Institute of
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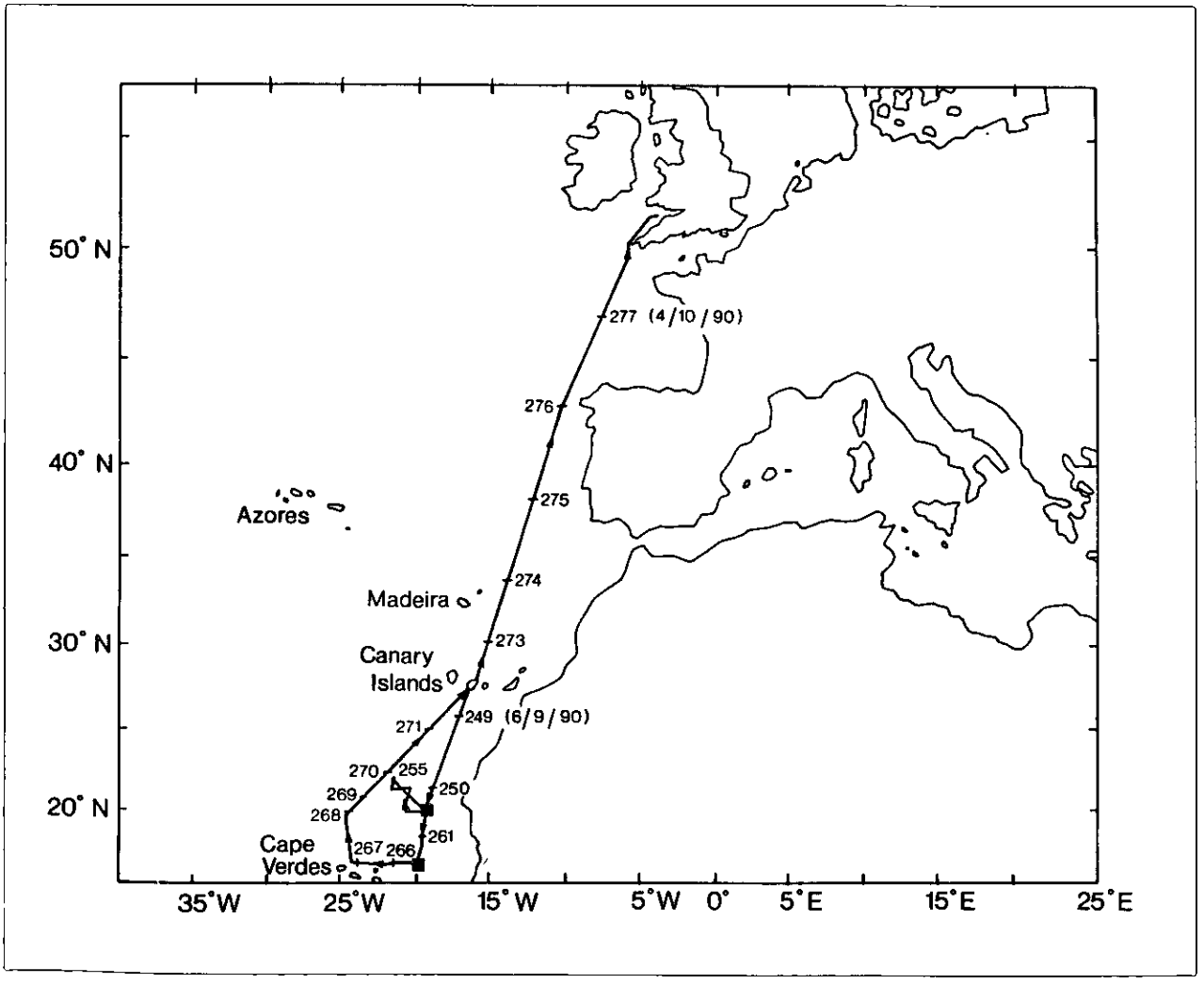
Deacon Laboratory

RRS Discovery Cruise 195

05 Sep - 05 Oct 1990

Photobiology, physiology and distribution of oceanic animals in the tropical North Atlantic

Cruise Report No 220 1990



Natural Environment Research Council

INSTITUTE OF OCEANOGRAPHIC SCIENCES

DEACON LABORATORY

Wormley, Godalming,
Surrey, GU8 5UB, U.K.

Telephone: 0428 79 4141
Telex: 858833 OCEANS G
Telefax: 0428 79 3066

Director: Dr. C.P. Summerhayes

Natural Environment Research Council

INSTITUTE OF OCEANOGRAPHIC SCIENCES

DEACON LABORATORY

CRUISE REPORT NO. 220

RRS DISCOVERY CRUISE 195
05 SEP-05 OCT 1990

Photobiology, physiology and distribution of oceanic animals in the tropical North Atlantic

Principal Scientist
P J Herring

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HERRING, P J et al

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ABSTRACT

Discovery cruise 195 combined midwater and benthic sampling programmes with experimental studies of the physiology of oceanic animals. The work area was primarily in the tropical NE Atlantic, adjacent to the upwelling region off NW Africa.

Five sampling programmes were undertaken: 1) rectangular midwater trawl (RMT) tows in midwater to study the vertical distribution of animals in the upper 1000m; 2) RMT tows close to the bottom (at ca. 4000m) to investigate the near-bottom pelagic fauna; 3) RMT tows in midwater (ca. 250m) to examine effects of lights on catches; 4) OTSB14 tows on the bottom to investigate the benthopelagic fish fauna and 5) 24hr neuston net samples to investigate diel changes in the surface fauna.

Physiological studies focussed on the photobiology of the crustaceans and fishes, in particular. Studies of eye structure and function, visual pigments, lens pigments, reflective tapeta and day/night changes were undertaken. Behavioural studies investigated the responses of free-swimming animals to particular optical stimuli including simulated prey targets. Bioluminescence work involved the genetic analysis of luminous bacterial symbionts in anglerfishes, behavioural studies with an image-intensified and infra-red mixed light imaging system, and the collection of material for subsequent molecular biochemistry.

Associated experimental studies involved flying fish morphometrics, locomotory and respiratory mechanisms in specific fish and crustaceans and examination of gelatinous zooplankton species.

KEYWORDS

AMPHIPOD BEHAVIOUR
ATLANTIC(NE)
ATTRACTING TECHNIQUES
BIOLUMINESCENCE
DEMERSAL FISHES
DISCOVERY/RRS - cruise(1990)(195)
FLYING FISH
LIGHTS ON NETS
LUMINOUS BACTERIA
MIDWATER TRAWLS
NEAR BOTTOM TRAWLS
NEUSTON
OTTER TRAWLS
PHOTOBIOLOGY
VISUAL PHYSIOLOGY

ISSUING ORGANISATION

Institute of Oceanographic Sciences
Deacon Laboratory
Wormley, Godalming
Surrey GU8 5UB. UK.

Director: Colin Summerhayes DSc

Telephone Wormley (0428) 684141
Telex 858833 OCEANS G.
Facsimile (0428) 683066

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SCIENTIFIC PERSONNEL

HERRING, Peter J.(Principal Scientist)	IOSDL
ANGEL, Martin V.	IOSDL
BOORMAN, Benjamin	IOSDL
DAVENPORT, John	UCNW, Bangor
DOUGLAS, Ronald, H.	City University
GATEN, Edward	Leicester University
GREEN, Philip R.S.	Imperial College, London
HAYGOOD, Margo H.	Scripps Inst. of Oceanography
LAND, Michael F.	Sussex University
MASON, Peter J.	RVS
MERRETT, Nigel R.	Natural History Museum
PARTRIDGE, Julian C.	Bristol University
PHIPPS, Richard A.	RVS
SHELTON, Peter M.J.	Leicester University
WEBB, Andrew J.	IOSDL
WHITE, David	IOSDL
WIDDER, Edith A.	Harbor Branch Oceanographic Inst.
WOODLEY, C. (Bernie) H.	RVS

SHIPS PERSONNEL

HARDING, M.A.	Master
CLARKE, J.L.	Chief Officer
OLDFIELD, P.T.	2nd Officer
BURRIDGE, P.A.	3rd Officer
KILBANE, P.	Radio Officer
MOSS, S.A.	Chief Engineer
ANDERSON, J.E.	2nd Engineer
DEAN, S.F.	3rd Engineer
SHAW, J.W.	3rd Engineer
DECKER, V.N.	Electrical Engineer
DRAYTON, M.	CPO
LEWIS, T.G.	PO
NEALE, P.E.	Seaman
BOWEN, A.M.	"
DAVIES, H.	"
LEWIS, E.F.J.	"
HEBSON, H.R.	"
VRETTOS, C.	"
HEALY, A.	Motorman
BAILEY, G.B.	"
PERRY, C.K.	Cook Steward
McAULIFFE, A.G.	Cook
ROUTLEDGE, A.A.	2nd Steward
ELLIOTT, C.J.	Steward
SMITH, S.J.	"
BALDWIN-WHITE, L.	"

ITINERARY

Depart Santa Cruz, Tenerife, 5 September

[Arrive & depart Santa Cruz, Tenerife, 29 September (boat transfer)]

Arrive Barry, South Wales, 5 October

OBJECTIVES

1. To identify the visual and bioluminescent adaptations and behaviour of meso- and bathypelagic animals.
2. To investigate the distribution and locomotory mechanisms of near-surface species.
3. To compare the distributions of (a) demersal fishes, and (b) near-bottom and upper water column zooplankton and nekton with previously sampled sites further north and east.

