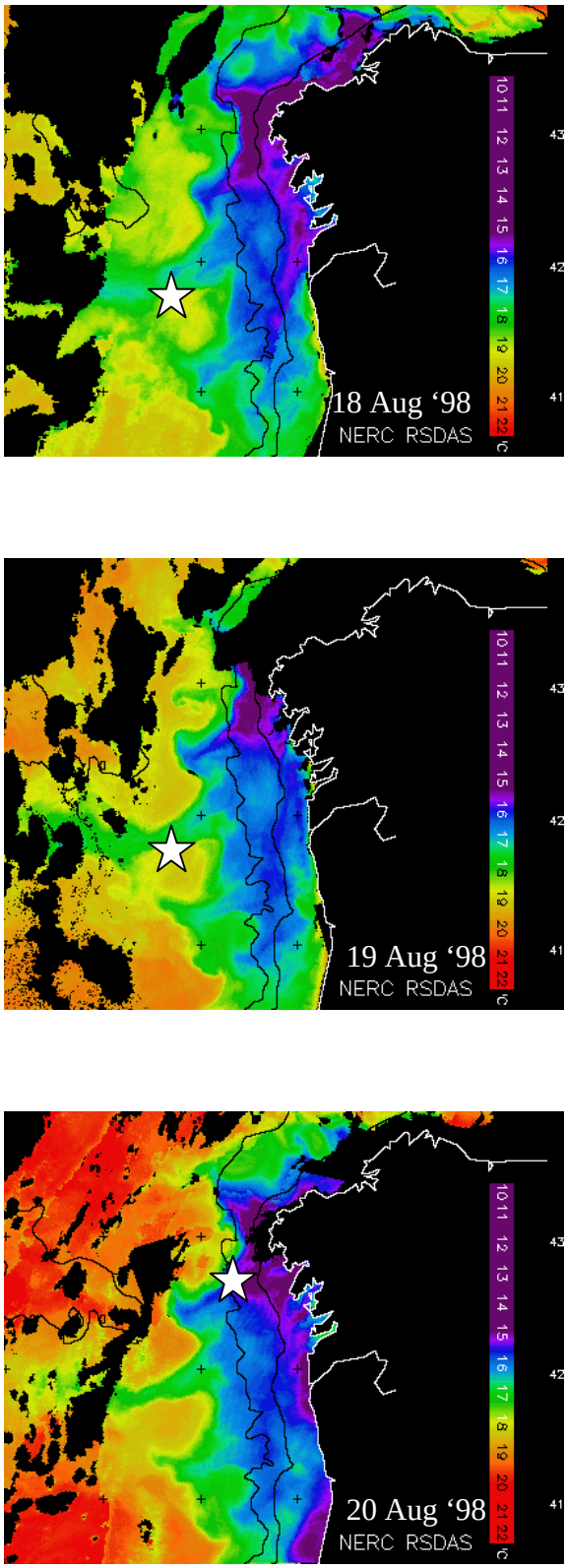
The following Figures show SST. Changes in upwelling and filament formation during the cruise are clearly visible. The position of the ship on each day is indicated.



Sea Surface Temperature images of the study area during Leg 1. The position of the ship is shown (☆) at the time of the pre-dawn CTD sample for production experiments; the 200m and 2000m depth contours are also indicated. The regions of upwelling and off-shore filaments are clearly visible as colder surface water.



Sea Surface Temperature images of the study area during Leg 1 (up to 10 August) and Leg 2 (from 10 August). The position of the ship is shown (☆) at the time of the pre-dawn CTD sample for production experiments; the 200m and 2000m depth contours are also indicated. The regions of upwelling and off-shore filaments are clearly visible as colder surface water.



Sea Surface Temperature images of the study area during Leg 2 (from 10 August). The position of the ship is shown (☆) at the time of the pre-dawn CTD sample for production experiments; the 200m and 2000m depth contours are also indicated. The filaments under study is clearly visible as a region of colder surface water.

Individual Research Reports

1. Physical Processes: Leg 1

Mark Inall, Ricardo Torres, and Ray Wilton,
University of Wales, Bangor, UK

The physics programme aimed to fulfil 2 roles. Firstly, to provide information on the hydrographic, turbulence and current environment during the drifting phase as a complement the other multi-disciplinary measurement programmes, and secondly to investigate the vertical mixing within tidally generated internal waves near the shelf break. Both activities were achieved by using a combination of CTD, hull mounted ADCP and the turbulence measuring Free-fall Light Yo-yo profiler (FLY). Additionally a lightweight thermistor and current meter mooring was deployed 2 km from the shelf break in 170 m of water to continuously measure the internal wave field for objective 2. Details of FLY and ADCP activities are given in Tables 1 and 2 respectively.

Approximately half of the FLY data were processed to the level of turbulence dissipation rates onboard using the SPIDER processing software developed at UCES. The instrument appeared to behave well, with data quality looking good. Objective 1 was thus attained successfully. The navigational error which resulted in the FLY cable becoming entangled with the ship's propeller curtailed FLY usage for leg 1, but fortunately did not result in equipment loss. As a consequence of this the planned experiment of measuring internal waves at three locations as they propagated on-shelf was not possible. One 24 hour FLY station next to the thermistor/current meter mooring was accomplished. Thus partial success was achieved in relation to objective 2 (internal wave study).

Table 1. Summary of FLY deployments.

Date	Time	Series ID	Latitude N	Longitude W	Comments
03 August 98	11:40-12:31	1	42° 32.56'	09° 22.27'	8 drops, 160 m
03 August 98	16:00-18:15	2	42° 30.47'	09° 20.54'	14 drops, 275 m
03 August 98	21:06-23:35	3	42° 25.66'	09° 22.21'	15 drops, 340 m
04 August 98	10:10-12:01	4	42° 19.62'	09° 19.87'	7 drops 250 m westward transect
04 August 98	15:48-17:10	5	42° 18.05'	09° 21.25'	7 drops 230 m eastward transect
04 August 98	20:31-21:13	6	42° 15.68'	09° 22.88'	6 drops 260 m, next to rig,
04 August 98	21:00				fault in data cable,
05 August 98	-11:30				FLY cable replaced with spare
05 August 98	15:37-17:39	7	42° 11.24'	09° 24.68'	10 drops, 285-610 m, next to rig
05 August 98	20:07-21:47	8	42° 09.81'	09° 24.35'	10 drops, 300 m
06 August 98	10:05-12:07	9	42° 07.78'	09° 25.74'	11 drops, 610-710 m
06 August 98	16:25-17-37	10	42° 06.75'	09° 24.86'	7 drops, 430 m, strong SST front
06 August 98	21:35-22:16	11	42° 03.71'	09° 27.15'	4 drops, 1020 m, battery ends series
07 August 98	01:05-02:42	12	42° 05.87'	09° 26.47'	8 drops, 930-825 m, dead calm
07 August 98	10:03-12:1-	13	42° 03.81'	09° 26.79'	12 drops, 1000 m, next to rig, calm
07 August 98	14:37-17:10	14	42° 04.51'	09° 26.09'	14 drops, 860 m
08 August 98	08:31-10:16	15	42° 03.62'	09° 25.46'	10 drops, 800-940 m, thick fog
08 August 98	16:02-				153 drops. Int. Wave Exp by mooring
09 August 98	-16:37	16	41° 55.11'	09° 19.34'	cable tangled round prop, FLY end.

The hull mounted ADCP recorded continuously throughout Leg 1. Data quality was good down to the seabed on the shelf and good down to 280 m off-shelf. Bin size was held constant at 8 m but ensemble average time was varied between 120 s and 300 s, depending on the activity in progress (e.g. 150 s sampling was used during internal wave/mooring experiment). Details of ADCP settings are given in Table 2. Erroneously there was initially a 179.9° offset in the onboard calibration file, this was changed when noticed and will be fully accounted for during post processing. Navigation data were recorded separately, and the ASHTECH system will be used to calibrate the ship's gyro. Raw ADCP and corrected navigation data will be processed through the CODAS system to produce the final ADCP velocity estimates.

Table 2. Summary of ADCP settings.

Date	Time	Bottom Track	Ensemble Period (s)	Heading Offset (°)
02 August 98	10:32	on	180	179.9
02 August 98	19:26	off	180	179.9
02 August 98	22:17	off	300	179.9
02 August 98	23:11	on	300	179.9
03 August 98	09:23	on	120	179.9
03 August 98	14:00	on	120	0.0
04 August 98	21:14	on	300	0.0
08 August 98	14:43	on	150	0.0
10 August 98	12:48	on	300	0.0
10 August 98	13:06	off	300	0.0
10 August 98	17:18	on	300	0.0
11 August 98	12:29 (last record)	on	300	0.0

2. Physical Processes: Leg 2

Des Barton, Ricardo Torres, and Ray Wilton
University of Wales, Bangor, UK

During this leg, roughly 140 FLY (shear, temperature, conductivity, pressure probe) were obtained to an approximate depth of 250 m in the 42^{o}N upwelling filament, five Argos tracked drifters were released into the filament, and ADCP data were logged continuously with the RD Instruments DAS software. During the period of strong winds of late 11 to 13 August, when other work was impossible, a number of ADCP only surveys were made of the filament's northern boundary. ADCP penetration during the leg was poor, often around 100 m or less. This is likely caused by the generally rough sea state and a lack of reflectors in the water column. Location of the sampling was guided by the Sea Surface temperature images provided by PML and the initial CTD transect of 11 August. On 14 August weaker winds allowed the launching of the drifters at the corners of a 6 mile diagonal square with the optical drifter at the centre, 41^{o} 56.4'N 9^{o} 50.9'W. The productivity rig was launched each day close to the optical drifter, where some short FLY time series were made. Two closely spaced FLY cross-filament transects were completed a few miles west of the drifter cluster during 15-18 August in the intervals between CTD, nutrient and net sampling at the drifting rig. The five drifters performed satisfactorily throughout. The optical one was recovered on 19 August; the others will be tracked until they depart the area of interest. On 20 August a small developing filament near the STABLE recovery site was crossed with CTD and FLY.

Initial results are that the southern boundary of the filament had temperature and salinity contrasts of 2^{o}C and 0.2 psu in a distance of about 2 km. ADCP currents near the boundary were weak (< 10 cm s^{-1}) but convergent. Currents were generally weak to the southwest (along filament) almost everywhere. The drifters initially moved southwestward but turned south towards the temperature and salinity front where they appeared to stall, consistent with a convergence. Closely spaced FLY profiles across the boundary measured the fine structure, including an apparently subducted layer, in the convergent front. The two cool filament cores seen in satellite imagery were sampled with several FLY series. It was found that the northern filament boundary was less well defined though currents seemed stronger there. The apparent convergence was consistent with a general weakening of the filament in SST imagery despite the strong winds at start and end of the leg. As the main filament weakened, a new smaller filament developed to its north. Currents in the core of the new filament were about 30 cm s^{-1} to the west, twice or more those measured in the main filament.

3. Inorganic Carbon: Legs 1 and 2

Alberto Borges,
University of Liège, Belgium

Cruise Objectives: Description and understanding of the variability and dynamics of inorganic carbon and on the continental shelf and across the shelf edge during an upwelling/relaxation cycle off the Galician coast. This study is closely related to the investigation of the dynamics of production, degradation and export of organic matter carried out by other partners.

Sampling strategy: Sampling strategy is similar for both legs of the cruise: discrete vertical samples of pH, TAlk and dissolved oxygen will be taken at two "biological stations" (pre-dawn, and 2-3 pm) were primary and secondary production will also be investigated. These stations will be chosen near the deployed drifting buoy. Discrete vertical samples will also be taken during the "survey mode" of the "filament experiment" and during the "tidal cycle study" of the "shelf experiment". Underway measurements of pCO_2, pH and O_2 in subsurface water will be carried out through out the cruise.

Methodology: The determination of pCO_2 is carried out using both direct and indirect methods. The direct one consists to equilibrate seawater with air and then measure CO_2 using an IR analyser. The indirect method relies on the calculation of pCO_2 from experimental determination of pH and Total Alkalinity. These measurements can also been used to calculate the dissolved inorganic carbon (DIC) which will be used, together with dissolved oxygen (Winkler method and polarographic electrode) to discuss CO_2 dynamics with linked biological, physical and chemical processes.

Cruise achievements: Discrete vertical samples of pH, TAlk and dissolved oxygen were taken at two "biological stations" (pre-dawn, and 2-3 pm) during both legs of the cruise. Sampled stations and depths are detailed in Table 1. Underway measurements of pCO_2, pH and O_2 in subsurface water were carried out through out the cruise.
Figures 1 and 2 show preliminary underway results obtained during the first leg of the cruise (the data presented is raw: pCO_2 and O_2 values are not corrected for the variation of temperature between in-situ and laboratory conditions). Figure 1 shows clearly a diel signal in the variations of pCO_2 and O_2 associated to the daily variations of primary production/respiration.