NARRATIVE

RRS *Discovery* sailed from Santa Cruz, Tenerife at 0900 5/9/90 bound for the station position at 20° 21'N 19°40'W previously worked on Cruise 168 in 1987. The main objectives of the cruise were to investigate the physiology of the oceanic fauna, in collaboration with the large number of university participants aboard. Particular emphasis was placed on aspects of photobiology, including bioluminescence and vision. This physiological focus complemented sampling programmes involving the distribution of demersal fishes, the effects of lights on nets, and the composition of the near-bottom fauna.

A short scientific meeting was held at 1030/5/9, to inform the participants of the overall scientific programme, and echo-sounding began at 1400 following deployment of the Precision Echo Sounder (PES) fish. A meeting for all scientific staff was later held by the captain, in order to outline the ship's arrangements and routines. Passage to the work station took until a.m. 7/9 when the sampling programme was started, slightly delayed by hydraulic power failure to the Schat davit.

At the first station (12176 #1) a rectangular midwater trawl combination net (RMT 1+8) was fished at 800-875 m. This corroborated previous impressions of richness in the area by producing a very large catch which included an octopod of unusually large size. This was followed by two more trawls later in the day and a fourth one (12176 #4) early in the morning of 8/9. The prevailing NE winds increased markedly during the latter tow and prevented further fishing activities during the morning. It was decided to head west to the 4000 m contour where it would be possible to fish an otter trawl even if conditions did not improve. However by 1610 conditions had improved sufficiently to deploy the RMT 1+8 *en route* (12177 #1). The otter trawl (OTSB14) was shot at 2027 that evening and recovered at 0930 9/9. The pinger trace was lost for a considerable time on the bottom, but a very good catch of large fish (including the grenadier *Nematonurus*

armatus), echinoderms, barnacles, decapods and sipunculids was achieved. The *Nematonurus* were later greatly enjoyed by the ships company as the main course of one of the evening meals.

An RMT followed the otter trawl but closed prematurely due to a monitor fault. After the monitor had been changed the closing codend (CCE) was employed for the first time very successfully (12177 #4) and three more RMTs using this device were fished during the night of 9/9. A trio of near-bottom multiple RMTs were then begun in a sounding of about 4080 m. The near-bottom echosounder trace failed to appear and the tows therefore became 4000 m repeats with fishing depths ranging from 3920 to 4120 m. The apparent discrepancy between the sounding and fishing limits is probably a function of the respective calibrations. As expected the catches were very small, with the largest elements (fish) probably resulting from leakage.

It was then decided to head NW to a sounding of 4500 m, to carry out another OTSB14 at this depth. Two RMT 1+8 CCE tows (12178 #1 & #2) were made on the way, early in the morning of 11/9, particularly aimed at capturing live dark-adapted crustaceans. The OTSB14 position was reached later in the morning and the gear deployed. A pinger problem necessitated its recovery at an early stage, but the problem was identified as a broken wire, soon repaired, and the gear relaunched. The haul was typical of a productive abyssal area, and was largely lacking in species restricted to tropical regions. It also included a large wooden fish crate, riddled with boring bivalves.

Passage was then made to 20°30'N 19°40'W to begin a series of tows with and without a light on the trawl. This was to complement a similar series of tows at 800m at the same position in 1987. The first set of three two-hour tows comprised station 12181 #1, #2 and #3, and this was repeated on the four succeeding nights. By the end of #3 the weather had deteriorated, with winds of 25-30 kts, and after a closing codend haul (#4) and a combination net without the codend (#5) the vessel hove to until the second set of light tows (#6,#7,#8) by which time the wind had moderated.

A pattern of closing codend hauls by day and the light tows by night continued until the final series of light tows (#22,#23,#24) overnight 16/17 September. A 24hr series of neuston net hauls of 1/2hr duration in every hour was run concurrently with the trawling programme from 1245/14/09 to 1315/15/09. A CTD dip to 250m with lightmeter (#20) was slightly delayed by burst hydraulic fittings. This, and temporary failures of crane and winch on separate occasions, were rapidly rectified by the technical support group. An attempt was made on 16/9 to test the Near-Bottom Echo Sounder (NBES) on the main warp, in 3600m depth, but no satisfactory bottom signal was achieved and the plan to carry out near-bottom tows at this station was abandoned.

The last set of light tows (#22,#23,#24) was marred by the failure of the "light on" haul when the battery lead pulled out, but with the completion of the series the vessel set course south to 17°N 20°W, the position of the next otter trawl, where it was also hoped to encounter a slightly different midwater fauna. Two closing codend RMTs were fished *en route* (12182 & 12183 #1). The OTSB14 at the position (12183 #2) was very successful, with a very strong bottom echo from the monitor, and yielded a large number of small

sponges as well as decapods, fish, anemones etc. Two RMT tows followed early on 19/9, before embarking on a mini vertical series, sampling the water column to a depth of 900 m by day and by night, at 100 m intervals. This was successfully completed by 0300/21/9, and demonstrated that the midwater populations in the area were extremely rich and diverse. Closing codend RMTs followed (12183 #24,#25 & #26) for experimental material, and an overnight series of neuston net tows of half hour duration on every hour.

Despite the failure of the NBES to give an adequate signal on the wire test, it was decided to attempt a series of near-bottom hauls with the multinet. This was the result of the experience with the OTSB, which had shown the possibility of using the net monitor bottom echo instead. In the event an excellent NBES signal was obtained and three good hauls (dominated by several large fish) were achieved (12183 #27,#28,#29).

Course was then set westward, north of the Cape Verde Islands, passing over Senghor seamount on the way. Closing codend RMTs were fished during the passage to 17°10'N 24°30'W, at which point the vessel headed northwards towards 20°N 25°W . This position marks the edge of the 4500 m contour and the plan was to fish an OTSB14 at this station for comparison with those carried out in previous years further to the east. Increased wind and seas overnight 23-24/9 prevented further closing codend hauls being made prior to arrival on station 12189 at 1830/24/9.

The OTSB14 fished at station 12189 hit an obstacle and stuck fast, with the tension increasing to over 7 tons. It was freed by stopping the vessel and paying out and when finally recovered had suffered no damage whatever. The catch, however, was small and included some pieces of rotten timber. Three RMTs were fished on 25/9 on the passage route back to Tenerife and a CTD cast made to 300 m for bacterial samples(12191 #2). A computer problem necessitated repeating the cast. Three more RMTs were fished the following day along the route (12193,12194 & 12195) and these completed the sampling programme up to Tenerife. A wire test on the release system of a Bathysnap intended to be deployed in the Bay of Biscay coincided with an instruction from IOSDL not to proceed with the deployment! The EM logs subsequently developed a fault that could not be remedied until three days before arrival in the UK. On 27/9 a short scientific meeting was held to round off the programme and later in the day PES watches ceased when the Mufax developed problems.

Passage to Tenerife on 28/9 was interrupted by a much-appreciated swim call, after which a number of sperm whales were encountered and followed for a while. The vessel arrived in the vicinity of Tenerife later that evening and nine of the scientific party were transferred ashore by boat at 0800hr 29/9. Those leaving were Drs Angel, Partridge, Douglas, Shelton, Widder and Haygood, Prof.. Land, Mr Merrett and Mr Gaten. Dr Widder and Dr Haygood transferred their equipment ashore for its return to the USA. Nine scientific staff remained aboard to complete the passage back to the UK.

The vessel sailed as soon as the transfer of scientists and equipment had been completed and undertook two further RMT tows with the closing codend during the afternoons of 29/9 and 30/9 (stns 12196 &

12197 respectively). The P.E.S. fish was brought inboard after the last haul and passage made back to Barry. A collection of Bay of Biscay seawater was made on 3/10 for the Standard Seawater Service

PJH

PROJECT REPORTS

PHOTOBIOLOGY

Fish Lens Pigments

The wavelengths an animal perceives depend not only on the visual pigments contained within the photoreceptors of the retina, but also on the transmission properties of the ocular media. If wavelengths are absorbed by either the cornea, lens or humours they will not reach the retina and consequently the animal will not be sensitive to that part of the spectrum. During the last few years this has led me to study the short wavelength absorbing pigments contained within the lenses of many teleost fish. Prior to this cruise I had examined around 200 species of coastal marine as well as tropical and temperate freshwater species. The lenticular pigments a particular animal contains seems to be related to a variety of factors including its age, phylogenetic grouping and ecological niche. Although many distinct groups of fish have now been examined, little is known about such pigments within the deep-sea fauna. To date only 33 species of deep-sea fish have been examined, 10 of which have been found to contain some kind of lenticular pigment. However, such studies have been mainly qualitative and the identity and function of these pigments is largely unknown.

The aim of this study was:

1. To determine how widespread such pigments are in deep-sea fish.

2. To identify the pigments.

3. To try and elucidate their function.

It was hoped to achieve these ends by collecting as many species of teleost as possible and scanning their lenses (200-700nm) on board using a modified Shimadzu spectrophotometer with an integrating sphere. Once spectra were obtained all lenses were frozen for later biochemical analysis and identification of pigments.