The variation of pCO_2 normalised to 16°C shows that the variation of pCO_2 is not related to the variation of temperature that is know to strongly influence pCO_2. On the 5^{th} of August, the drifting buoy left the shelf to enter an upwelling filament and from then on the variation of pCO_2 stooped following the diel pattern described above and remained relatively constant. Work hypothesis to explain this are the diminution of primary production and/or the shift of the chlorophyll maximum below the thermocline that thus stops affecting pCO_2 in the mixed layer. Figure 2 shows the variation of pCO_2,O_2, and temperature along a transect across the upwelling filament during the second leg of the cruise. At the edge of the filament (arrows) there is a clear signal in the parameters that can be related to a coastal jet that carries from the shelf, cooler water that is biologically more active than the surrounding water.

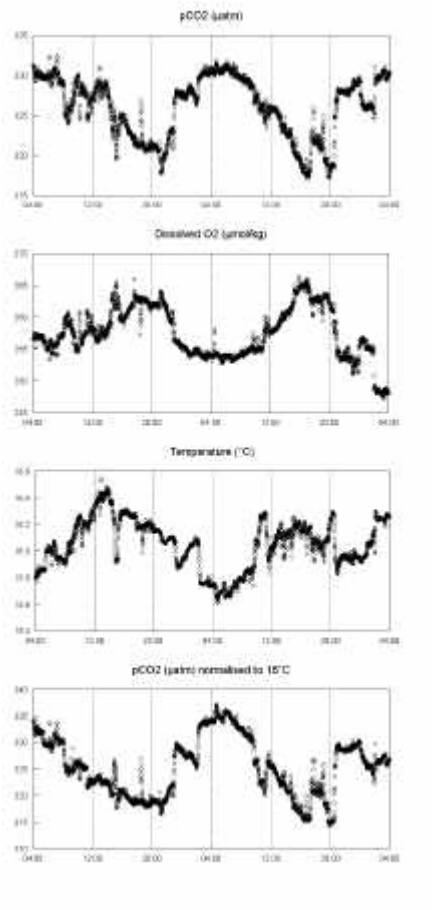


Figure 1: Variations from the 3th to the 5th of August, of pCO_2 (µatm), dissolved O_2 (µmol/kg), temperature (°C) and pCO_2 (µatm) normalised to 16°C in subsurface seawater, during the first leg of the CD114 cruise

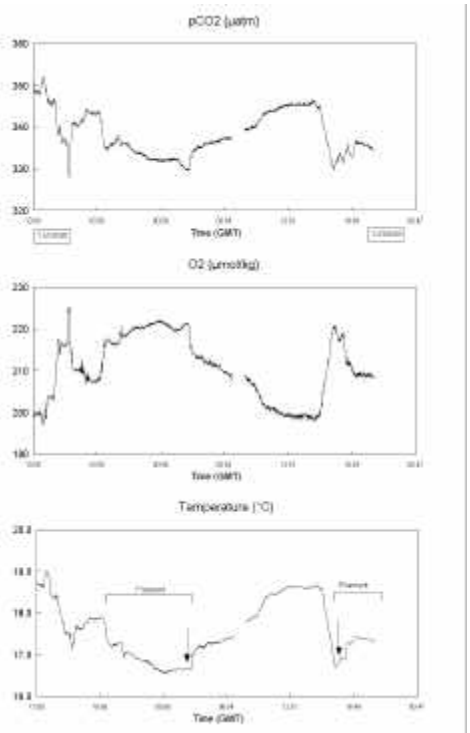


Figure 2: Variations from the 11th to the 12th of August, of pCO_2 (µatm), dissolved O_2 (µmol/kg) and temperature (°C), in subsurface seawater, along a transect across the upwelling filament, carried out during the second leg of the CD114 cruise

Table 3: Stations and depths sampled by Ulg for pH, TAlk and dissolved O_2 during both legs of the CD114 cruise.

		Sampled Depths (m)																			
Leg	**Station**	30	20	15	13	10	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5
1	1												x				x					x
1	4				x	x	x				x				x				x			
1	6	x	x			x					x				x				x			x
1	9					x					x		x		x		x	x	x	x		
1	11			x				x					x							x		x
1	13			x			x				x			x	x		x	x	x	x	x	x
1	15				x						x				x		x		x			x
1	19			x					x						x		x	x	x	x	x	x
1	21			x			x							x			x				x	x
1	24			x					x						x		x	x	x	x	x	x
1	26			x			x				x				x				x			x
1	30			x			x								x		x	x	x	x	x	x
1	32			x			x						x				x			x		x
1	37			x			x								x		x	x	x	x	x	x
1	38					x							x				x					x
1	39					x									x			x				x
1	40					x									x			x				x
1	41					x											x			x		x
2	57					x							x		x		x	x	x	x	x	x
2	58			x		x							x		x		x				x	x
2	60					x							x		x		x		x	x	x	x
2	61					x							x		x		x		x			x
2	63					x		x			x		x	x		x		x		x	x	x
2	64					x					x			x			x		x		x	x
2	66					x		x						x	x	x		x		x	x	x
2	67					x						x	x		x		x				x	x
2	69					x				x	x	x	x		x		x		x		x	x
2	70					x					x	x	x				x				x	x
2	71					x			x				x	x	x	x		x		x	x	
2	73		x	x		x							x		x						x	
2	79					x							x					x		x	x	x
2	83				x	x							x						x	x	x	

4. Micro- and nano-nutrient concentrations: Legs 1 and 2

Malcolm Woodward, Denise Cummings and Andy Rees,
Plymouth Marine Laboratory, UK

Objectives: To study the spatial and temporal variations of the micro nutrients Nitrate, Nitrite, Phosphate, Silicate and Ammonia, in the upwelling region of Cape Finistere, Northern Spain. Where ambient concentrations were below the detection limits of the colorimetric systems during the second leg of the cruise, a nanomolar Ammonia analysis system, plus a nanomolar chemiluminescence analysis system for detection of Nitrate and Nitrite were deployed. The transect was to study in particular a filament from the upwelling, and also with regular, daily CTD sections for water column sampling.

Methods: The nutrient analyser was a 5 channel Technicon AAII, segmented flow autoanalyser. The chemical methodologies used were: Nitrate, (Brewer and Riley, 1965); Nitrite, (Grasshoff, 1976); Phosphate (Kirkwood, 1989); Silicate (Kirkwood, 1989), and Ammonia (Mantoura and Woodward, 1983). Nanomolar Nitrate and Nitrite detection methodology was from Garside (1982), and the nanomolar Ammonia system adapted from Jones, 1991.

Water samples were taken from the 10 litre CTD/Rosette system (SeaBird), these were sub sampled into clean Nalgene bottles and analysis for the nutrient samples was in every case complete within 3 hours of sampling. Clean handling techniques were employed to avoid any contamination of the samples, particularly by ammonia. No samples were stored.

Sample analysis was also regularly carried out for zooplankton grazing experiments (Edwards). Underway continuous surface sampling was from the non-toxic water system, and the water flow was in-line filtered (Morris *et al*, 1978), by a 0.45um Millipore filter, before analysis for the macro nutrients.

All CTD samples were analysed successfully with a negligible sample loss rate. As usual the Technicon system showed its reliability and reproducibility in the extreme environment of marine research.

The nanomolar nitrate/nitrite chemiluminescent system worked as well as could be expected, although this system was at the limits of its detection for many mixed layer samples from the oligotrophic stations. The ammonia system had a motorised valve breakdown, and the sampling was not as efficient as with the valve in line.

Table 4: CTD Samples analysed for nitrate, nitrite, ammonium, phosphate and silicate.

Date	CTD	Number of depths	Depth range sampled (m)
1 August 1998	00	3	5 – 50
2 August 1998	01/02	3	21 – 133
	04	6	5 – 313
	06	7	5 – 40
3 August 1998	09	7	5 – 150
	11	6	5 – 40
4 August 1998	13	7	5 – 130
	15	6	5 – 150
5 August 1998	19	10	5 – 200
	21	7	5 – 150
6 August 1998	24	10	5 – 150
	26	6	5 – 150
7 August 1998	30	9	5 – 150
	32	6	5 – 150
8 August 1998	35	6	5 – 150
9 August 1998	37	8	5 – 150
	38	7	5 – 100
	39	6	5 – 100
	40	4	5 – 100
10 August 1998	41	4	5 – 100
13 August 1998	056		10 - 400
14 August 1998	057		5 - 1200
14 August 1998	058		5 - 150
15 August 1998	060		5 - 1300
15 August 1998	061		5 - 500
16 August 1998	063		5 - 148
16 August 1998	064		5 - 250
17 August 1998	066		5 - 110
17 August 1998	067		5 - 500
18 August 1998	069		5 - 150
18 August 1998	070		5 - 500

Date	CTD	Number of depths	Depth range sampled (m)
19 August 1998	072		5 - 150
19 August 1998	073		10 - 200
20 August 1998	079		10 - 500
20 August 1998	081		10 - 280
20 August 1998	083		10 - 130

Table 5: Underway samples analysed for nitrate, nitrite, ammonium, phosphate and silicate.

Start	End
13 August 1998: 1005	13 August 1998: 1600
19 August 1998: 1524	19 August 1998: 1743
19 August 1998: 2013	20 August 1998: 0508
20 August 1998: 0721	20 August 1998: 0804
20 August 1998: 0954	20 August 1998: 1613
20 August 1998: 1635	20 August 1998: 1800

Data analysis: No on-board analysis of the data was carried out, other than that required for the ^{15}N uptake experiments, (A. Rees, PML). The underway nutrient analysis will be carried out at BODC, and the CTD data profiles analysed at PML. All data will be lodged at BODC, once calculated and quality controlled.

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5. Primary Production: Legs 1 and 2

Ian Joint,
Plymouth Marine Laboratory, UK

Objectives: Upwelling of cold, nutrient rich waters into the near-surface layers of the ocean result in increases in phytoplankton biomass. This increased biomass on the narrow Iberian shelf is an important factor for the economy of the region since the phytoplankton production sustains large commercial shellfish fisheries in the Rias of Galicia. One aim of this cruise, which was the basis of the experiment in Leg 1, was to measure phytoplankton production in upwelled waters as it travelled along the shelf and to follow changes as the nutrients were utilised by the increased phytoplankton biomass. The second objective was to assess how the phytoplankton assemblage changed as water was advected off the shelf and into the ocean as a filament; this was the rationale for Leg 2. Nutrient concentrations within the filament were very low and so there was a strong contrast between the two Legs, with high nutrient concentrations and elevated chlorophyll concentrations on Leg 1 and low nutrient concentrations and declining chlorophyll concentrations on Leg 2.

A second objective was to assess how different phytoplankton assemblages respond to the changing nutrient climate. It is commonly observed that only the smallest phytoplankton cells (the picophytoplankton) dominate in oligotrophic waters. In water with increased nutrient concentrations, larger phytoplankton cells, which are frequently but not exclusively diatoms, are usually the most abundant phytoplankton. Therefore, measurements of primary production in different size fractions gives a measure of how natural phytoplankton assemblages respond to changing nutrient concentrations.

Methods: Phytoplankton production was measured by the incorporation of ^{14}C bicarbonate in 24h incubations. Most experiments involved incubations *in situ* but a small number of on deck incubations were also done. Water samples were taken before dawn with 10l Niskin bottles on the CTD rosette. Care was taken to avoid exposure to light and all experimental manipulations were done in subdued light. Water samples were taken for 8 depths in the water column and 4 acid-cleaned polycarbonate bottles were filled from each depth. Each bottle was inoculated with 10µCi ^{14}C bicarbonate solution. One bottle from each depth was wrapped with aluminium foil and tape to exclude all light. This dark bottle and 3 transparent bottles were fixed to a clear acrylic bottle rack. The 8 bottle racks were then attached to a rope at intervals corresponding to the depth at which the water samples were taken. The rope was suspended from a toroid buoy and left free floating in the sea for 24h hours. A Dahn buoy with light, radio beacon and radar reflector was attached to the toroid buoy and used to locate the position of the incubation rig at various times during the day and for recovery in the early hours of the following day.

At about 2 hours before dawn each day, the water samples were taken close to the position of the incubation rig which was used to mark the water patch in the Lagrangian experiment. The bottles were inoculated as described above and then the primary production rig from the previous day's experiment was recovered on deck. The bottle racks of the previous day's experiment were removed and replaced with the current set of experimental bottles. The incubation rig was then redeployed. The aim was to deploy the incubation rig before dawn to prevent any possibility of light shock to the experimental phytoplankton; on most occasions, it was still dark when the production rig was deployed.

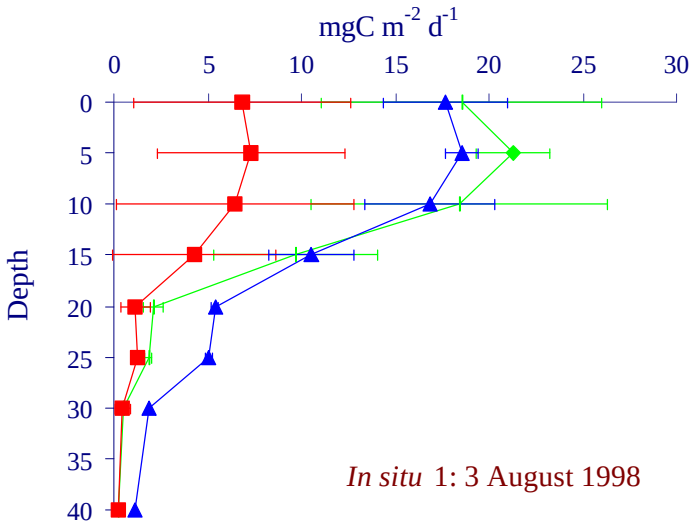

Figure 3 ^{14}C fixation rates by 3 size fractions of phytoplankton on 3 August at the beginning of Leg 1. ◆ *>5µm* ■ *<5µ - >2µm* % *<2µm - >0.2µm*

The recovered bottles were then filtered sequentially through 5µm, 2µm and 0.2µm pore size polycarbonate filters. The filters were dried in a desiccator and the samples were counted on board ship in a liquid scintillation counter; results were available 36 hours after the end of each incubation. On Leg 1, 6 *in situ* incubations were completed and on Leg 2, there were 4 *in situ* experiments and 2 on deck incubations. However, on Leg 2 there was poor return of the experimental bottles after the incubation rig was hit by a passing tanker – about 40% of the bottles were recovered.

In addition to ^{14}C fixation experiments, the uptake of phosphate was also measured using ^{33}P. The experimental procedures were identical to those used in the ^{14}C experiments, except that the filters were washed with lithium chloride:phosphate buffer to remove any unassimilated ^{33}P. The number of *in situ* and on deck incubations completed for phosphate uptake were identical to the ^{14}C experiments.

Results: At the beginning of Leg 1, chlorophyll and nutrient concentrations in the newly upwelled waters were high. Primary production rates were also high; on 3 August, the total carbon fixation rate is calculated to be 788 mgC m^{-2} d^{-1} (65.7µmolC m^{-2} d^{-1}). Fig. 3 shows the depth profiles of primary production by three size fractions of phytoplankton on 3 August 1998.

The picophytoplankton fraction was surprisingly important. It was anticipated that the elevated nutrient concentrations would have resulted in increased production by the >5µm fraction; these cells were responsible for about 40% of the measured production. However, picophytoplankton, which is usually dominant in extreme oligotrophic conditions, was also very active and accounted for about 44% of the daily primary production. The third size fraction, between 5µm and 2µm, fixed 124 mgC m^{-2} d^{-1} - about 16% of the daily primary production. This dominance of both the largest and smallest size fractions was maintained throughout the Lagrangian experiment on Leg 1.

On Leg 2, the samples were taken within a filament, which was identified from satellite remote sensing. The water mass was marked with 5 Argos buoys and daily samples for primary production were taken as in Leg 1. Nutrient concentrations were much lower than on Leg 1 and at times, nitrate concentrations were undetectable by standard colorimetric analysis. Primary production rates were lower than on Leg 1 and, as can be see from Figure 4, the most productive phytoplankton fraction was the picophytoplankton.

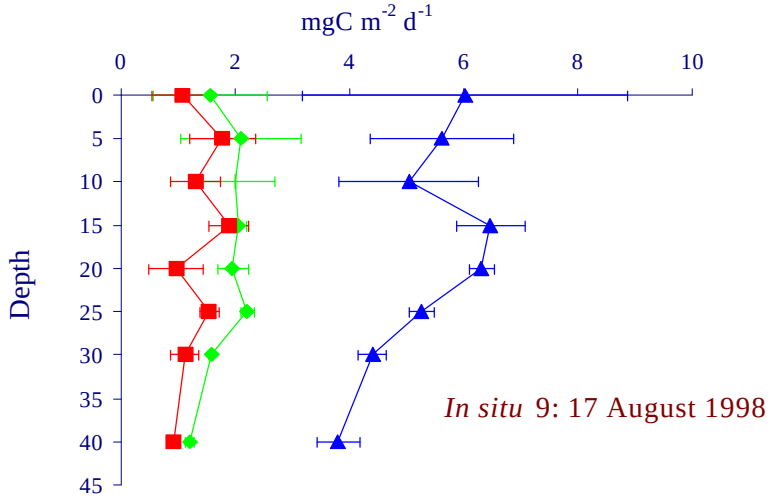

Figure 4 ^{14}C fixation rates by 3 size fractions of phytoplankton on 17 August on Leg 2.

◆ *>5µm* ■ *<5µ - >2µm* % *<2µm - >0.2µm*

On 17 August, the daily primary production was 337 mgC m^{-2} d^{-1} and picophytoplankton accounted for 62% of this carbon fixation. The >5µm cells were responsible for 22% of the production and the <5µm to >2µm fraction for 16% of the daily rate.

6. Nutrient, organic matter & phytoplankton distributions, P–E curves and bio-optical parameters: Leg 1

Xosé Antón Álvarez-Salgado, Francisco Gómez Figueiras, and Gavin H. Tilstone
Instituto de Investigacións Mariñas, CSIC, Vigo, Spain.

*Introduction :*The upwelling of Eastern North Atlantic Water (ENCAW) typically occurs along the NW coast of Spain from April to September. Little work has been undertaken to characterise the chemical and biological short term changes of specific upwelled waters in this region. A Lagrangian approach was employed to analyse changes in nutrients, DOC, POC, the C/N ratio of organic matter, phytoplankton communities, photosynthesis, primary production and light absorption.

Objectives: To study the short term variability in

1. Nutrients, DOC, POC, C/N ratio of organic matter.
2. Phytoplankton species, P-E parameters, spectral underwater light field, phytoplankton light absorption, light fluorescence excitation spectra and primary production.

Methodology.

Nutrients and organic matter

Samples for 5-nutrient analyses were filtered through Whatman polypropylene filters (0.45 µm) and collected into 50 ml polyethylene containers. They will be analysed with an `Alpkem Corporation` analyser working under the principle of segmented flow analysis. DOC/TDN samples were filtered through Whatman GF/F filters. The filtrate was collected into 10 ml ampoules, acidified with H_3PO_4 and, subsequently, heat sealed. DOC/TDN will be analysed by high temperature catalytic oxidation with CO_2-IRGA and NO-Chemiluminescence detection. POC/PON were collected onto Whatman GF/F filters, dried on silica gel, and preserved at –20°C. Samples will be analysed with a `Perkin Elmer` CNH analyser. A total of 147 samples were collected for nutrients and organic matter analyses.

Phytoplankton

Phytoplankton samples for counting and identification were preserved with Lugol and formaldehyde for further analyses under inverted and epifluorescence microscopy, respectively. A total of 110 samples were collected.

Photosynthetic parameters and primary production were measured by inoculating sea water sub-samples with $NaHC^{14}O_3$ and incubating for 2.5 hours at 14 irradiance levels.

Phytoplankton and detrital light absorption spectra were derived from measurements on GF/F filters using spectrofluorometric and spectrophotometric techniques.

The downwelling spectral light field of the water column was measured using a LICOR spectroradiometer. A total of 52 P-E curves were preformed.

Table 6: Stations and variables sampled by IIM

Julian Day	Time (GMT)	Latitude Longitude	CTD No.	Depths (m)	Samples
214	16:02	42°37.05'N 9°06.49'W	2	5, 30, 50	Nutrients, DOC, TDN, POC, PON, phytoplankton
214	18:03	42°36.87'N 9°23.90'W	4	20, 40, 60, 85, 105, 133	Nutrients, DOC, TDN, POC, PON, phytoplankton
214	20:06	42°36.7'N 9°28.4'W	6	5, 20, 40, 60, 100, 200, 340	Nutrients, DOC, TDN, POC, PON, phytoplankton
215	3:29	42°36.95'N 9°23.89°W	9	5, 10, 15, 20, 25, 30, 40, 50, 60, 100	Nutrients, DOC, TDN, POC, PON, phytoplankton
215	8:41	42°34´ N 9°21´ W		Surface, 5, 10, 15, 20, 30, 40, 50, 60	Spectroradiometer (cast 1)

Julian Day	Time (GMT)	Latitude Longitude	CTD No.	Depths (m)	Samples
215	9:30	42°34´ N 9°21´ W	10	5, 15, 25, 40, 60, 120	Nutrients, DOC, TDN, POC, PON, phytoplankton, chl a, epifluorescence, P-E curves, light absorption.
215	13:30	42°31´02.86´´N 9°23´00.04´´ W		Surface, 5, 10, 15, 20, 30, 40, 50, 60	Spectroradiometer (cast 2)
215	14:03	42°31´02.86´´N 9°23´00.04´´ W	11	5, 15, 25, 50	Nutrients, DOC, TDN, POC, PON, phytoplankton, chl a, epifluorescence, P-E curves, light absorption.
216	2:45	42°22.71'N 9°20.41'W	13	5, 10, 15, 20, 25, 30, 45, 80, 150	Nutrients, DOC, TDN, POC, PON, phytoplankton
216	8:00	42°19´50.20´´ N 9°19´ 31.44´´W		Surface, 5, 10, 15, 20, 30, 40, 50, 60	Spectroradiometer (cast 3)
216	8:24	42°19´50.20´´ N 9°19´ 31.44´´W	14	5, 15, 25, 40, 60, 130	Nutrients, DOC, TDN, POC, PON, phytoplankton, chl a, epifluorescence, P-E curves, light absorption.
216	14:00	42°18´14.52´´ N 9°20´57.73´´ W		Surface, 5, 10, 15, 20, 30, 40, 50, 60	Spectroradiometer (cast 4)
216	14:26	42°18´14.52´´ N 9°20´57.73´´ W	15	5, 20, 30, 40, 60, 130	Nutrients, DOC, TDN, POC, PON, phytoplankton, chl a, epifluorescence, P-E curves, light absorption.
217			19	5, 10, 15, 20, 25, 30, 40, 70, 150	Nutrients, DOC, TDN, POC, PON, phytoplankton
217	8:00	42°12´15.9´´ N 9°23´35.8´´ W		Surface, 5, 10, 15, 20, 30, 40, 50, 60	Spectroradiometer (cast 5)
217	8:29	42°12´15.9´´ N 9°23´35.8´´ W	20	5, 15, 30, 40, 80, 150	Nutrients, DOC, TDN, POC, PON, phytoplankton, chl a, epifluorescence, P-E curves, light absorption.
217	13:15	42°11´20.16´´ N 9°23´48.34´´ W		Surface, 5, 10, 15, 20, 30, 40, 50, 60	Spectroradiometer (cast 6)
217	13:57	42°11´20.16´´ N 9°23´48.34´´ W	21	5, 10, 30, 45, 80, 150	Nutrients, DOC, TDN, POC, PON, phytoplankton, chl a, epifluorescence, P-E curves, light absorption.
218			24	5, 10, 15, 20, 25, 30, 40, 70, 150	Nutrients, DOC, TDN, POC, PON, phytoplankton
218	8:00	42°07´22.00´´ N 9°25´03.20´´ W		Surface, 5, 10, 15, 20, 30, 40, 50, 60	Spectroradiometer (cast 7)
218	8:36	42°07´22.00´´ N 9°25´03.20´´ W	25	5, 15, 30, 45, 80, 150	Nutrients, DOC, TDN, POC, PON, phytoplankton, chl a, epifluorescence, P-E curves, light absorption.
218	14:00	42°07´3.99´´ N 9°25´ 10.13´´W		Surface, 5, 10, 15, 20, 30, 40, 50, 60	Spectroradiometer (cast 8)
218	14:35	42°07´3.99´´ N 9°25´ 10.13´´W	26	5, 20, 40, 60, 80, 150	Nutrients, DOC, TDN, POC, PON, phytoplankton, chl a, epifluorescence, P-E curves, light absorption.
219			30	5, 10, 15, 20, 25, 30, 40, 80, 150	Nutrients, DOC, TDN, POC, PON, phytoplankton

Julian Day	Time (GMT)	Latitude Longitude	CTD No.	Depths (m)	Samples
219	7:50	42°03´ 55.98´´N 9°26´ 48.04´´W		Surface, 5, 10, 15, 20, 30, 40, 50, 60	spectroradiometer (cast 9)
219	8:18	42°03´ 55.98´´N 9°26´ 48.04´´W	31	5, 20, 40, 60,80, 150	nutrients, DOC, TDN, POC, PON, phytoplankton, chl a, epifluorescence, P-E curves, light absorption.
219	12.00	42°04´ 11.10´´N 9°26´ 33.69´´W		Surface, 5, 10, 15, 20, 30, 40, 50, 60	spectroradiometer (cast 10)
219	12.42	42°04´ 11.10´´N 9°26´ 33.69´´W	32	5, 15, 30, 50, 80, 150	nutrients, DOC, TDN, POC, PON, phytoplankton, chl a, epifluorescence, P-E curves, light absorption.
220			37	5, 10, 15, 20, 25, 30, 40, 80, 150	Nutrients, DOC, TDN, POC, PON, phytoplankton
220	7.16	41°54’ 46.92’’N 9°19’ 30.52’’W	38	5, 30, 50, 100	nutrients, DOC, TDN, POC, PON, phytoplankton, chl a, epifluorescence, P-E curves, light absorption.
220	12.19	41°53’ 39.55’’N 9°17’ 48.58’’W	39	5, 25, 40, 100	nutrients, DOC, TDN, POC, PON, phytoplankton, chl a, epifluorescence, P-E curves, light absorption.
220	18.45	41°54’ 26.30’’N 9°17’ 23.95’’W	40	5, 25, 40 , 100	nutrients, DOC, TDN, POC, PON, phytoplankton, chl a, epifluorescence, P-E curves, light absorption.
221	1.10	41°52’ 22.57’’N 9°16’ 27.42’’W	41	5, 15, 30, 100	Nutrients, DOC, TDN, POC, PON, phytoplankton, chl a, epifluorescence, P-E curves, light absorption.