In total the following material was collected:

250 deep-sea teleosts belonging to 76 species

98 flying fish belonging to 4 species

25 cephalopods belonging to 10 species.

Of the 76 deep-sea teleost species 15 had pigment within their lenses. Taking into account previously published data, a total of 102 species of deep-sea teleosts have now been examined and 21 of these have

been found to have pigmented lenses. This cruise has therefore increased the number of species whose lenses have been examined by a factor of 3 and has more than doubled the number of species known to have pigmented lenses.

It is hoped that a comparison of all factors that species with pigmented lenses have in common may point to the functional significance of such pigments. The material collected will also give some insight into the ageing properties of these pigments within deep-sea animals. However, it is already clear from the whole lens transmission data that a large number of different pigment systems are involved, pointing to the importance of lens pigments to many species.

RHD

Vision in deep-sea fishes

The investigation of the visual systems of deep-sea fishes seeks to answer questions about how the vision of these animals is adapted to cope with the severe constraints imposed by the light environment in the deep oceans. A fundamental adaptation is the link between the spectral sensitivities of retinal photoreceptors and the spectrum of the available light.

The absorption spectra of visual pigments of some 83 species of deep-sea fishes have now been measured. This work has demonstrated that c. 90% of deep sea fish have but one type of retinal rod with a visual pigment maximally sensitive to the wavelengths of light best transmitted by oceanic water. These pigments have peak absorbances (λ max) between 470 and 495nm. However, some nine species are known to have more than one visual pigment and microspectrophotometry (MSP) has shown that these visual pigments are located in separate retinal rods. The collection of fish during *Discovery* cruise 195 presented a rare opportunity to investigate further the organization of deep-sea fish retinae. 120 retinae were collected for the following specific studies:-

(1) MSP of hitherto unmeasured species

24 species were collected that have not had the absorption spectra of their visual pigments measured. Retinae of these animals have been preserved by controlled freezing or by light glutaraldhyde treatment for measurement by MSP at the University of Bristol.

(2) Topographic organization of visual pigments

Of those few deep-sea fishes with two visual pigments some have two distinct sizes of photoreceptor. 26 specimens of 6 such species have been collected and retinae preserved for EM, LM and MSP with the retention of retinal orientation, with the aim of determining how the different visual pigments are organized in the retinae.

(3) Topographic organization of ganglion cell densities

The densities of ganglion cells in vertebrate retinae has been shown to be a good indicator of what parts of the visual field are most "important" to the animal. The retinae of 19 species of deep-sea fish were collected, for subsequent ganglion cell mapping, by careful dissection and fixation of eyes without loss of orientation. Species collected included animals from a wide range of depths and those with and without peri-orbital photophores.

(4) Red-sensitive visual pigments

A few genera of deep-sea fish (*Malacosteus, Pachystomias, Aristostomias*) have photophores emitting red light and also have red-sensitive visual pigments in their retinae. The photophore light is well beyond the spectral sensitivities of most deep-sea fishes, giving these animals a potentially "secret" wavelength. However, the match between the wavelengths of emitted light and their own most red-sensitive retinal pigment is very poor and their sensitivity to their own photophore emission should be extremely low. One possible explanation of this unlikely situation is that a photostable pigment found in the retinae of these animals acts as a sensitizing pigment, increasing long-wavelength sensitivity. If so, this is a unique system among vertebrates. 16 samples of *M. niger* retinae have been preserved for the investigation of the spectral sensitivity of its retinal photopigments.

(5) Visual pigments based on 4-hydroxyretinal

In general, animals have visual pigments based on retinal, 3-dehydroretinal or 3-hydroxyretinal. In one deep-sea squid (*Watasenia scintillans*), however, a visual pigment based on 4-hydroxyretinal has been found. At present this animal is unique, but the collection of eyes of both cephalopods and fishes during *Discovery* 195 will enable a wider search to be made for other species which may have this type of pigment.

In addition, 41 corpses of 26 species of deep-sea fish were frozen at -70°C. These will be used for DNA extraction and sequencing of the opsin genes. Fish were selected as having visual pigments in the same λ max cluster point. It will be interesting to discover if the degree of similarity in visual pigment absorbance spectra is matched in the opsin genes.

JCP

Decapod eye and photophore structure and function

Differential spectral sensitivity of proximal and distal rhabdoms in *Systellaspis debilis*

In the compound eyes of most decapod crustaceans, each ommatidium contains eight retinula cells. Of these, seven contribute microvilli to a large spindle-shaped proximal rhabdom. The eighth retinula cell

forms a separate small distal rhabdom. In most decapod species the retinula cells associated with the proximal rhabdom show a spectral sensitivity maximum at a wavelength close to that of maximum transmission through the water. This is often green for coastal species and blue for oceanic ones. The spectral sensitivity of the retinula cells associated with the distal rhabdoms are unknown for mesopelagic decapods although in lobsters and crayfish they are most sensitive in the violet part of the spectrum. This study was designed to compare the relative spectral sensitivities of proximal and distal rhabdoms using spectrally controlled light sources to induce irreversible rhabdom breakdown. Such breakdown occurs when the eyes of crustaceans with eyes adapted for operation in low light levels are exposed to the relatively high light intensities characteristic of the surface. Using monochromatic light we previously showed that, in the benthic species *Nephrops norvegicus* and *Munida rugosa*, proximal and distal rhabdoms can be selectively damaged. Thus, information on retinula cell spectral sensitivity can be obtained.

In the present study we chose to work with *Systellaspis debilis* because it has well differentiated proximal and distal rhabdoms and we have preliminary evidence that excess blue (475nm) light selectively damages the proximal rhabdom. Two light sources were used - the sun and a quartz halogen lamp. Narrow pass band filters at a variety of wavelengths were used to selectively alter the spectral quality of the light (360, 400, 440, 480, 500 and 520nm). After exposure to measured amounts of light the animals were kept in the dark for 12-24 hours prior to fixation and embedding for later electron microscopic analysis.

PMJS, EG

Regional variation in the structure and function of compound eyes in selected mesopelagic decapod crustaceans

In the Crustacea with reflecting superposition eyes, optical considerations limit possible regional differentiation of the retina. Thus such eyes lack foveas or acute zones. Nevertheless early reports on the eye structure of various oplophorid and sergestid eyes indicated considerable regional specialization of various cell types. However, this work was of low resolution and the material used was undoubtedly light damaged. Preliminary studies by us on material fixed in the dark provided evidence that some regional specialization is present. This includes non-uniform distribution of tapetal cells. Consequently, we used two methods to examine regional variation in eye structure and function. First the eyeshine was photographed from dorsal, lateral, ventral, anterior and posterior aspects of each eye. Some eyes were light adapted, most were dark adapted. Eyeshine photographs were obtained from *Systellaspis debilis, Acanthephyra purpurea, A. kingsleyi, A. pelagica, Oplophorus spinosus* and *Notostomus gibbosus*. In all cases eyeshine is very much brighter in the anteriorly and ventrally directed parts of the eye. In *A. purpurea* eyeshine is negligible laterally. The eyeshine photographs will be used to measure effective apertures and the relative brightness of eyeshine in different regions of the eyes of the above species.

To complement the eyeshine data, a large number of eyes were fixed and embedded for light and electron microscopical studies of the underlying eye structure. Some species from deeper water such as

Systellaspis cristata and *Acanthephyra acanthitelsonis* were obtained for comparison with the shallower related species. Where possible eyes were fixed in both light- and dark-adapted states.

PMJS, EG, PJH

Photophore structure in *Systellaspis debilis* and *Oplophorus spinosus*

Both *S. debilis* and *O. spinosus* carry ventrally directed photophores. These are thought to be associated with camouflage against the downwelling irradiance. While the structure of photophores in certain fishes is well known, there is a lack of fine structure information on those in mesopelagic decapod crustaceans. Material from both the above species was obtained from the maxillae, the pereiopods, the pleopods, the eyestalks and the cephalothorax for later fine structure analysis.

PMJS, PJH

Decapod crustacean eye development

Very few developmental studies of crustacean compound eyes have been carried out, and none on mesopelagic shrimps. Within the Oplophoridae two distinct reproductive strategies occur. Some genera, including *Acanthephyra* and *Notostomus* lay small eggs from which hatch zoeae. Others such as *Oplophorus* and *Systellaspis* have fewer, larger eggs in which development proceeds much further before the juveniles hatch. To compare eye structure in these two groups, eyes from late embryos of *A. kingsleyi*, *N. gibbosus*, *N. auriculatus*, *O. spinosus* and *S. debilis* have been fixed and embedded for electron microscopy. In addition, juvenile *O. spinosus* eyes from the first to the sixth instars have been similarly prepared to study ultrastructural changes occurring during the development from juvenile apposition eyes to adult superposition eyes.

EG, PJH

The visual behaviour of mid-water crustaceans

The aim of this project was to provide a ship-borne environment in which amphipods and other crustaceans would behave reasonably normally, and where they could be observed and filmed under controlled conditions. Hitherto, there have been virtually no observations of such behaviour.