7. Nitrogen cycling: Legs 1 and 2

Andrew Rees
CCMS Plymouth Marine Laboratory, U.K.

Objectives: Leg 1: 1. To determine the rates and relative proportions of nitrate, ammonium and urea assimilation by size fractionated marine phytoplankton, during an upwelling event at the Iberian peninsular.

2. To perform uptake experiments to determine the kinetic parameters of nitrate and ammonium assimilation.

3. To determine concentrations onboard of dissolved nutrient species; nitrate, nitrite, ammonium, silicate, and phosphate and to collect samples for laboratory analysis of urea.

Leg 2: 1. To estimate changes in the nitrogen budget during the development of an offshore filament, through determination of nitrogen uptake, ammonium regeneration and nitrification rates; and the concentrations of nitrous oxide and urea; and dissolved inorganic nutrients (Woodward), DON/PON (Alvarez-Salgado).

2. To evaluate the potential for nitrogen fixation by ^{15}N methodology.

Methodology

Nitrogen uptake

Assimilation rates for nitrate, ammonium and urea were determined following the incorporation of the stable isotope ^{15}N. Duplicate samples of water from each depth were distributed into 620 ml clear polycarbonate bottles and $^{15}N\text{-}NO_3$, $^{15}N\text{-}NH_4$ and $^{15}N\text{-}CO(NH_2)_2$ were added at a final concentration of 10% ambient nitrate or ammonium concentration. Incubations were made in situ using a free-floating buoyed rig or in an on deck incubator. This consisted of a series of tanks with spectrally corrected light screens, which permitted transmission of ambient irradiance in the range 97 – 1% and was maintained at surface seawater temperature. Incubations were performed for both 24 hours and for shorter time periods of approximately 4 hours to determine mean daily and linear uptake rates respectively. Incubations were then terminated by filtration (< 40 cm Hg vacuum) onto ashed Whatman GF/F filters, which were dried onboard and stored over silica gel desiccant until return to the laboratory, where they will be analysed by continuous flow nitrogen analysis-mass spectrometry.

Ammonium regeneration

Following inoculation with $^{15}N\text{-}NH_4$ and 24 hour incubation as described above, the filtrate from a number of samples throughout the euphotic zone were stored in ashed, acid cleaned Pyrex bottles with mercuric chloride. Ammonium regeneration will be estimated according to an isotope dilution technique following the extraction of dissolved ammonium in the laboratory.

^{15}N uptake kinetics

In oligotrophic waters a series of experiments were performed to allow examination of the uptake rate kinetics of nitrate and ammonium. $^{15}N\text{-}NO_3$ and $^{15}N\text{-}NH_4$ were added at concentrations ranging from 5 – 120nM to 620ml samples which were then incubated for <4hours in the on-deck incubator. Incubations were terminated by filtration onto GF/F filters and dried prior to analysis in the laboratory.

Nitrification

The bacterial oxidation of ammonium to nitrite and nitrate was estimated by two methods from a number of depths throughout the water column.

(i) The first involved the incorporation of ^{14}C in the dark with and without the presence of a nitrification inhibitor – allylthiourea (ATU). 6 x 100ml polycarbonate bottles were filled from a

number of depths, 10µCi of ^{14}C bicarbonate was added to each, then to three of the bottles ATU was added to a final concentration of 10mgl^{-1}. Incubations were in the dark at ambient temperature for approximately 6 hours and were terminated by filtration onto 0.2µm polycarbonate filters, which were then dried over silica gel desiccant prior to analysis by liquid scintillation counter onboard ship.

(ii) On samples collected for determination of ammonium regeneration; following extraction of dissolved ammonium, samples will be further treated with Devarda's alloy to allow extraction of dissolved nitrate, and following isotopic ratio analysis of $^{15}N/^{14}N$ an estimate will be made of ammonium oxidation based on the isotope dilution theory.

Nitrous Oxide

At a number of depths (10 – 12) throughout the water column, a single 100ml universal bottle was overfilled by three times it's volume. 200µl of saturated mercuric chloride solution was added and the bottle was sealed and stored in the dark at room temperature prior to analysis by electron capture detector gas chromatography in the laboratory.

Nutrient concentrations (With Denise Cummings)

Analyses of dissolved inorganic nutrient concentrations were completed within three hours of collection. Determination was by colorimetric autoanalysis using the methods of Brewer and Riley (1965) for nitrate, Grasshoff (1976) for nitrite, Mantoura and Woodward (1983) for ammonium, and Kirkwood (1989) for silicate and phosphate. 60ml samples for the analysis of urea were filtered through acid rinsed 0.45µm filters and frozen at –20°C prior to analysis in the laboratory by the method described by Goeyens *et al*. (1998).

Nitrogen fixation

At one station only (16 August 98) 30l of seawater was concentrated into 2l, 100ml aliquots were then distributed in to 23 universal bottles, sealed and flushed for 5 minutes with argon. 3 were filtered immediately for chlorophyll, PON and ^{15}N-atom% analysis. The remainder were divided into 2 groups of 10, one to be incubated in the light and the other in the dark. Both sets of bottles were then amended with:

No.s 1&2	+ 50ml $^{15}N_2$:
No. 3	+ 50 ml $^{15}N_2$ + HgCl
No. 4	+ 50 ml $^{15}N_2$ + trace metals
No. 5	+ 50 ml $^{15}N_2$ + trace metals + HgCl
No.s 6,7&8	+ 50 ml $^{14}N_2$
No.s 9&10	blank.

Following incubation for approx 48 hours all samples were filtered onto 25mm GF/F's and will be analysed for ^{15}N-atom% in the laboratory.

Table 7: Dates and positions of nitrogen cycling experiments

	Date	Position	Number of depths	Depth Range (m)	Variables
Leg 1	3 August	42°37'N	7	0 – 40	^{15}N uptake – 24h, size fractionated
		09°24'W	1	10	^{15}N uptake – 4h,
			1	10	^{15}N-uptake kinetics.
			7	0 – 40	Urea concentration
	4 August	42°22'N	8	0 – 40	^{15}N uptake – 24h, size fractionated
		09°20'W	1	10	^{15}N uptake – 4h
			1	10	^{15}N-uptake kinetics.
			7	0 – 40	Urea concentration
	5 August	42°13'N	8	0 – 40	^{15}N uptake – 24h, size fractionated
		09°24'W	1	10	^{15}N uptake – 4h
			1	10	^{15}N-uptake kinetics
			7	0 – 40	Urea concentration
	6 August	42°09'N	8	0 – 40	^{15}N uptake – 24h, size fractionated
		09°25'W	1	10	^{15}N uptake – 4h
			8	0 – 50	Urea concentration
	7 August	42°05'N	8	0 – 40	^{15}N uptake – 24h, size fractionated
		09°25'W	1	10	^{15}N uptake – 4h
			8	0 – 80	Urea concentration
	9 August	41°55'N	8	0 – 40	^{15}N uptake – 24h, size fractionated
		09°18'W	1	10	^{15}N uptake – 4h
			8	0 – 80	Urea concentration
Leg 2	14 August	41°56'N	8	0 – 40	^{15}N uptake – 24h.
		09°50'W	4	0 – 10	^{15}N uptake – 4h
			3	10 – 30	^{15}N-NH_4 – regeneration/oxidation
			8	0 - 50	Urea concentration
			5	25 – 100	^{14}C – nitrification
			11	0 – 500	N_2O
	15 August	41°54'N	8	0 – 40	^{15}N uptake – 24h.
		09°54'W	5	0 – 25	^{15}N uptake – 4h
			5	10 – 50	^{15}N-NH_4 – regeneration/oxidation
			8	0 – 50	Urea concentration
			5	25 – 100	^{14}C – nitrification
			12	0 – 500	N_2O
	16 August	41°52'N	8^^	0 – 45	^{15}N uptake – 24h.
		09°58'W	4	0 – 45	^{15}N uptake – 4h
			4	10 – 60	^{15}N-NH_4 – regeneration/oxidation
			8	0 – 50	Urea concentration
			5	30 – 100	^{14}C – nitrification
			12	0 – 500	N_2O

Date	Position	Number of depths	Depth Range (m)	Variables
17 August	41°52'N	8	0 – 45	^{15}N uptake – 24h.
	10°01'W	5	10 – 75	^{15}N-NH_4 – regeneration/oxidation
		8	0 – 60	Urea concentration
		5	30 – 100	^{14}C – nitrification
		12	0 - 500	N_2O
18 August	41°48'N	7**	0 – 50	^{15}N uptake – 24h.
	10°07'W	1	10	^{15}N uptake – 4h
		4	10 – 60	^{15}N-NH_4 – regeneration/oxidation
		8	0 – 60	Urea concentration
		5	30 – 100	^{14}C – nitrification
		12	0 – 500	N_2O
		1	10	^{15}N-uptake kinetics
19 August	41°46'N	8^^	0 – 45	^{15}N uptake – 24h.
	10°06'W	5	10 - 70	^{15}N-NH_4 – regeneration/oxidation
		8	0 – 60	Urea concentration
		5	30 – 100	^{14}C – nitrification
		1	10	^{15}N-uptake kinetics

^^ On-deck incubation, all other 24h experiments *in situ*. ** number of bottles lost following damage to free-floating rig.

8. Phytoplankton Chemotaxonomy using Chlorophyll and Carotenoid Pigments

Denise G. Cummings
CCMS Plymouth Marine Laboratory, UK

Introduction: In biological oceanography the photosynthetic pigments, in particular Chlorophyll *a* are recognised as unique and convenient markers of phytoplankton biomass. Although spectrophotometric and fluorometric techniques are widely used to determine biomass, the utilisation of high performance liquid chromatography (HPLC) not only permits a more accurate measurement of Chlorophyll *a*, but also allows simultaneous separation and quantification of a range of other chloropigments and carotenoids in marine phytoplankton.

Determination of Pigments by HPLC: Water samples(~1000ml) were filtered through glass fibre filters(GF/F). Filters were stored under liquid nitrogen(-196 °C) to be later analysed at the Plymouth Marine Laboratory. The phytoplankton harvested on the filters will be extracted using 90% acetone with ultrasonification. Ammonium acetate buffer will be added in equal volume and chloropigments and carotenoids in the extract resolved by binary reverse-phase HPLC with absorbance detection(440nm) on a 10cm C8 column using a programmed gradient elution with methanol:ammonium acetate(70:30) and methanol mobile phases.

Objectives: (1)To investigate the fluxes of chlorophyll and carotenoid pigment distribution, production, sedimentation and degradation across the NW Iberian shelf and shelf break in order to understand the dynamics of plankton production and associated organic matter transformation in relation to the hydrography of the region.
(2)Undertake surface pigment mapping for ground truthing remotely sensed ocean colour satellite data.