The set-up consisted of a perspex tank, 40cm high, 25cm wide and 10cm deep, completely filled with sea-water leaving no meniscus. Animals were kept in this for up to 18hr. Above the tank was a VDU screen on which stimuli, typically moving dark or light spots, could be displayed against a variable but uniform background representing the animals "surface". Under computer control, this background could be varied from 0.1 to 30cd m^{-2}, roughly the luminance range 200-400m deep in clear water. The tank was backlit with infra-red light, and filmed with a high-resolution, high-sensitivity video camera (Sony) and S-VHS recorder. The whole apparatus was kept in a cold-room at 15°C. The video-tapes were examined frame by frame using the recorder and a monitor. Animals studied included the hyperiid amphipods *Platyscelus*, *Brachyscelus*, *Parapronoe*, *Phronima*, *Phrosina* and *Streetsia*, various euphausiids (to be identified), juvenile shrimp

(*Oplophorus*) and a number of ostracods and polychaetes. Only the amphipods and euphausiids behaved with consistency.

Two general classes of behaviour were observed: responses to imposed stimuli and responses of one animal to another. In the first category 3 distinct kinds of response were seen frequently. 1) Animals at the top of the tank would drop down when a large spot approached overhead. Both amphipods and euphausiids showed this kind of "escape" behaviour. 2) Amphipods and euphausiids would also approach spots from below. This was particularly likely to occur if the animal was 10cm or more below the surface, and the response was usually aimed at the centre of the spot. It is assumed that this behaviour is "investigatory" in nature. 3) The euphausiids in particular would occasionally "track" a spot most of the way across the top of the tank. Again it is assumed that this is "investigatory" behaviour. The spots the animals responded to were light or (more commonly) dark, subtended a few degrees at the animal's eyes, and travelled at 5-20°s^{-1} as seen by the animal.

The amphipods (especially *Platyscelus* and *Parapronoe*) responded to each others' presence in various somewhat belligerent ways. The commonest behaviour was for one to run into another at speed, usually at or near the top of the tank. The collision would often dislodge the victim, causing it to drop down. Fragmentary episodes of chasing were also seen, but they never lasted longer than a few seconds, and did not result in capture. One bizarre capture episode did, however, occur when a *Phronima* (in its barrel) approached a *Platyscelus* from below, and trapped it in the top of the barrel, subsequently swimming with it to the bottom. It seems likely that these inter-animal behaviours do indeed reflect the kinds of things that go on at depth.

Another robust finding was that different species preferred to be active at different light intensities. *Phronima* and *Platyscelus* were active at surface luminances below 5 cd m^{-2}, whereas *Brachyscelus* and *Phrosina* preferred luminances above this value. *Parapronoe* and the euphausiids seemed more tolerant of light conditions. Presumably these differences correspond to the light conditions at the depths these animals normally inhabit. This seems likely as *Phronima* and *Platyscelus* were often taken from the deeper catches.

Although this new method was partially successful there remain problems. The animals were often reluctant to swim, although seemingly in good condition. A modest upward current might help this. They could not be kept for more than 24 hours in the closed tank, presumably because of anoxia. A further inevitable problem is the confined space, which meant that the animals often collided with the walls. However, in the middle of the tank the swimming looked 'normal' enough. The most difficult problem to be faced is in the statistical interpretation of the data, and the attribution of intentionality. Did an amphipod really mean to hit another one, or was it just that they reached the same place at the same time? There is no straightforward statistical technique for settling such crucial questions, and a major task on shore is to develop one.

MFL

Imaging bioluminescent behaviour

Field tests of the Mixed Light Imaging System (MLIS), which will be used during an ONR supported Mediterranean cruise in April 1991, were conducted during Cruise 195.

The MLIS consists of two video cameras: an intensified camera (Dage ISIT 66) for recording bioluminescence, and an infra-red sensitive camera (Dage 68) for simultaneous recording of the IR illuminated organisms. Both cameras record the same field of view through a Nikon Multi-image Module, fitted with a 580nm dichroic filter cube. The filter cube directs wavelengths below 580nm to the intensified camera and wavelengths above 580nm to the IR sensitive camera. The intensified camera is further protected against the IR illumination with a heat filter. IR illumination originates from a wall of 144 infra-red LEDs which is arranged to back-light the organisms through a white plastic diffuser. The LEDs are synchronized with the video signal so as to flash during the vertical synch pulse with a selectable pulse width of between 13 and 33 µsec. The IR illumination therefore provides stop action of rapid motion. Video output from each of the cameras is fed through a video mixer, superimposing the two images, providing high resolution, stop-action images of the organism superimposed on the intensified images of bioluminescence.

The MLIS was an unqualified success and effectively circumvented the difficulties which have previously plagued efforts to record bioluminescence behaviours. Because intensified cameras, sensitive enough to record bioluminescence behaviour, generally have very poor resolution, observations of behaviour associated with bioluminescence emissions have been severely limited. The more than 30hr of video recordings made of bioluminescence behaviours with the MLIS during the cruise attest to the effectiveness of this new approach.

A major portion of the effort was concentrated on the bioluminescent copepods which are believed to be primary contributors to the bioluminescence potential in certain oceanic regions. Responses to mechanical, electrical and photic stimuli were recorded. In addition, several responses to predation by the decapod shrimp, *Oplophorus*, were also recorded. Copepods from which recordings were made included:

Euaugaptilis magnus
E. laticeps
Lucicutia sarsi
Pleuromamma borealis
P. xiphias
Gaussia princeps
Disseta palumboi
Oncaea conifera
Heterorhabdus sp.
Hemirhabdus sp.

In all but *Oncaea conifera* bioluminescence emission consisted of secretory emissions, usually originating from the tail or legs. Release of the secretory material from the copepod generally involved very strong tail flips and/or leg flips. However, for the smaller copepods, such as the smaller species of *Pleuromamma*, such behaviours were often insufficient to cause release and the bioluminescence secretions remained attached to their appendages. The hydrodynamic restraints of releasing secretions from very small

organisms may account for the lack of secretions from *Oncaea conifera*, the smallest of bioluminescent copepods.

An unexpected diversity in the character of secretions was found. Besides considerable variability in the kinetics of the stimulated bioluminescence, the character of the secretions also exhibited striking differences. For example, while many of the secretions were diffuse, those from *Disseta palumboi* were particulate, with extremely long and variable delays. Escape behaviours associated with bioluminescence emissions were also diverse and computer image analysis will be used to quantify acceleration, trajectory and duration of the associated swimming behaviour.

Gelatinous organisms from which bioluminescence recordings were made included the siphonophores *Vogtia spinosa*, *V. glabra*, *Hippopodius* sp., the scyphozoan *Atolla wyvillei*, as well as several other siphonophores and ctenophores which were preserved for subsequent identification. The highly complex forms of most siphonophores had previously made analysis of their bioluminescence emissions very difficult. However, with the ability of the MLIS to superimpose the pattern of bioluminescence emission on a high resolution image of the organisms, this problem was overcome. This particular feature will be extremely important for the analysis of bioluminescent gelatinous organisms planned for the Mediterranean cruise.

Other organisms from which bioluminescence recordings were made during the cruise included several species of the amphipod *Scina*, the decapods *Oplophorus* and *Systellaspis*, the mysid shrimp *Gnathophausia*, two species of euphausiid, the anglerfish *Melanocetus johnsoni* and the fish *Malacosteus niger*, *Melanostomias valvidiae*, and *Photonectes braueri*.

EAW, PJH

Fluorescence and bioluminescence studies

The fluorescence and/or bioluminescence spectra of a number of fish, squid and crustaceans were recorded for comparison with similar data from previous cruises. In no case was there a precise spectral match between fluorescence and bioluminescence, which suggests that internal fluorophores were not involved in energy transfer within the photocytes. The recorded fluorescence is more likely to be derived from luciferin or a luciferin reaction product. Among the most interesting species examined were the red-emitting fishes *Pachystomias*, *Aristostomias* and *Malacosteus*. Fluorescent spectra from various regions of the photophores were recorded and will provide information on the intracellular mechanisms involved in this remarkable bioluminescence. Other animals studied included the cephalopods *Vampyroteuthis*, *Chiroteuthis* and *Ctenopteryx*, and a number of stomiatoid fishes. The post-orbital photophores of these fishes all have a spectrally similar blue-green fluorescence, which may be indicative of a common bioluminescent chemistry. The equivalent photophores of astronesthid fishes have a spectrally different fluorescence.

Fixed and/or frozen material from a variety of groups (including fish, cephalopods, crustaceans and coelenterates) was processed for later morphological and biochemical analysis.

PJH, PRSG

Bioluminescent bacterial symbionts

Although most bioluminescent fishes are self-luminescent, a significant minority employ luminous bacterial symbionts for light emission. In most cases the bacteria are readily cultured and have been identified as members of common free-living species. In a few cases the bacteria have not been successfully cultured and the identity of the symbionts is unknown. Deep-sea anglerfishes fall into this category. *Photobacterium phosphoreum* is the only species of free-living luminous bacteria commonly found in anglerfish habitats but *P. phosphoreum* is readily cultured from other midwater luminous symbioses such as *Opisthoproctus*. The central question is therefore: what is the identity of the anglerfish symbionts, and how are they related to free-living luminous bacteria such as *P. phosphoreum*?

Approach

Although the bacteria cannot be cultured and the escas (light organs) of anglerfishes are usually tiny, it is now possible to amplify selected genes from such samples by the polymerase chain reaction (PCR). Our goal is to amplify 16S ribosomal RNA genes from escal DNA to provide general phylogenetic information, and luminescence genes for ascertaining closer relationships among the luminous bacteria. Preliminary attempts to extract DNA from frozen *Haplophryne* escas yielded degraded DNA. It is possible that processing light organs from freshly caught fish might improve the quality and quantity of DNA obtained.

Specific goals

1) To process escas for DNA immediately after capture with methods that will render the DNA stable for transport to the laboratory.

2) To collect liver samples for DNA extraction in order to elucidate the relationships among the fish hosts to see if symbionts and hosts have co-evolved.

3) To isolate *P. phosphoreum* from *Opisthoproctus* light organs to provide a comparison between culturable and unculturable symbionts.

Results

Samples were taken from 88 anglerfishes from 13 species. Sufficient samples to evaluate symbiont variation within host species were obtained from *Melanocetus johnsoni*, *Cryptopsaras couesi*, *Ceratias holboelli* and *Oneirodes eschrichtii*. Liver samples were obtained from 41 fish in 8 species. Several different DNA extraction techniques were used with emphasis on guanidium isothiocyanate extraction, a technique that works well with tissues that have high levels of nucleases. Since it is possible that DNA in the escas degrades before the fish come on board, we cannot be sure of success until after the samples have been processed in the labortory. In cases where we have multiple samples, analysis should be possible even if degradation has occurred.

Three strains of *P. phosphoreum* from two species of *Opisthoproctus* were obtained.

MGH, PJH

ASSOCIATED STUDIES

Neuston and related studies

Neuston survey

This was the main objective and was carried out successfully. Using a fine mesh net (to capture animals of the size of radiolarians upwards) the manta-type neuston net was used to collect 30 minute samples at hourly intervals throughout a 24 hour period. This revealed the expected great increase in surface macrofaunal biomass at night, but also showed that there were large quantities of radiolarians present during the day, making the overall fluctuations in biomass less extreme. The composition of the macrofauna showed waves of migration into the neustonic community from dusk to dawn, with copepods entering at dusk and euphausiids at dawn. The middle hours of the night were dominated by fish, particularly flying fish and myctophids.

Two sampling programmes were carried out with a double net system, the upper net sampling the top 30cm of the water column, the lower taking the next 30cm slice. Hauls were carried out with fine and coarse nets and covered the period from midday to the following dawn. These hauls allowed identification of the endemic neuston animals (few in numbers and making up little biomass except in the middle of the day) and gave further information about migrations into and out of the surface layers.

Many neuston samples contained tarballs. Tarballs were collected during the day and at night because it seems that they support populations of isopods and amphipods at night. The microbial flora of these balls will be studied to determine whether migratory browsers are removing such flora at night, and thereby removing carbon and nitrogen from them (in contrast to the ideas of the early 1980s which involved eutrophication of the neuston by tarballs).

Biology of neustonic crabs

Neuston samples containing floating inanimate material (e.g. *Spirula* shells, tarballs) often contained small grapsid crabs. These were filmed to elucidate swimming (obviously different from the mechanism employed by portunid swimming crabs), and a number of observations of feeding biology made. Live specimens are being transported back to the UK for further study of energetics and biological rhythms.

Flying fish studies

More than 100 flying fish (4 species) were collected and their extended fins filmed for later analysis; they were frozen to allow a variety of other parameters (e.g. weight, fin ray diameter etc.) to be determined.

This material will form the basis of an allometric study of wingloading and structural strength in both 2 and 4 winged flying fish.

More flying fish were preserved to provide material for MSc Fisheries Biology and Management student(s) at UCNW. Analysis of gut contents and otolith rings will be carried out as a student project.

Gelatinous material

A variety of gelatinous planktonic animals (salps, medusae, pyrosomas, pteropods, siphonophores) were collected. These will be analysed for stable isotope and fatty acid content as part of an energetic/trophic relationship programme.

Biomechanical studies

During the cruise a variety of neustonic and midwater animals were filmed by high speed video to study swimming, sinking and ventilation of respiratory surfaces. An onboard density gradient was also used to measure the density of animals or parts of animals. Much material was not replicated adequately, but good sequences of the locomotion of the hyperiid amphipod *Phronima sedentaria* and the anglerfish *Melanocetus johnsoni* were obtained. Two specimens of the midwater *Anoplogaster cornutum* were extensively filmed; they appear to use the pectoral fins to help in gill ventilation, particularly during feeding on large prey items.

JD

Demersal fishes

Substantial differences in species composition of the dominant abyssal demersal fishes, together with their biomass and mean size, feeding strategy, and fecundity, occur on either side of the boundary zone around 40°N which divides the seasonal eutrophic northern waters from the oligotrophic, less seasonal region to the south. The aim of the set of semi-balloon otter trawl (OTSB) samples taken on this cruise was to investigate these aspects of the abyssal ichthyofauna under the influence of tropical upwelling with high surface production.

Three abyssal collections were made between 20-22°N and between 20-25°W in mid-depth soundings of 4066-4550m. They yielded 81kg of fish from a total distance towed on the seabed of some 51km. (The final tow in 4550m was curtailed by the net coming fast on the bottom after a tow of only 5km.) The 133 specimens collected overall represented 16 species and were dominated by the rattails, *Coryphaenoides (Lionurus) carapinus* and *C. (Chalinura) profundicolus*, together with the tripodfish, *Bathypterois longipes* and a variety of ophidioids.

A fourth sample was taken at continental rise soundings (3453m mid-depth) on the Cape Verde Terrace which yielded 19kg of fish from 8 nautical miles towing distance. The 84 fish caught represented at

least 15 species. They were again dominated by *C. (L.) carapinus*, but together here with the alepocephalid *Bellocia koefoedi*, and the synaphobranchid eel *Ilyophis brunneus*.

This preliminary analysis suggests that the abyssal fish biomass under this productive surface regime is more akin to that found beneath northern seasonal waters, rather than the oligotrophic, aseasonal waters of mid-latitudes. In species composition, the high proportion of *C. (C.) profundicolus* is indicative of the northern ichthyofaunal composition also, although *B. longipes* is more typical of the oligotrophic fauna. The microphagous *C. (L.) carapinus* does not fit into either pattern, as it only occurs at much shallower levels in the north. The richness of the ophidioid fauna, too, is noteworthy and is typical of low latitude regions elsewhere. Further sampling is required to support this evidence and to explore the transition area between this zone and the oligotrophic waters to the north and west.

A subsidiary aim of the collections was to obtain tissue samples for the examination of possible racial differences in deep demersal fish populations around the North Atlantic Basin by DNA and electrophoretic studies. Material was collected for host/parasite relations investigation in this connection also. Otoliths were taken, too, for crystallographic studies on the possible value of calcium/strontium ratios as a means of interpreting individual life history patterns of these species.

NRM

Zooplankton and nekton distributions

Near-bottom tows

Two attempts were made to sample the 100m of the water column immediately overlying the seabed. The first at station 12177#8-10 was over a sounding of about 4100m. Sea conditions were moderate but the acoustic reception was only just adequate to pick up the direct transmissions, so no bottom echoes could be detected. The near-bottom echosounder (NBES) system had locked on to the surface on deployment, but because of the high air temperatures on deck and warmth of the wind-mixed layer, there was interaction between the temperature/flow pulse and the NBES pulse. This generated an uncertainty about whether the NBES was funtioning properly. Consequently, when there was no sign of it locking on to the bottom as the monitor depth exceeded the sounding, it was deemed sensible not to go on paying out and risk landing the net on the sea-bed. So the haul was fished as a series of 4000m repeat tows and must have been about 200 metres above the bottom (mab). The catches were disappointingly small and contained few if any benthopelagic species.

The second attempt (station 12183#27-29) was much more successful. It was fished over a shoaling sounding of about 3400m in ideal conditions. The sediment was hard, and very strong and clear bottom echoes were received. Once again there was a hiatus in the traces near the surface, and no sign of the NBES locking on to the bottom when the bottom echoes indicated the net was 100 mab. The haul continued, relying on the bottom echoes for determining the height above the bottom. At 50 mab the NBES pulse

appeared, indicating that the net was 100 mab; clearly there was a factor of 2 error in the calibration. The haul was successfully completed, and the catches were large, containing several very good specimens of fish and many specimens of deep-living copepods.

Vertical Series

A day and night vertical series was completed to a depth of 900m at station 12183#5-23 using the multiple net system (although the day series was completed using a single combination net haul). The monitor depths in the surface 100m were clearly erroneous since the apparent depth was greater than the wire paid out; the depth calibration is affected by the monitor heating up on deck. The depths were subsequently estimated on the depth of the thermocline at the CTD station. Once the net had reached 200m the monitor depths were again trustworthy.

All the samples were volumed onboard, 24-48hr after collection. The animals in the RMT1 samples which were large enough to be also taken by the RMT8, were picked out and volumed separately. The volumes for each sample were standardised to ml displacement volume per 1000 cubic metres of water filtered, based on the flow meter records. These standardised data are shown in Table 1.