Pigment Chemotaxonomy: Many species of phytoplankton have strong chemotaxonomic associations, through which it is possible to obtain an understanding of the taxonomic composition of the overall phytoplankton biomass.

PIGMENT	TAXONOMIC CLASS
Chlorophylls	
Chlorophyll a	Total biomass
Chlorophyll b	Chlorophytes/prasinophytes
Chlorophyll c1c2	Diatoms
Divinyl chlorophyll a	Prochlorophytes
Divinyl chlorophyll b	Prochlorophytes
Carotenoids	
Alloxanthin	Cryptophytes
Fucoxanthin	Diatoms
19'-Butanoyloxyfucoxanthin	Chrysophytes/pelagophytes
19'-Hexanoyloxyfucoxanthin	Prymnesiophytes
Peridinin	Dinoflagellates
Zeaxanthin	Cyanobacteria/Prochlorophytes

There is increasing evidence that each species of phytoplankton interacts in a unique way with the biotic and abiotic environment and in doing so exerts a unique impact on ocean chemistry and biogeochemical cycling.

Table 8 Stations sampled for pigment analyses

Date	Time	CTD Station	Depths
2 August	16:00	1	5,30,50
		4	21,41,60,84,104,133
3 August	3:28	9	5,10,15,20,25,30,40
	14:50	11	5,15,25,50,75,150
4 August	2:44	13	non-toxic surface water, 10,20,30,40,60,80,150
		15	5,20,30,40,60,100,130,150,200
5 August	3:40	19	5,10,20,30,40,50,70,150
		21	5,10,30,45,80,100,150,200
6 August	3:43	24	5,10,15,20,30,50,70,150
		26	5,10,20,30,80,150,200
7 August	2:42	30	5,10,15,20,30,40,80,150
	12:41	32	5,10,15,30,50,80,150,200
8 August	9:00		non-toxic
		35	5,10,20,40,60,78,150,167
9 August	2:00	37	5,10,15,20,25,30,40,150
	7:05	38	5,10,20,30,40,50,150
	12:20	39	5,10,25,30,40,100
	18:42	40	5,25,40,100
10 August	1:13	41	5,15,30,100
14 August	3:30	57	5,10,15,20,25,30,40,50,100
	13:00	58	10,25,40,50,100,150
15 August	2:44	60	5,10,15,25,30,40,100
	14:00	61	10,30,40,50,100,150
16 August	3:15	63	5,10,20,30,45,50,60,100
	14:00	64	10,20,30,45,100,150
17 August	3:00	66	5,10,20,30,45,60,75,100
	14:00	67	10,30,40,55,100,150
18 August	2:45	69	10,20,30,40,50,60,70,100
		70	10,30,40,55,100,150
19 August	4:00	72	10,20,30,45,50,60,70,100
		73	10,40,50,100,150,200
20 August	8:45	79	5,10,15,25,50,100
	16:30	81	10,30,50,100
	18:34	83	10,20,45,50,100

9. Bacterial Activity: Legs 1 and 2

Ana Barbosa and Pedro Mendes
Universidade do Algarve, Portugal

Introduction: Short-term variability of selected physical, chemical, and biological processes was evaluated during an event of upwelling in the Galician coast through the use of a Lagrangian sampling strategy. this context, the particular objectives of UALG were to study the short term variability in:

(i) bacterial abundance and biomass
(ii) bacterial production
(iii) bacterial respiration.

Methods: Bacterial abundance, mean cell size, FDC (frequency of dividing cells), and biomass were determined after filtration of fixed water samples through 0.2µm polycarbonate filters and staining with acridine orange. Samples were filtered within 8 h of sample collection and will be analysed under epifluorescence microscopy at UALG.

Bacterial production was evaluated with the addition of saturating concentrations of ^{14}C-leucine followed by incubation in a water bath at 15±1°C. The effect of incubation time (2-4 h) was tested at several stations. Further analysis will be undertaken in IIM and UALG. Incorporation of leucine will be converted to biomass production with the use of an empirically derived conversion factor (Prof. Stockhom Cruise, WP 2).

Bacterial respiration was based on the recovery of $^{14}CO_2$ produced after additions of ^{14}C-leucine. Additional analysis of blanks was performed due to the potential "contamination" of $^{14}CO_2$ derived from primary production estimates which were undertaken in the same fume-hood.

Table 9: Samples and variables analysed

(Variables measured: 1 bacterial abundance, 2 bacterial mean cell volume, 3 bacterial biomass, 4 Frequency of Dividing Cells (FDC), 5 bacterial production, 6 bacterial respiration)

Date	Cast #	Depth levels	Variables
03 August 98	9	10, 15, 20, 30, 50, 100 m	1, 2, 3, 4, 5
03 August 98	10	5, 15, 25, 40, 60, 120 m	1, 2, 3, 4, 5
03 August 98	11	5, 15, 25, 50, 75, 150 m	1, 2, 3, 4, 5
04 August 98	13	5, 15, 25, 45, 80, 150 m	1, 2, 3, 4, 5
04 August 98	14	5, 15, 25, 40, 60, 130 m	1, 2, 3, 4, 5
04 August 98	15	5, 20, 30, 40, 60, 130 m	1, 2, 3, 4, 5
05 August 98	19	5, 20, 30, 40, 70, 150 m	1, 2, 3, 4, 5
05 August 98	20	5, 15, 30, 40, 80, 150 m	1, 2, 3, 4, 5
05 August 98	21	5, 10, 30, 45, 80, 150 m	1, 2, 3, 4, 5
06 August 98	24	5, 15, 30, 40, 70, 145 m	1, 2, 3, 4, 5
06 August 98	25	5, 15, 30, 45, 80, 147 m	1, 2, 3, 4, 5
06 August 98	26	5, 20, 40, 60, 80, 150 m	1, 2, 3, 4, 5
07 August 98	30	5, 15, 30, 40, 80, 150 m	1, 2, 3, 4, 5
07 August 98	31	5, 20, 40, 60, 80, 150 m	1, 2, 3, 4, 5
07 August 98	32	5, 15, 30, 50, 80, 150 m	1, 2, 3, 4, 5
09 August 98	37	5, 15, 40 m	1, 2, 3, 4, 5, 6
09 August 98	38	5, 30, 50 m	1, 2, 3, 4, 5, 6
09 August 98	39	5, 25, 40 m	1, 2, 3, 4, 5, 6
09 August 98	40	5, 25, 40 m	1, 2, 3, 4, 5, 6
10 August 98	41	5, 15, 30 m	1, 2, 3, 4, 5, 6

10. Microzooplankton Herbivory and Community Structure

Elaine Fileman (nee Edwards)
CCMS Plymouth Marine Laboratory, UK

Objectives: a) To quantify the distribution and standing stocks of microzooplankton (20-200 μm) and heterotrophic nanoplankton (2-20 μm) within surface waters associated with Lagrangian drift experiments.
b) To quantify the trophic impact of microzooplankton grazing on phytoplankton using shipboard experiments.

Methods
Microzooplankton biomass studies: Water samples were collected from 8 depths within the top 200m of the water column from dawn CTD casts. Samples were treated as follows:-
a) 500mls water sample was fixed in 1% acid Lugols solution. These samples will be analysed at PML using inverted microscopy and image analysis for the determination of total microzooplankton abundance, biomass and species composition.
b) 30-50mls water sample was fixed in 0.5% glutaraldehyde, dual-stained with DAPI and proflavine (final concentration 5 $\mu g\ ml^{-1}$) and filtered onto 0.8μm black polycarbonate filters. The filters were mounted onto slides and frozen. Heterotrophic nanoplankton abundance and biomass will be determined from these samples by inverted fluorescence microscopy.

Herbivory: A total of 12 microzooplankton grazing experiments were carried out using the dilution technique described by Landry & Hassett in 1982 (*Mar Biol* 67: 283-288). Six experiments were carried out during each Lagrangian experiment. Experimental water was collected pre-dawn from a depth of 10m using a 30 litre Go-flo bottle. Half of this water was gravity filtered through a 0.2 μm Gelman Suporcap filter which had been pre-soaked in Milli-Q water overnight. The remaining water was pre-screened using a 200 μm mesh bag to exclude larger predators. A series of dilutions were made up by gently combining the screened water with the filtered water in 1 or 2 litre polycarbonate bottles. To determine the potential effects of nutrient limitation three additional bottles of undiluted seawater sample were enriched with a nutrient mixture of 0.5μM NH_4, 0.03μM PO_4, 1.0nM $FeSO_4$ and 0.1nM $MnSO_4$. All incubations were carried out over a 24 hour period in an ambient temperature-cooled deck incubator screened to the 33% light level. Sub-samples were taken at T_0 and T_{24} for the determination of (i) chlorophyll concentration (ii) microzooplankton and HNAN biomass and community structure and (iii) nutrient concentration. All chlorophyll samples were extracted with 90% acetone and analysed on board by fluorometry. Nutrient samples were analysed by Denise Cummings on Leg I and Malcolm Woodward on Leg II. Community structure samples will be analysed at PML as described above.
During Leg II, experiments were also carried out by Sonia Batten to determine the proportion of microzooplankton consumed by the mesozooplankton (see cruise report). These experiments were set-up in parallel to the microzooplankton dilution experiments

Apsteins: A series of Apstein net hauls were carried out to a depth of 50-75m. The Apstein was fitted with a 20 μm mesh net . This allows the qualitative assessment of the larger rarer and less delicate of the microzooplankton such as the tintinnids, large heterotrophic dinoflagellates, sarcodines and metazoa, together with the larger phytoplankton cells. A number of photomicrographs were taken and a video recording made of both phytoplankton and microzooplankton cells present in the samples.
During Leg I, the phytoplankton community was dominated by pennate diatoms many of which were typical of upwelling waters. Examples of the species found include *Asterionella* sp. *Thalassionema* sp. *Navicula* spp. *Nitzschia* spp. *Pleurogramma* sp. *Chaetoceros* spp.

Rhizosolenia stolterfothii, *R.delicatula*, *Eucampia* sp.and *Guinardia*. Dinoflagellates such as *Ceratium horridum* and *C.tripos* were also present. Of the microzooplankton several species of tintinnid were present, (*Dictyocysta*, *Eutintinnus*, *Salpingella*, *Tintinnopsis* sp?) and heterotrophic *Protoperidinium* spp. and *Gyrodinium* spp. were abundant. During Leg II, much less material was collected with the net. Microscopic observation showed the community to be dominated by flagellates mostly small but with a number of species of *Ceratium*, e.g. *C. lineatum*, *C.furca*, *C.azoricum*, *C.bucephalum*, *C.tripos*, and *C.fusus*. Diatoms were present but in very low numbers.

Results

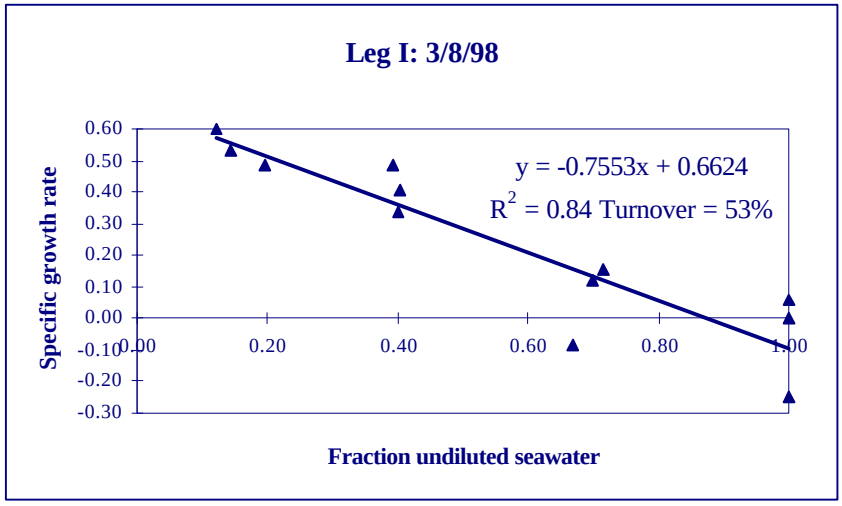

Figure 5: Examples of results obtained from microzooplankton grazing experiments carried out during Leg I and II of cruise CD114, August 1998. Turnover = amount of chlorophyll turned over by the microzooplankton day^{-1}; Slope (m) = phytoplankton mortality due to microzooplankton grazing; Y axis intercept = phytoplankton growth.

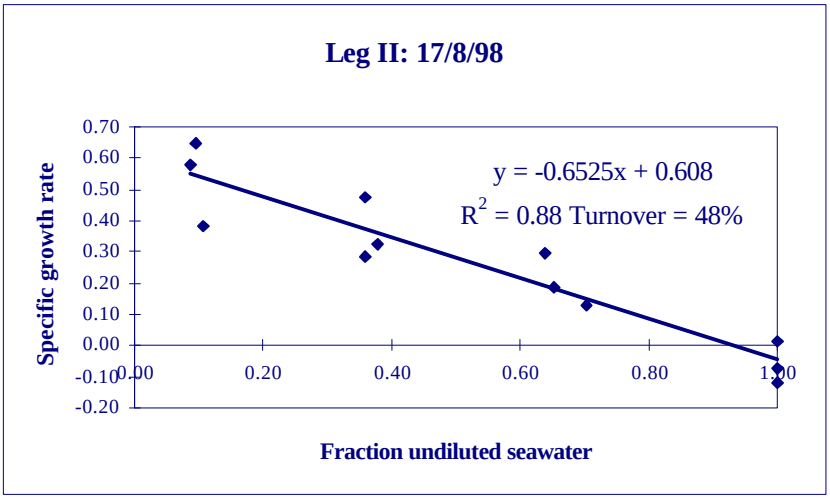

Table 10: Microzooplankton Sample Log

Date	CTD Station	Samples taken	Depths sampled (m)
3 August	09	Lugols	5, 10, 20, 30, 40, 50, 60, 100
		Glutaraldehyde	5, 10, 20, 30, 40, 50
4 August	13	Lugols	5, 10, 20, 30, 40, 60, 80, 150
		Glutaraldehyde	5, 10, 20, 30, 40, 60, 80
5 August	19	Lugols	5, 10, 20 30, 40, 50, 70, 150
		Glutaraldehyde	5, 10, 20, 30, 40, 50, 70
6 August	24	Lugols	5, 10, 20, 30, 40, 50, 70, 150
		Glutaraldehyde	5, 10, 20, 30, 40, 50, 70
7 August	30	Lugols	5, 10, 20, 30, 40, 50, 70, 150
		Glutaraldehyde	5, 10, 20, 30, 40, 50, 70
9 August	37	Lugols	5, 10, 20, 30, 40, 50, 80, 150
		Glutaraldehyde	5, 10, 20, 30, 40, 50, 80
14 August	57	Lugols	5, 10, 20, 30, 40, 50, 100
		Glutaraldehyde	5, 10, 20, 30, 40, 50
15 August	60	Lugols	5, 10, 20, 30, 40, 50, 100
		Glutaraldehyde	5, 10, 20, 30, 40, 50
16 August	63	Lugols	5, 10, 20, 30, 40, 50, 75, 100
		Glutaraldehyde	5, 10, 20, 30, 40, 50
17 August	66	Lugols	5, 10, 20, 30, 45, 60, 75, 100
		Glutaraldehyde	5, 10, 20, 30, 45, 60, 75
18 August	69	Lugols	5, 10, 20, 30, 40, 55, 75, 100
		Glutaraldehyde	5, 10, 20, 30, 40, 55, 75
19 August	72	Lugols	5, 10, 20, 30, 40, 50, 70, 100
		Glutaraldehyde	5, 10, 20, 30, 40, 50, 70
19 August	73	Lugols	10, 40, 50, 100
		Glutaraldehyde	10, 40, 50

11. Mesozooplankton (Leg 1)

Elisabeth Halvorsen
Norwegian College of Fishery Science
University of Tromsø, Norway

Objectives: The main objective of the mesozooplankton activity during Leg 1 was to study the diurnal variability in vertical distribution, taxonomic composition, abundance and biomass on the shelf. Sampling was carried out close to the drifting rig, approximately every six hours (early morning, midday, early evening and midnight). Following the same water mass, two diurnal cycles were covered. In addition, a functional response experiment was carried out on two occasions, as well as two gut evacuation experiments. This was intended as a background for the herbivorous grazing studies which will be the main objectives on leg 2. In the functional response experiment, the grazing rate of the mesozooplankton in response to different concentrations of phytoplankton was studied, whereas the gut evacuation time is needed to be able calculate the grazing rate from instant chlorophyll gut content

(Ingestion rate = gut pigment * evacuation rate).

Methods: The sampling for taxonomic composition, abundance and biomass was intended to be collected with a MOCNESS, which would have provided oblique hauls from discrete depth intervals, but due to an incompatibility between the cable and the deck unit of the MOCNESS, this was not possible. Instead, a WP-2 net was used, giving vertical depth integrated samples. The depth intervals sampled were: bottom-surface, 100 m -surface and 50 m -surface.
The samples from each haul were fractionated through a sieving system, giving fractions of 2000-1000 um, 1000-500 um and 500-200 um, and preserved in 4% formaldehyde.

Mesozooplankton for the functional response and gut evacuation experiments were collected with a WP-2 net with a 20 l cod end (towed vertically at a speed of 10 m/min).

Functional response: Water was taken with the CTD from chlorophyll max (30 m). Three 10 l carboys were filled with water directly from the CTD, three carboys were filled with a higher concentration of chlorophyll (reverse filtration of CTD water through 20 um net), and three carboys were filled with a diluted concentration (half CTD water and half filtered seawater). 250 ml water was taken from each carboy and filtrated for chlorophyll analysis. Animals were added, and incubated on deck (carboys submerged in running sea-surface tempered seawater) for 4-5 hours. The experiment was terminated by anaesthetising the animals with soda water (1:5 v/v), filtering them onto GF/C filters and frozen (-20 ^{o}C). Analysis for gut chlorophyll content will be carried out later.

Gut evacuation: Once collected, the animals were carefully size fractionated into three fractions and rinsed in filtered seawater. One fraction was transferred to each of 3 10l carboys filled with filtered seawater. A 500 ml fraction from each was drained from the carboys at the beginning of the experiment, to give time 0. Then 500 ml was drained from each after 5, 15, 20,30,45,60 and 120 minutes. the animals were filtered onto GF/C filters and frozen.

Table 11. Mesozooplankton activity 3-10 August 1998.

Date	**GMT**	**Station**	**Latitude (N)**	**Longitude (W)**	**Activity**
3 August	11:30	A	42° 32’ 14	09° 22’ 18	WP-2 Abundance/Biomass
	13:50	11	42° 37’	09° 23’ 56	CTD
	18:00	B	42 26’ 50	09° 21’ 36	WP-2 Abundance/Biomass
4 August	23:20	C	42° 24’ 03	09° 22’ 54	WP-2 Abundance/Biomass
		12			CTD
	06:00	D	42° 20’ 39	09° 19’ 17	WP-2 Abundance/Biomass
		13			CTD
	12:20	E	42° 19’ 06	09° 20’ 23	WP-2 Abundance/Biomass
		15			CTD
	17:40	F	42° 16’ 09	09° 21’ 28	WP-2 Abundance/Biomass
		16			CTD
5 August	00:30	G	42° 15’ 04	09° 24’ 27	WP-2 Abundance/Biomass
		18			CTD
	06:00	H	42° 12’ 38	09° 24’ 01	WP-2 Abundance/Biomass
		19			CTD
	12:00	I	42° 11’ 17	09° 23’ 36	WP-2 Abundance/Biomass
		21			CTD
	17:40	J	42° 10’ 08	09° 24’ 10	WP-2 Abundance/Biomass
		22			CTD
6 August	17:00	28			CTD Water 30m
	19:00	K			WP-2 Functional response
7 August	17:00	33			CTD Water 30m
	18:00	L			WP-2 Functional response
9 August	11:15	M	41° 54’ 19	09° 17’ 46	WP-2 Gut evacuation
10 August	23:30	N	41° 52’ 35	09° 16’ 58	WP-2 Gut evacuation

12. Mesozooplankton (Leg 2)

Elisabeth Halvorsen
Norwegian College of Fishery Science
University of Tromsø, Norway

Andrew Hirst
Southampton Oceanography Centre
Southampton, UK

Objectives: The aims of the present investigation were to examine spatio-temporal changes in total herbivorous grazing in size fractions of the mesozooplankton, together with changes in the size fractionated abundance, biomass, and taxonomic composition, whilst following a water mass 'drogue' (primary production and sediment trap rig) in an offshore filament off the west Atlantic coast of Spain. In addition time allowed an egg production experiment to be undertaken on the 20-08-98. The times, locations and sampling details are all given in Table 12, and methods are described briefly below.

Methods

1. Grazing: The method used to examine grazing was adapted from that described by Morales *et al*. (1991). Live copepods were collected over the top 200m of the water column using a 20litre cod-end net towed vertically at 10m.min^{-1}. Upon retrieval animals were anaesthetised by diluting the cod end to give a 1:5 (v/v) soda/seawater solution. Animals were gently size fractionated using a wet sieve method into the fractions >2000um, 1000-2000um, 500-1000um, and 200-500um. The >2mm fraction was discarded whilst the other fractions were filtered onto GF/C filters, placed in Petri dishes and frozen (-20^{o}C) in the dark. Animals from each of the size fractions will later be analysed for chlorophyll a and phaeo-pigment gut contents upon return to the laboratory. We attempted to collect these 'gut content' samples at approximately 6 hour intervals, close to the drogue marker, allowing a description of the diel variation associated with day-night changes in grazing and vertical location.

In addition to gut content analysis we completed 2 experiments on this leg to determine the evacuation rate, one experiment close to midday and one close to mid-night (thus allowing any diel variation in this parameter to be assessed). Samples were collected in the same manner except no anaesthetic was used. Each of the three size fractions were incubated separately in 10 litre carboys filled with GF/F filtered seawater. These were gently mixed and sub-samples taken at time zero, 5, 10, 15, 20, 30, 45, 60 and 120 minutes. During incubation the samples were kept in a constant temperature room at 18^{o}C. Sub-samples were filtered and frozen as before, and will be analysed using a fluorometric method upon return to the laboratory.

2. Abundance/taxonomic composition: Samples for abundance and taxa composition were taken at the same locations as the gut content samples. In this case a WP2 design net was deployed vertically to 200m and retrieved at a rate of 10m.min^{-1}. These samples were size fractionated by washing rather than wet sieving, and preserved in 4% formaldehyde-seawater.

3. Egg production: A single egg production experiment was completed on the 20th August 1998. Live animals were collected using a drifting net deployed to 10 metres (station location 42^{o} 37' 01.99''N 9^{o} 28' 33.42''W). Live adult females were separated from the catch and incubated for 24 hours (from 18.05GMT) at 13^{o}C in 64um screened seawater, this water having been collected using a 10 litre Niskin bottles from 10 metres depth.

Reference: Morales C.E., Bedo,A, Harris,R.P., Tranter,P.R.G. (1991) Grazing of copepod assemblages in the north-east Atlantic: the importance of the small size fraction. *Journal of Plankton Research* 13: 455-472.

Table 12. Mesozooplankton activities 14-20 August 1998.

Date	GMT	Station	Latitude (N)	Longitude (W)	Activity
14 August	23:15	O	41° 56’ 31	09° 49’ 47	WP-2
14 August	23:50	O	41° 56’ 31	09° 49’ 47	WP-2 Gut content
14 August	06:00	P	41° 56’ 03	09° 50’ 36	WP-2
14 August	06:30	P	41° 56’ 03	09° 50’ 36	WP-2 Gut content
14 August	11:30	Q	41° 56’ 00	09° 50’ 46	WP-2
14 August	13:30	Q	41° 56’ 00	09° 50’ 46	WP-2 Gut content
14 August	17:20	R	41° 54’ 50	09° 50’ 46	WP-2
14 August	18:15	R	41° 54’ 50	09° 50’ 46	WP-2 Gut content
15 August	05:45	S	41° 53’ 47	09° 54’ 48	WP-2
15 August	06:50	S	41° 53’ 47	09° 54’ 48	WP-2 Gut content
15 August	12:30	T	41° 53’ 17	09° 56’ 15	WP-2
15 August	13:35	T	41° 53’ 17	09° 56’ 15	WP-2 Gut content
15 August	18:15	U	41° 53’ 25	09° 54’ 48	WP-2
15 August	19:05	U	41° 53’ 25	09° 54’ 48	WP-2 Gut content
16 August	23:50	V	41° 52’ 38	09° 58’ 10	WP-2
16 August	00:45	V	41° 52’ 38	09° 58’ 10	WP-2 Gut content
16 August	05:00	W	41° 51’ 49	09° 58’ 10	WP-2
16 August	06:05	W	41° 51’ 49	09° 58’ 10	WP-2 Gut content
16 August	11:10	X	41° 52’ 01	09° 59’ 17	WP-2
16 August	12:55	X	41° 52’ 01	09° 59’ 17	WP-2 Gut content
16 August	21:00	Y	41° 52’ 39	09° 58’ 50	WP-2
16 August	22:00	Y	41° 52’ 39	09° 58’ 50	WP-2 Gut content
17 August	23:45	Z	41° 53’ 22	09° 59’ 14	WP-2
17 August	00:35	Z	41° 53’ 22	09° 59’ 14	WP-2 Gut content
17 August	05:15	AB	41° 51’ 58	10° 00’ 58	WP-2
17 August	06:10	AB	41° 51’ 58	10° 00’ 58	WP-2 Gut content
17 August	12:25	AC	41° 50’ 41	10° 03’ 34	WP-2
17 August	13:30	AC	41° 50’ 41	10° 03’ 34	WP-2 Gut content
17 August	18:10	AD	41° 49’ 10	10° 04’ 10	WP-2
17 August	19:15	AD	41° 49’ 10	10° 04’ 10	WP-2 Gut content
18 August	23:10	AE	41° 48’ 09	10° 06’ 09	WP-2
18 August	00:05	AE	41° 48’ 09	10° 06’ 09	WP-2 Gut evacuation
18 August	11:15	AF	41° 46’ 48	10 °07’ 18	WP-2
18 August	12:15	AF	41° 46’ 48	10° 07’ 18	WP-2 Gut evacuation
20 August	16:00	AG	42° 37’ 05	09° 28’ 38	Drifting net Egg
20 August		81			CTD Water 10m