The integrated biomass per square metre of sea surface in each series were calculated, and these proved to be as high as the standing crops observed during the spring bloom during cruise 191. The richness of the pelagic populations was likely to be the result of the jet which carries water offshore from the coastal upwelling region. The ratios between the macroplankton catches taken by the RMT1 and the micronekton catches in the RMT8 showed the usual decrease with depth. What was unusual was that the micronekton standing crop exceeded that of the macroplankton at deep mesopelagic depths. The movement of biomass per square metre in and out of the wind-mixed layer proved to be high; 7ml for the macroplankton and 3.4ml for micronekton. Assuming that 1ml displacement volume is equivalent to 15µg of organic carbon, then vertical migration resulted in daily flux in and out of the wind-mixed layer of about 150µg orgC; this is probably very close to the amount of carbon fixed daily by photosynthesis in the region.

MVA

Effects of lights on decapod catches by midwater trawls

A series of RMT8 tows at 800m±25m depth were carried out in 1987 at 20°20'N 19°40'W with a switchable light on the net. The results showed no significant changes in the decapod numbers or volumes whether or not the light was on. However, these tows effectively sampled only the non-migrant populations. A similar series of tows were carried out at the same position on cruise 195, but at a depth of 200±25m. Three tows were undertaken each night from 12/9 to 16/9 inclusive at the end of the moon's third quarter, each of two hours duration, with the lights alternately on and off. Tows began at 2200Z and ended by 0430Z (with one exception), approximately two hours after sunset and before sunrise to allow the night distributions to be stabilized. Of the 15 hauls one light 'on' failed when the battery lead pulled out, converting it to a light 'off'

tow. There were therefore 8 tows with the light 'off' and 7 with it 'on'. Preliminary analysis showed that the volume of decapod crustaceans was always lower with the light 'on' than with it 'off' in any trio of tows. The differences were not always large but were consistent, even though the total volume varied considerably from night to night. The initial conclusion, therefore, is that the active decapod migrants are affected by a light on the net; this is in agreement with similar results achieved on cruise 194 in the Madeira area.

PJH, DW

COMPUTING SUPPORT

The computing system was run for the duration of the cruise. Navigation and meteorological data was logged continuously and CTD data was logged during CTD stations. Biological station data and bathymetric data were entered into the computer system manually as they became available.

Track plots, station plots, profile plots and listings were produced as required during the cruise. The data was put on to tape in GF3 format or put onto a floppy disk at the end of the cruise.

The level 'A's all functioned well and without failure, but the Cambridge ring stopped at the start of the cruise. It was restarted and subsequently functioned satisfactorily. The level 'B' ran continuously without problems and the Sun workstations functioned well but the parser and user machines re-booted themselves independently on four occasions.

The em log failed towards the end of the cruise. The second log was not working and because there was not a spare sensor head, it could not be repaired. Hence there were no log data for the last two stations. Navigation was taken directly from gps_av and copied into bestnav for this period. The log was eventually repaired using the head (incorrect impedance coil) from the second log.

The port and starboard light meters appear to be out of calibration and have a substantial offset. The light values are seriously affected by the ships "red - white - red" navigation lights.

There is a problem with the laser printer when using it in landscape mode. The laser filter may generate line feeds automatically for portrait mode, resulting in spurious line feeds being introduced to any text being printed in landscape mode. The biostation cruise report file required to be edited to make it acceptable when listed in landscape mode. Due to the problem with the laser printer, the data had to be split up to one page per file, to ensure correct pagination

PJM

CONCLUSIONS

The focus of a main theme, namely photobiology, encompassing a range of complementary projects, proved an effective means of maximizing the returns from the sampling programme. For example, it proved possible to achieve separate studies of the bioluminescence, fluorescence, visual and lens pigments on a

single specimen. Critical to the effective use of trawled material was its capture and maintenance in good condition. The closing codend and constant temperature containers were vital factors in achieving these aims.

Although a passage of 3375nm was necessary, 390hr of station time were also achieved (Table 2). The anticipated high productivity of the area sampled was confirmed by the vertical series at station 12183. The combination of the productivity and faunal diversity enabled comparative physiological and distributional data to be obtained for a large number of species, especially fish and crustaceans.

The cruise demonstrated that with appropriate experimental ingenuity realistic studies on the behaviour and physiology of both groups of animals can be undertaken on board ship. These studies can give insights into the behaviours and distributions of such animals *in situ*.

PJH

ACKNOWLEDGEMENTS

This was the last cruise of *Discovery* prior to her major restructuring. It is a tribute to all involved in her operation and maintenance that the demanding sampling programme and extensive passage was achieved without any major problems. It is also a pleasure to acknowledge the great assistance provided by Captain Harding and the ships company throughout the entire cruise. This was a major contribution to its overall success.

TABLE 1

Standardised displacement volumes of macroplankton and micronekton in the vertical series at Station 12183

Depths	Haul	Volume/1000 m^3 RMT1	RMT8	Ratio RMT1:RMT8
DAY				
0-60	16	153.3	7.3	21.0
60-200	17	62.1	11.4	5.5
200-300	18	81.8	34.1	2.4
300-400	19	61.4	32.5	1.9
400-500	9	45.1	17.8	2.5
500-600	8	43.0	27.0	1.6
600-700	5	27.4	24.9	1.1
700-800	6	24.6	40.6	0.6
800-900	7	19.9	20.3	1.0
Total biomass/m^2 (ml)		48.2	21.7	2.2
NIGHT				
0-60	13	223.3	41.1	5.4
60-200	14	40.2	21.5	1.9
200-300	15	37.6	32.1	1.2
300-400	23	41.8	27.1	1.5
400-500	22	40.6	26.2	1.6
500-600	21	24.7	27.4	0.9
600-700	12	27.0	23.7	1.1
700-800	11	30.5	20.2	1.5
800-900	10	23.9	25.7	0.9
Total biomass/m^2 (ml)		41.6	23.7	1.8

Gear Codes used in the station list

MS	Rosette multisampler
CTD	Conductivity, temperature, depth probe
LMD	Photodiode light meter
OTSB14	Semi-balloon otter trawl
RMT1	1m^2 rectangular midwater trawl (330µm mesh)
RMT8	8m^2 rectangular midwater trawl (4.5mm mesh)
RMT1M	Multiple 1m^2 rectangular midwater trawl system
RMT8M	Multiple 8m^2 rectangular midwater trawl system
RMT8ML	Multiple 8m^2 rectangular midwater trawl system with lights
CCE	Closing codend (on RMT8)

STN.	DATE 1990	POSITION LAT.	LONG.	GEAR	DEPTH (M)	TIMES GMT	COMMENT
12176 # 1	7/ 9	20 25.8N 20 31.4N	19 39.8W 19 38.0W	RMT1 RMT8	800- 875	1215-1415 Day	Catch not retained Flow Dist. 9.755 km.
12176 # 2	7/ 9	20 35.6N 20 39.4N	19 36.6W 19 37.6W	RMT1 RMT8	225- 300	1654-1830 Day	Catch not retained Flow Dist. 7.255 km.
12176 # 3	7/ 9	20 42.8N 20 46.1N	19 37.1W 19 37.5W	RMT1 RMT8	0- 120	2050-2220 Night	Catch not retained Flow Dist. 6.630 km.
12176 # 4	8/ 9	20 24.8N 20 29.2N	19 40.8W 19 42.2W	RMT1 RMT8	970-1060	0350-0550 Night	Catch not retained
12177 # 1	8/ 9	20 36.0N 20 38.8N	20 53.4W 20 53.7W	RMT1 RMT8	610- 700	1705-1835 Day	Catch not retained Flow Dist. 5.662 km.
12177 # 2	9/ 9	21 0.7N 21 8.5N	20 58.0W 20 55.2W	OTSB14	4050-4140	0124-0435 Night	Depths est. - traces lost. Tow Dist. 15.001 km.
12177 # 3	9/ 9	21 16.3N 21 17.2N	20 48.3W 20 47.4W	RMT1 RMT8	100- 245	1053-1128 Day	Monitor fault - No flow
12177 # 4	9/ 9	21 19.9N 21 21.2N	20 44.0W 20 42.9W	RMT1 RMT8 CCE	635- 700	1440-1540 Day	Catch not retained Flow Dist. 2.920 km.
12177 # 5	9/ 9	21 23.6N 21 25.8N	20 41.2W 20 39.9W	RMT1 RMT8 CCE	960-1025	1816-2000 Dusk	Catch not retained Flow Dist. 4.548 km.
12177 # 6	9/ 9 10/ 9	21 29.8N 21 32.8N	20 38.3W 20 37.4W	RMT1 RMT8 CCE	275- 345	2325-0055 Night	Catch not retained Flow Dist. 5.100 km.