13. Mesozooplankton grazing

Sonia Batten
Sir Alister Hardy Foundation for Ocean Science

Introduction: The consumption of protozoa by mesozooplankton is a potentially important process that is not often determined. It is a mechanism by which small algal and bacterial cells incorporated into protozoa may become available to larger organisms such as calanoid copepods and may be, therefore, a vital trophic link. The proportion of a copepods' diet composed of microplankton in a natural prey assemblage has been shown to vary, and may depend on the density of phytoplankton. For the first time within OMEX this cruise allowed the determination of mesozooplankton grazing of microplankton at the same time, and under the same conditions, as mesozooplankton grazing of phytoplankton, faecal production rates, microzooplankton grazing and primary production experiments were carried out. Most of the steps in the production and transformation of organic carbon were, therefore, simultaneously determined.

Objectives: It was hoped that the leg would begin in chlorophyll rich coastal waters which would become subsequently depleted as the ship drifted in the off shore filament allowing the determination of mesozooplankton grazing of microplankton in changing chlorophyll concentrations. Experiments were to be run on successive days for the duration of the biology component of the leg. A secondary objective was to deploy and tow an instrumented Continuous Plankton Recorder to obtain both plankton samples and salinity, temperature and chlorophyll (fluorescence) measurements. The latter were to be compared with the ships underway sampling data so that the data collected on monthly CPR tows could be verified.

Methodology: The methods employed were a modified version of Gifford (1993). Copepods were collected each morning around dawn from 10m depth using a WP2 net with a solid cod end that was allowed to drift horizontally for 10 minutes. The catch was anaesthetised with carbonated sea water and undamaged copepods were sorted and transferred to 2L acclimating jars. All manipulations were carried out in the constant temperature laboratory. Water from the non-toxic supply was used as a food source. The jars were placed in an on-deck incubator, with screening to simulate 10m light levels, and manually rotated every 2-4 hours for approximately 20-22 hours.

Water for the grazing experiments was collected from 10m depth, pre-dawn, using a 30L Go-Flo. The water was gently siphoned into 1L grazing jars through a 200μm mesh to remove any mesozooplankton. The water was left to stabilise for one hour and then the copepods were transferred from the acclimating jars. Stocking densities were chosen based on literature values of clearance rates for similar species at similar temperatures and were approximately 5/l for *Calanus helgolandicus* and approximately 25/l for *Acartia* sp. For each experiment three control bottles were set up and three (sometimes two or one) replicates of each copepod species/size fraction. Numerically dominant species were chosen with the aim of including a range of size fractions. The bottles were placed in the on deck incubator for approximately 24 hours and again manually rotated every 2-4 hours. A further bottle was filled from the Go-Flo and used for the T_0 samples. Aliquots were filtered for chlorophyll determination, preserved in Lugols for cell counts and Glutaraldehyde for epifluorescence determinations. Similar aliquots were taken from each experimental and control bottle at the end of each experiment (T_{24}). The copepods were removed and preserved in 4% buffered formaldehyde for species verification, size and weight determination in the laboratory.

Chlorophyll levels were determined on board using the fluorometric JGOFS protocol. Cell counts will be determined in the laboratory and grazing rates calculated. Allometric relationships will be used to estimate community grazing rates.

The remainder of each net sample, together with an additional WP2 night haul, was preserved in 4% formaldehyde for length/weight measurements to be made in the laboratory.

Achievements: The leg began in offshore, chlorophyll poor waters, however the final experiment used water obtained from in shore waters where the chlorophyll concentration was much higher (a factor of 10, see Table 13) so comparisons of grazing rates at different concentrations will be possible. Altogether 6 experiments were carried out, all chlorophyll levels have been determined and mortality of the experimental copepods was negligible and so although the cell counts still need to be done the experiments appear to have been successful.

Table 13. Experimental details

Experi-ment	Date	Time	Latitude	Longitude	Time zero Chlorophyll µg/l (mean of 3)	Grazing Bottles
1	15 August	2:30	41° 53.80	9° 54.83	0.355	3 x Control 2 x Calanus helgolandicus 3 x Acartia sp. 1 x Centropages spp.
2	16 August	2:45	41° 51.90	9° 59.36	0.327	3 x Control 2 x Acartia sp. 2 x Acartia sp. 2 x Parapseudocalanus spp. 2 x Centropages spp.
3	17/08/89	2:15	41° 52.31	10° 00.51	0.222	3 x Control 3 x Calanus helgolandicus 3 x Parapseudocalanus spp.
4	18 August	2:15	41° 48.03	10° 07.39	0.268	3 x Control 3 x Calanus helgolandicus 3 x Parapseudocalanus spp.
5	19 August	2:40	41° 45.05	10° 06.02	0.247	3 x Control 2 x Acartia sp. 1 x Centropages spp. 1 x Calanus helgolandicus 1 x Clausocalanus spp.
6	19 August	18:30	42° 40.44	9° 30.91	2.109	3 x Control 3 x Calanus helgolandicus 3 x Parapseudocalanus spp.

The instrumented CPR successfully collected temperature, salinity, depth and fluorescence data although it still has to be compared with the ships underway data. The plankton samples will be analysed as part of the routine CPR analysis.

Reference: Gifford, D.J. (1993). Consumption of protozoa by copepods feeding on natural microplankton assemblages. In: *Handbook of Methods in Aquatic Microbial Ecology*. 723-729. Lewis.

14. Sediment traps

Kalle Olli and Christian Wexels Riser
Norwegian College of Fishery Science
University of Tromsø, Norway

Leg 1, 3 – 11 August: Sediment traps were deployed at three depths (30m, 40m, 50m) on the following dates: August 3, 4, 5, 6, 7, 9 (*i.e.* 6 deployments from Leg1). The deployment time was approximately 24h, starting in the morning before sunrise

The parameters to be measured from the sediment traps samples at each depth are -
1) POC/N (3 replicates)
2) Chlorophyll a (3 replicates)
3) Particulate silicon (3 replicates)
4) Transparent Exopolymer Particles (TEP) (5 replicates)
5) Mesozooplankton faecal pellets and phytoplankton (fixed in Lugol)

The following water column measurements were done on the days when traps were in the water:
1) Suspended faecal pellets twice per day (close to noon and midnight) from depths 10m, 30m, 50m, 100m, 150m, 200m
2) TEP once per day from depths 5m, 10m, 20m, 30m, 40m, 50m.
(5 replicates per depth)

Leg2 11 – 21 August: Sediment traps were deployed at eight depths (40m, 50m, 60m, 75m, 90m, 120m, 150m, 200m) on 14, 15, 17, and 18 August (*i.e.* 4 deployments during Leg2). The deployment times and measured parameters were the same as on Leg1.

Water column measurements were done on every day from Aug 14 - 19
Measured parameters as during Leg1.
In addition:
1) Particulate silicon from depths 10m, 30m, 50m, 100m, 150m (once per day)
2) phytoplankton samples from 5 depths selected on base of CTD profile once or twice per day (samples for IIM)

Mesozooplankton faecal pellet production experiments (Christian) during 5 days from Aug. 14 - 18; twice per day (at midnight and at noon, i.e. a total of 10 experiments).

Appendix A - Postal and E-mail Addresses of Cruise Participants

Anna Barbosa
UCTRA, Universidade do Algarve,
Gambelas, 8000 Faro, Portugal
abarbosa@ualg.pt

Dr E. Des Barton
School of Ocean Sciences
University of Wales, Bangor,
Menai Bridge, Anglesey, LL59 5EY, UK
e.d.barton@sos.bangor.ac.uk

Dr Sonia Batten
Sir Alister Hardy Foundation for Ocean Sciences
The Hoe,
Plymouth, PL1 3BN, UK
soba@wpo.nerc.ac.uk

Alberto Borges
Unité d'Océanographie Chimique
Université de Liege, B – 4000 Sart Tilman
Belgium
alberto.borges@ulg.ac.be

Denise Cummings
CCMS Plymouth Marine Laboratory,
Prospect Place, The Hoe,
Plymouth, PL1 3DH, UK
d.cummings@pml.ac.uk

Dr Francisco Gómez Figueiras
Instituto de Investigacións Mariñas, CSIC,
Eduardo Cabello 6,
36208 Vigo, Spain.
paco@iim.csic.es)

Elaine Fileman
CCMS Plymouth Marine Laboratory,
Prospect Place, The Hoe,
Plymouth, PL1 3DH, UK
ese@pml.ac.uk

Elizabeth Halvorsen
Norwegian College of Fishery Science
University of Tromsø
9037 Tromsø, Norway
elisabeth@nfh.uit.no

Dr Andrew Hirst
George Deacon Division for Ocean Processes
Southampton Oceanography Centre, Empress Dock
Southampton, SO14 3ZH, UK
andrew.hirst@soc.soton.ac.uk

John Humphrey
CCMS Proudman Oceanographic Laboratory,
Bidston Observatory, Birkenhead, Merseyside,
L43 7RA, UK
jdh@pol.ac.uk

Dr Mark Inall
School of Ocean Sciences
University of Wales, Bangor,
Menai Bridge, Anglesey, LL59 5EY, UK
m.inall@uces.bangor.ac.uk

Dr Ian Joint
CCMS Plymouth Marine Laboratory,
Prospect Place, The Hoe,
Plymouth, PL1 3DH, UK
i.joint@PML.ac.uk

Pedro Mendes
UCTRA, Universidade do Algarve,
Gambelas, 8000 Faro, Portugal
hgalvao@ualg.pt

Dr Kalle Olli
Institute of Botany and Ecology
University of Tartu, Estonia
olli@ut.ee

Andrew Rees
CCMS Plymouth Marine Laboratory,
Prospect Place, The Hoe,
Plymouth, PL1 3DH, UK
apre@pml.ac.uk

Christian Riser
Norwegian College of Fishery Science
University of Tromsø
9037 Tromsø, Norway
chrisr@stud.nfh.uit.no

Dr Xosé Antón Álvarez-Salgado
Instituto de Investigacións Mariñas, CSIC,
Eduardo Cabello 6,
36208 Vigo, Spain.
xsalgado@iim.csic.es

Dr Gavin H. Tilstone
Instituto de Investigacións Mariñas, CSIC,
Eduardo Cabello 6,
36208 Vigo, Spain.
gtilston@iim.csic.es

Ricardo Torres
School of Ocean Sciences
University of Wales, Bangor,
Menai Bridge, Anglesey, LL59 5EY, UK
r.torres@sos.bangor.ac.uk

Ray Wilton
School of Ocean Sciences
University of Wales, Bangor,
Menai Bridge, Anglesey, LL59 5EY, UK
r.j.wilton@sos.bangor.ac.uk

Malcolm Woodward
CCMS Plymouth Marine Laboratory,
Prospect Place, The Hoe,
Plymouth, PL1 3DH, UK
emsw@pml.ac.uk

Remote Sensing Group at PML

Steve Groom
CCMS Plymouth Marine Laboratory,
Prospect Place, The Hoe,
Plymouth, PL1 3DH, UK
sbg@pml.ac.uk

Peter Miller
CCMS Plymouth Marine Laboratory,
Prospect Place, The Hoe,
Plymouth, PL1 3DH, UK
p.miller@pml.ac.uk

Tim Smyth
CCMS Plymouth Marine Laboratory,
Prospect Place, The Hoe,
Plymouth, PL1 3DH, UK
t.j.smyth@pml.ac.uk

Appendix B: BRIDGE LOG OF POSITIONS, TIMES AND DEPTHS OF CTD PROFILES - Leg 1 (1- 11 August 1998)