STN.	DATE 1990	POSITION LAT.	POSITION LONG.	GEAR	DEPTH (M)	TIMES GMT	COMMENT
12177 # 7	10/ 9	21 38.6N 21 41.6N	20 34.6W 20 32.7W	RMT1 RMT8 CCE	1150-1250	0446-0626 Night	Catch not retained Flow Dist. 5.901 km.
12177 # 8	10/ 9	21 34.3N 21 37.7N	20 39.7W 20 36.8W	RMT1M/1 RMT8M/1	3965-4120	1429-1629 Day	Attempted near bottom. No NBES signal
12177 # 9	10/ 9	21 37.7N 21 41.0N	20 36.8W 20 34.5W	RMT1M/2 RMT8M/2	3985-4070	1629-1829 Day	Attempted near bottom. No NBES signal
12177 #10	10/ 9	21 41.0N 21 44.1N	20 34.5W 20 32.3W	RMT1M/3 RMT8M/3	3920-4095	1829-2029 Dusk	Attempted near bottom. No NBES signal
12178 # 1	11/ 9	21 47.9N 21 47.8N	20 35.1W 20 37.5W	RMT1 RMT8 CCE	185- 240	0021-0121 Night	Catch not retained Flow Dist. 3.460 km.
12178 # 2	11/ 9	21 48.9N 21 48.9N	20 48.3W 20 51.0W	RMT1 RMT8 CCE	235- 300	0324-0424 Night	Catch not retained Flow Dist. 4.315 km.
12179 # 1	11/ 9	22 8.1N 22 15.3N	21 48.7W 21 44.2W	OTSB14	4527-4630	1857-2140	Tow Dist. 17.224 km.
12180 # 1	12/ 9	20 44.8N 20 46.8N	19 58.2W 19 59.2W	RMT1 RMT8 CCE	360- 400	1732-1830 Day	Catch not retained Flow Dist. 3.641 km.
12181 # 1	12/ 9 13/ 9	20 30.9N 20 35.2N	19 40.0W 19 40.9W	RMT8ML/1	175- 225	2215-0018 Night	Light series #1. Light ON Flow Dist. 7.412 km.
12181 # 2	13/ 9	20 35.2N 20 39.4N	19 40.9W 19 41.7W	RMT8ML/2	180- 232	0018-0219 Night	Light series #2. Light OFF Flow Dist. 7.684 km.

STN.	DATE 1990	POSITION LAT.	POSITION LONG.	GEAR	DEPTH (M)	TIMES GMT	COMMENT
12181 # 3	13/ 9	20 39.4N 20 43.6N	19 41.7W 19 42.3W	RMT8ML/3	180- 235	0219-0419 Night	Light series #3. Light ON Flow Dist. 8.045 km.
12181 # 4	13/ 9	20 33.9N 20 37.4N	19 40.5W 19 41.9W	RMT1 RMT8 CCE	860-1000	0905-1035 Day	Catch residue retained Flow Dist. 6.270 km.
12181 # 5	13/ 9	20 30.9N 20 33.8N	19 39.7W 19 38.8W	RMT1 RMT8	345- 510	1404-1534 Day	Catch not retained Flow Dist. 5.415 km.
12181 # 6	13/ 9 14/ 9	20 29.7N 20 30.4N	19 38.4W 19 33.5W	RMT8ML/1	180- 225	2211-0012 Night	Light series #4. Light ON Flow Dist. 7.414 km.
12181 # 7	14/ 9	20 30.4N 20 31.1N	19 33.5W 19 28.3W	RMT8ML/2	179- 212	0012-0211 Night	Light series #5. Light OFF Flow Dist. 8.225 km.
12181 # 8	14/ 9	20 31.1N 20 31.7N	19 28.3W 19 22.9W	RMT8ML/3	180- 215	0211-0411 Night	Light series #6. Light ON Flow Dist. 8.540 km.
12181 # 9	14/ 9	20 32.1N 20 33.8N	19 38.1W 19 34.2W	RMT1 RMT8 CCE	920-1105	0906-1036 Day	Catch residue retained Flow Dist. 7.125 km.
12181 #10	14/ 9	20 32.1N 20 33.3N	19 33.0W 19 29.9W	RMT1 RMT8 CCE	225- 300	1407-1537 Day	Catch not retained Flow Dist. 5.010 km.
12181 #11	14/ 9 15/ 9	20 31.4N 20 35.5N	19 39.3W 19 36.6W	RMT8ML/1	170- 224	2215-0015 Night	Light Series #7. Light OFF Flow Dist. 8.315 km.
12181 #12	15/ 9	20 35.5N 20 39.2N	19 36.6W 19 34.4W	RMT8ML/2	198- 220	0015-0215 Night	Light Series #8. Light ON Flow Dist. 7.820 km.

STN.	DATE 1990	POSITION LAT.	POSITION LONG.	GEAR	DEPTH (M)	TIMES GMT	COMMENT
12181 #13	15/ 9	20 39.2N 20 40.9N	19 34.4W 19 29.6W	RMT8ML/3	170- 223	0215-0415 Night	Light Series #9. Light OFF Flow Dist. 8.697 km.
12181 #14	15/ 9	20 29.5N 20 26.8N	19 39.7W 19 40.6W	RMT1 RMT8 CCE	615- 720	1121-1251 Day	Catch residue retained Flow Dist. 4.380 km.
12181 #15	15/ 9	20 26.3N 20 29.0N	19 39.1W 19 35.7W	RMT1 RMT8 CCE	910-1295	1559-1739 Day	Catch not retained
12181 #16	15/ 9 16/ 9	20 34.3N 20 38.7N	19 39.9W 19 40.2W	RMT8ML/1	181- 225	2315-0115 Night	Light Series #10. Light ON Flow Dist. 7.662 km.
12181 #17	16/ 9	20 38.7N 20 42.6N	19 40.2W 19 40.8W	RMT8ML/2	178- 225	0115-0320 Night	Light Series #11. Light OFF Flow Dist. 7.365 km.
12181 #18	16/ 9	20 42.6N 20 46.4N	19 40.8W 19 41.7W	RMT8ML/3	178- 225	0320-0520 Night	Light Series #12. Light ON Flow Dist. 7.235 km.
12181 #19	16/ 9	20 50.6N 20 53.2N	19 41.3W 19 42.8W	RMT1 RMT8 CCE	220- 295	0856-1024 Day	Catch not retained Flow Dist. 5.259 km.
12181 #20	16/ 9	20 53.7N 20 53.6N	19 42.9W 19 42.9W	CTD	0- 250	1215-1230 Day	No bottle samples
12181 #21	16/ 9	20 47.9N 20 50.6N	19 42.0W 19 41.8W	RMT1 RMT8 CCE	830- 920	1434-1604 Day	Catch residue retained Flow Dist. 5.640 km.
12181 #22	16/ 9 17/ 9	20 32.8N 20 34.3N	19 39.5W 19 34.2W	RMT8ML/1	180- 225	2232-0032 Night	Light series #13. Light OFF Flow Dist. 8.337 km.

STN.	DATE 1990	POSITION LAT.	POSITION LONG.	GEAR	DEPTH (M)	TIMES GMT	COMMENT
12181 #23	17/ 9	20 34.3N 20 35.5N	19 34.2W 19 29.2W	RMT8ML/2	175- 225	0032-0232 Night	Light #14. Light failed. Depths est. Flow Dist. 8.382 km.
12181 #24	17/ 9	20 35.5N 20 36.2N	19 29.2W 19 23.6W	RMT8ML/3	175- 200	0232-0432 Night	Light series #15. Light OFF Flow Dist. 9.800 km.
12182 # 1	17/ 9	18 40.8N 18 40.2N	19 47.4W 19 45.1W	RMT1 RMT8 CCE	765- 915	1804-1904 Dusk	Catch not retained Flow Dist. 3.370 km.
12183 # 1	18/ 9	16 56.4N 16 53.5N	20 0.7W 20 1.0W	RMT1 RMT8 CCE	315- 375	0747-0847 Day	Catch not retained Flow Dist. 4.090 km.
12183 # 2	18/ 9	17 1.9N 17 10.1N	20 1.6W 20 1.6W	OTSB14	3443-3463	1404-1724	Tow Dist. 15.186 km.
12183 # 3	19/ 9	17 1.5N 17 3.3N	19 58.9W 19 57.2W	RMT1 RMT8 CCE	185- 235	0045-0145 Night	Selected material retained Flow Dist. 4.090 km.
12183 # 4	19/ 9	17 1.1N 17 3.0N	19 58.9W 19 57.4W	RMT1 RMT8 CCE	400- 500	0436-0536 Night	Catch not retained Flow Dist. 4.180 km.
12183 # 5	19/ 9	17 2.5N 17 4.1N	19 56.3W 19 54.1W	RMT1M/1 RMT8M/1	600- 700	0942-1042 Day	Day vertical series #1 Flow Dist. 4.067 km.
12183 # 6	19/ 9	17 4.1N 17 5.8N	19 54.1W 19 52.0W	RMT1M/2 RMT8M/2	700- 800	1042-1142 Day	Day vertical series #2 Flow Dist. 4.225 km.
12183 # 7	19/ 9	17 5.8N 17 7.4N	19 52.0W 19 50.0W	RMT1M/3 RMT8M/3	795- 900	1142-1242 Day	Day vertical series #3 Flow Dist. 4.180 km.