CTD Number	Date (JD)	Time (GMT)	Latitude (°N)	Longitude (°W)	Depth (m)
1	2 August (214)	15:40	42°37.16’	09°06.44’	50
2	2 August (214)	16:02	42°37.05’	09°06.49’	50
3	2 August (214)	16:58	42°36.94’	09°13.78’	80
4	2 August (214)	18:03	42°36.87’	09°23.90’	130
5	2 August (214)	19:17	42°37’	09°26.8’	230
6	2 August (214)	20:06	42°36.7’	09°28.4’	320
7	2 August (214)	21:30	42°36.3’	09°30.9’	550
8	2 August (214)	22:26	42°36.37’	09°32.5’	900
9	3 August (215)	03:29	42°36.95’	09°23.89’	130
10	3 August (215)	09:37	42°34.4’	09°21.8’	130
11	3 August (215)	13.47	42°31.04’	09°22.92’	210
12	4 August (216)	00:27	42°24.09’	09°23.00’	330
13	4 August (216)	02:45	42°22.71’	09°20.41’	150
14	4 August (216)	08:29	42°19.7’	09°19.5’	150
15	4 August (216)	14:16	42°18.3’	09°20.82’	210
16	4 August (216)	16:35	42°18.01’	09°17.95’	210
17	4 August (216)	23:59	42°14.94’	09°24.2’	250
18	5 August (217)	01:27	42°15.00’	09°25.04’	250
19	5 August (217)	02:42	42°13.67’	09°24.37’	150
20	5 August (217)	09:35	42°12.2’	09°23.5’	150
21	5 August (217)	13:58	42°11.26’	09°23.78’	200
22	5 August (217)	18:44	42°09.74’	09°24.23’	260
23	6 August (218)	01:12	42°08.72’	09°24.24’	270
24	6 August (218)	02:40	42°08.08’	09°24.66’	150
25	6 August (218)	08:36	42°07.5’	09°25.9’	150
26	6 August (218)	14:44	42°06.95’	09°25.11’	400
27	6 August (218)	17:12	42°05.84’	09°25.89’	900
28	6 August (218)	17:57	42°05.37’	09°26.37’	50
29	6 August (218)	23:21	42°05.30’	09°26.43’	250
30	7 August (219)	02:45	42°05.20’	09°25.88’	200
31	7 August (219)	08:20	42°03.8’	09°26.7’	150
32	7 August (219)	12:46	42°04.13’	09°26.51’	200
33	7 August (219)	17:13	42°03.82’	09°26.46’	50
34	8 August (220)	02:05	42°03.63’	09°25.16’	200
35	8 August (220)	14:08	41°55.20’	09°20.46’	170
36	8 August (220)	23:18	41°54.17’	09°18.25’	150
37	9 August (221)	02:05	41°55.07’	09°18.49’	150
38	9 August (221)	07:07	41°54.7’	09°19.6’	150
39	9 August (221)	12:22	41°53.57’	09°17.77’	150
40	9 August (221)	18:44	41°54.35’	09°17.36’	130
41	10 August (222)	01:15	41°52.29’	09°16.43’	130
42	10 August (222)	04:37	41°54.37’	09°19.15’	150
43	10 August (222)	12:57	41°54.99’	09°23.47’	1000
44	10 August (222)	14:55	41°55.16’	09°22.67’	100
45	10 August (222)	15:49	41°55.33’	09°21.58’	380
46	10 August (222)	16:31	41°55.24’	09°20.46’	170
47	10 August (222)	17:10	41°55.12’	09°17.80’	130
48	10 August (222)	17:54	41°55.08’	09°13.40’	120
49	10 August (222)	18:47	41°55.97’	09°09.02’	115

Appendix C: BRIDGE LOG OF POSITIONS, TIMES AND DEPTHS OF CTD PROFILES - Leg 2 (11- 21 August 1998)

CTD Number	Date (JD)	Time (GMT)	Latitude (°N)	Longitude (°W)	Depth (m)
50	11 August (223)	13:12	41°29.95’	09°40.01’	500
51	11 August (223)	14:26	41°34.99’	09°39.95’	500
52	11 August (223)	15:42	41°40.08’	09°40.14’	500
53	11 August (223)	16:53	41°45.04’	09°40.14’	500
54	11 August (223)	18:25	41°52.50’	09°40.23’	500
55	11 August (223)	20:13	42°00’	09°40’	500
56	13 August (225)	16:29	41°56.29’	09°50.44’	500
57	14 August (226)	02:26	41°56.63’	09°50.03’	100
58	14 August (226)	13:52	41°55.80’	09°51.02’	500
59	15 August (227)	01:26	41°54.06’	09°53.45’	200
60	15 August (227)	02:44	41°54.13’	09°54.16’	100
61	15 August (227)	13:48	41°53.12’	09°56.17’	500
62	16 August (228)	01:35	41°52.26’	09°58.33’	200
63	16 August (228)	02:58	41°51.99’	09°58.84’	150
64	16 August (228)	13:41	41°51.98’	09°58.75’	500
65	17 August (229)	01:38	41°52.50’	09°59.89’	200
66	17 August (229)	02:45	41°52.14’	10°00.66’	100
67	17 August (229)	13:45	41°50.09’	10°04.11’	500
68	18 August (230)	00:11	41°48.04’	10°06.20’	200
69	18 August (230)	02:36	41°47.97’	10°07.40’	150
70	18 August (230)	13:40	41°47.07’	10°07.15’	500
71	19 August (231)	02:59	41°45.60’	10°06.05’	200
72	19 August (231)	04:01	41°45.77’	10°06.07’	150
73	19 August (231)	18:23	42°40.8’	09°30.86’	210
74	19 August (231)	22:05	42°46.10’	09°50.7’	500
75	19 August (231)	23:33	42°43.87’	09°46.10’	500
76	20 August (232)	00:49	42°41.51’	09°41.66’	500
77	20 August (232)	02:03	42°39.05’	09°37.07’	500
78	20 August (232)	03:12	42°36.97’	09°33.15’	500
79	20 August (232)	08:11	42°36.7’	09°31.06’	500
80	20 August (232)	13:24	42°44.92’	09°48.75’	500
81	20 August (232)	16:10	42°36.99’	09°28.53’	270
82	20 August (232)	18:06	42°37.08’	09°24.13’	130
83	20 August (232)	18:34	42°37.02’	09°24.47’	130

Appendix D: BRIDGE LOG OF POSITIONS, TIMES AND DEPTHS OF NET DEPLOYMENTS - Leg 1 (1 – 11 August 1998)

Net Number	Date (JD)	Time (GMT)	Latitude (°N)	Longitude (°W)
1	3 August (215)	1145	42°32.35’	09°22.28’
2	3 August (215)	1257	42°31.40’	09°22.46’
3	3 August (215)	1752	42°26.77’	09°21.65’
4	3 August (215)	1825	42°26.44’	09°21.74’
5	3 August (215)	1837	42°26.33’	09°21.80’
6	3 August (215)	1851	42°26.20’	09°21.86’
7	3 August (215)	2317	42°24.00’	09°22.86’
8	3 August (215)	2350	42°24.05’	09°22.96’
9	4 August (216)	0004	42°24.07’	09°22.99’
10	4 August (216)	0604	42°20.70’	09°19.20’
11	4 August (216)	0640	42°20.40’	09°19.00’
12	4 August (216)	0700	42°20.40’	09°19.30’
13	4 August (216)	1202	42°19.05’	09°20.31’
14	4 August (216)	1216	42°19.04’	09°20.35’
15	4 August (216)	1254	42°18.91’	09°20.42’
16	4 August (216)	1310	42°18.80’	09°20.47’
17	4 August (216)	1736	42°16.11’	09°21.40’
18	4 August (216)	1811	42°15.83’	09°21.85’
19	4 August (216)	1829	42°15.63’	09°22.18’
20	4 August (216)	1836	42°15.63’	09°22.23’
21	5 August (217)	0027	42°15.01’	09°24.36'
22	5 August (217)	0054	42°15.08’	09°24.65’
23	5 August (217)	0109	42°15.07’	09°24.83’
24	5 August (217)	0600	42°12.71’	09°24.06’
25	5 August (217)	0700	42°12.47’	09°23.85’
26	5 August (217)	1144	42°11.23’	09°23.58’
27	5 August (217)	1202	42°11.18’	09°23.50’
28	5 August (217)	1244	42°11.12’	09°23.61’
29	5 August (217)	1302	42°11.11’	09°23.66’
30	5 August (217)	1735	42°10.04’	09°24.13’
31	5 August (217)	1816	42°09.95’	09°24.22’
32	5 August (217)	1830	42°09.87’	09°24.24’
33	6 August (218)	1142	42°06.98’	09°26.08’
34	6 August (218)	1846	42°05.40’	09°26.90’
35	6 August (218)	1904	42°05.42’	09°27.18’
36	7 August (219)	1125	42°03.65’	09°26.89’
37	7 August (219)	1804	42°03.70’	09°26.22’
38	9 August (221)	1111	41°54.30’	09°17.72’
39	9 August (221)	2323	41°52.43’	09°16.95’

Appendix E: BRIDGE LOG OF POSITIONS, TIMES AND DEPTHS OF NET DEPLOYMENTS - Leg 2 (11 – 21 August 1998)

Net Number	Date (JD)	Time (GMT)	Latitude (°N)	Longitude (°W)
40	12 August (224)	1800	41°56.71’	09°51.11’
41	12 August (224)	2312	41°56.42’	09°49.74’
42	12 August (224)	2343	41°56.52’	09°49.90’
43	13 August (225)	0501	41°55.92’	09°50.34’
44	13 August (225)	0523	41°55.93’	09°50.45’
45	13 August (225)	0549	41°55.93’	09°50.61’
46	14 August (226)	1158	41°55.95’	09°50.78’
47	14 August (226)	1234	41°55.94’	09°50.74’
48	14 August (226)	1305	41°55.96’	09°50.86’
49	14 August (226)	1331	41°55.90’	09°50.94’
50	14 August (226)	1717	41°54.78’	09°52.19’
51	14 August (226)	1747	41°54.73’	09°52.25’
52	15 August (227)	0028	41°54.42’	09°53.36’
53	15 August (227)	0531	41°53.73’	09°54.79’
54	15 August (227)	0550	41°53.69’	09°54.75’
55	15 August (227)	0619	41°53.72’	09°54.76’
56	15 August (227)	1225	41°53.30’	09°56.08’
57	15 August (227)	1256	41°53.31’	09°56.18’
58	15 August (227)	1333	41°53.13’	09°56.22’
59	15 August (227)	1814	41°52.92’	09°57.94’
60	15 August (227)	1842	41°52.98’	09°57.85’
61	15 August (227)	2347	41°52.58’	09°58.13’
62	16 August (228)	0015	41°52.55’	09°58.09’
63	16 August (228)	0102	41°52.39’	09°58.25’
64	16 August (228)	0449	41°51.78’	09°59.49’
65	16 August (228)	0529	41°51.60’	09°59.59’
66	16 August (228)	0555	41°51.61’	09°59.55’
67	16 August (228)	1115	41°51.94’	09°59.19’
68	16 August (228)	1233	41°51.98’	09°59.06’
69	16 August (228)	1335	41°52.04’	09°58.87’
70	16 August (228)	2049	41°52.50’	09°58.70’
71	16 August (228)	2120	41°52.90’	09°58.90’
72	16 August (228)	2230	41°53.20’	09°59.00’
73	16 August (228)	2307	41°53.44’	09°59.11’
74	16 August (228)	2345	41°53.19’	09°59.31’
75	17 August (229)	0008	41°53.15’	09°59.29’
76	17 August (229)	0510	41°51.90’	10°00.92’
77	17 August (229)	0538	41°51.72’	10°00.96’
78	17 August (229)	0609	41°51.65’	10°01.07’
79	17 August (229)	1149	41°50.83’	10°03.36’
80	17 August (229)	1219	41°50.64’	10°03.54’
81	17 August (229)	1329	41°50.30’	10°03.93’
82	17 August (229)	1809	41°49.17’	10°04.80’
83	17 August (229)	1836	41°48.98’	10°04.10’
84	17 August (229)	2303	41°48.18’	10°06.09’
85	17 August (229)	2338	41°48.15’	10°06.10’
86	18 August (230)	0047	41°48.01’	10°06.60’
87	18 August (230)	0707	41°47.30’	10°06.66’
88	18 August (230)	1123	41°46.73’	10°07.28’
89	18 August (230)	1150	41°46.78’	10°07.31’
90	18 August (230)	1315	41°47.03’	10°07.18’
91	19 August (231)	0120	41°45.46’	10°06.34’
92	19 August (231)	0211	41°45.67’	09°06.26’