STN.	DATE 1990	POSITION LAT.	POSITION LONG.	GEAR	DEPTH (M)	TIMES GMT	COMMENT
12183	19/ 9	17 1.2N	19 57.8W	RMT1M/1	400- 495	1707-1807	Day vertical series #4
# 8		17 2.5N	19 55.9W	RMT8M/1		Day	Flow Dist. 3.572 km.
12183	19/ 9	17 2.5N	19 55.9W	RMT1M/2	495- 600	1807-1907	Day vertical series #5. (No net 3),
# 9		17 3.7N	19 54.0W	RMT8M/2		Day	Flow Dist. 3.730 km.
12183	19/ 9	17 3.5N	19 56.3W	RMT1M/1	800- 900	2158-2258	Night vertical series #1.
#10		17 5.6N	19 54.9W	RMT8M/1		Night	Flow Dist. 3.887 km.
12183	19/ 9	17 5.6N	19 54.9W	RMT1M/2	700- 800	2258-2358	Night vertical series # 2
#11		17 7.6N	19 53.5W	RMT8M/2		Night	Flow Dist. 4.090 km.
12183	19/ 9	17 7.6N	19 53.5W	RMT1M/3	595- 700	2358-0058	Night vertical series # 3
#12	20/ 9	17 9.6N	19 52.0W	RMT8M/3		Night	Flow Dist. 4.360 km.
12183	20/ 9	17 3.6N	19 56.7W	RMT1M/1	5- 60	0310-0400	Night vert. series # 4 - Max depth est.
#13		17 5.0N	19 55.7W	RMT8M/1		Night	Flow Dist. 2.725 km.
12183	20/ 9	17 5.0N	19 55.7W	RMT1M/2	60- 200	0400-0501	Night vert. series # 5 - Min depth est.
#14		17 6.5N	19 54.7W	RMT8M/2		Night	Flow Dist. 3.436 km.
12183	20/ 9	17 6.5N	19 54.7W	RMT1M/3	195- 300	0501-0601	Night vertical series # 6
#15		17 8.1N	19 53.7W	RMT8M/3		Night	Flow Dist. 3.437 km.
12183	20/ 9	17 1.2N	19 58.9W	RMT1M/1	10- 60	0930-1030	Day vertical series # 6
#16		17 3.3N	19 57.6W	RMT8M/1		Day	Flow Dist. 3.640 km.
12183	20/ 9	17 3.3N	19 57.6W	RMT1M/2	60- 200	1030-1130	Day vert. series # 7 - Min depth est.
#17		17 5.4N	19 56.3W	RMT8M/2		Day	Flow Dist. 3.842 km.
12183	20/ 9	17 5.4N	19 56.3W	RMT1M/3	200- 300	1130-1230	Day vertical series # 8
#18		17 7.5N	19 55.1W	RMT8M/3		Day	Flow Dist. 3.955 km.

STN.	DATE 1990	POSITION LAT.	POSITION LONG.	GEAR	DEPTH (M)	TIMES GMT	COMMENT
12183 #19	20/ 9	17 7.8N 17 6.0N	19 55.1W 19 56.1W	RMT1 RMT8 CCE	290- 398	1412-1512 Day	Day vertical series # 9 Flow Dist. 3.257 km.
12183 #20	20/ 9	17 0.8N 17 0.3N	20 0.5W 20 0.2W	CTD	0- 250	2043-2226	No bottle samples
12183 #21	20/ 9 21/ 9	17 2.3N 17 4.4N	20 0.5W 20 0.8W	RMT1M/1 RMT8M/1	500- 600	2333-0033 Night	Night vertical series # 7 Flow Dist. 3.460 km.
12183 #22	21/ 9	17 4.4N 17 6.6N	20 0.8W 20 0.8W	RMT1M/2 RMT8M/2	400- 500	0033-0133 Night	Night vertical series # 8 Flow Dist. 3.887 km.
12183 #23	21/ 9	17 6.6N 17 8.8N	20 0.8W 20 0.9W	RMT1M/3 RMT8M/3	300- 400	0133-0233 Night	Night vertical series # 9 Flow Dist. 3.977 km.
12183 #24	21/ 9	17 7.5N 17 10.3N	19 58.8W 19 57.0W	RMT1 RMT8 CCE	690- 820	0530-0700 Dawn	Catch not retained Flow Dist. 5.415 km.
12183 #25	21/ 9	17 14.2N 17 17.4N	19 55.6W 19 56.0W	RMT1 RMT8 CCE	880-1000	0946-1116 Day	Catch residue retained Flow Dist. 4.740 km.
12183 #26	21/ 9	17 11.4N 17 14.3N	19 57.8W 19 57.4W	RMT1 RMT8 CCE	265- 400	1354-1524 Day	Catch not retained Flow Dist. 4.875 km.
12183 #27	21/ 9	17 6.0N 17 10.3N	19 59.2W 19 58.5W	RMT1M/1 RMT8M/1	3361-3380	2102-2302	Near-bottom 49-105 m.a.b. Flow Dist. 5.840 km.
12183 #28	21/ 9 22/ 9	17 10.3N 17 14.8N	19 58.5W 19 57.6W	RMT1M/2 RMT8M/2	3335-3390	2302-0102	Near-bottom 21-51 m.a.b. Flow Dist. 7.100 km.

STN.	DATE 1990	POSITION LAT.	POSITION LONG.	GEAR	DEPTH (M)	TIMES GMT	COMMENT
12183	22/ 9	17 14.8N	19 57.6W	RMT1M/3	3353-3390	0102-0302	Near-bottom 10-30 m.a.b.
#29		17 19.7N	19 56.5W	RMT8M/3			Flow Dist. 8.000 km.
12183	22/ 9	17 23.5N	20 3.6W	RMT1	600- 770	0920-1020	Catch not retained
#30		17 22.8N	20 5.7W	RMT8		Day	Flow Dist. 3.235 km.
				CCE			
12184	22/ 9	17 19.1N	21 20.7W	RMT1	190- 320	1857-1957	Catch not retained
# 1		17 21.1N	21 19.5W	RMT8		Dusk	
				CCE			
12185	23/ 9	17 7.0N	22 2.7W	RMT1	450- 540	0200-0300	Catch not retained
# 1		17 8.9N	22 0.8W	RMT8		Night	Flow Dist. 4.000 km.
				CCE			
12186	23/ 9	17 10.7N	22 34.4W	RMT1	760- 900	0807-0907	Catch residue retained
# 1		17 10.5N	22 36.5W	RMT8		Night	Flow Dist. 3.415 km.
				CCE			
12187	23/ 9	17 12.1N	23 23.4W	RMT1	410- 510	1542-1642	Catch not retained
# 1		17 13.8N	23 22.4W	RMT8		Day	Flow Dist. 3.100 km.
				CCE			
12188	23/ 9	17 15.2N	23 56.0W	RMT1	210- 240	2124-2224	Catch not retained
# 1		17 17.4N	23 55.1W	RMT8		Night	Flow Dist. 4.022 km.
				CCE			
12189	24/ 9	20 8.9N	24 49.2W	OTSB14	4500-4600	2328-0040	Caught fast 0040-0300h. Depths est.
# 1	25/ 9	20 11.6N	24 48.8W				Tow Dist. 5.064 km.
12190	25/ 9	20 29.9N	24 22.1W	RMT1	707-1000	1105-1235	Catch residue retained
# 1		20 32.9N	24 20.5W	RMT8			Flow Dist. 5.752 km.
				CCE			

STN.	DATE 1990	POSITION LAT.	POSITION LONG.	GEAR	DEPTH (M)	TIMES GMT	COMMENT
12191 # 1	25/ 9	20 41.0N 20 41.2N	24 13.8W 24 13.7W	CTD MS	0- 296	1441-1516	WB @ 40, 100 & 296m. Computer fault.
12191 # 2	25/ 9	20 41.1N 20 41.2N	24 13.8W 24 13.6W	CTD MS	0- 307	1529-1549	WB @ 40, 100 & 307m.
12191 # 3	25/ 9	20 41.9N 20 43.6N	24 12.2W 24 9.2W	RMT1 RMT8 CCE	445- 600	1636-1806 Day	Catch not retained Flow Dist. 5.775 km.
12192 # 1	25/ 9	20 59.3N 21 1.2N	23 54.3W 23 53.6W	RMT1 RMT8 CCE	160- 230	2130-2230 Night	Catch not retained Flow Dist. 4.180 km.
12193 # 1	26/ 9	22 9.3N 22 11.6N	22 41.6W 22 39.4W	RMT1 RMT8 CCE	775- 950	0908-1038 Day	Catch not retained Flow Dist. 4.830 km.
12194 # 1	26/ 9	22 19.1N 22 21.4N	22 32.8W 22 30.7W	RMT1 RMT8 CCE	1015-1200	1504-1634 Day	Catch not retained Flow Dist. 4.920 km.
12195 # 1	26/ 9	22 32.7N 22 34.9N	22 19.7W 22 17.6W	RMT1 RMT8 CCE	515- 585	2014-2144 Night	Catch not retained Flow Dist. 5.168 km.
12196 # 1	29/ 9	29 12.8N 29 15.2N	15 50.0W 15 49.4W	RMT1 RMT8 CCE	920-1010	1430-1600 Day	Catch not retained Flow Dist. 4.695 km.
12197 # 1	30/ 9	32 55.5N 32 59.1N	14 20.9W 14 18.7W	RMT1 RMT8 CCE	800- 955	1612-1812 Day	Catch not retained Flow Dist. 6.290 km.

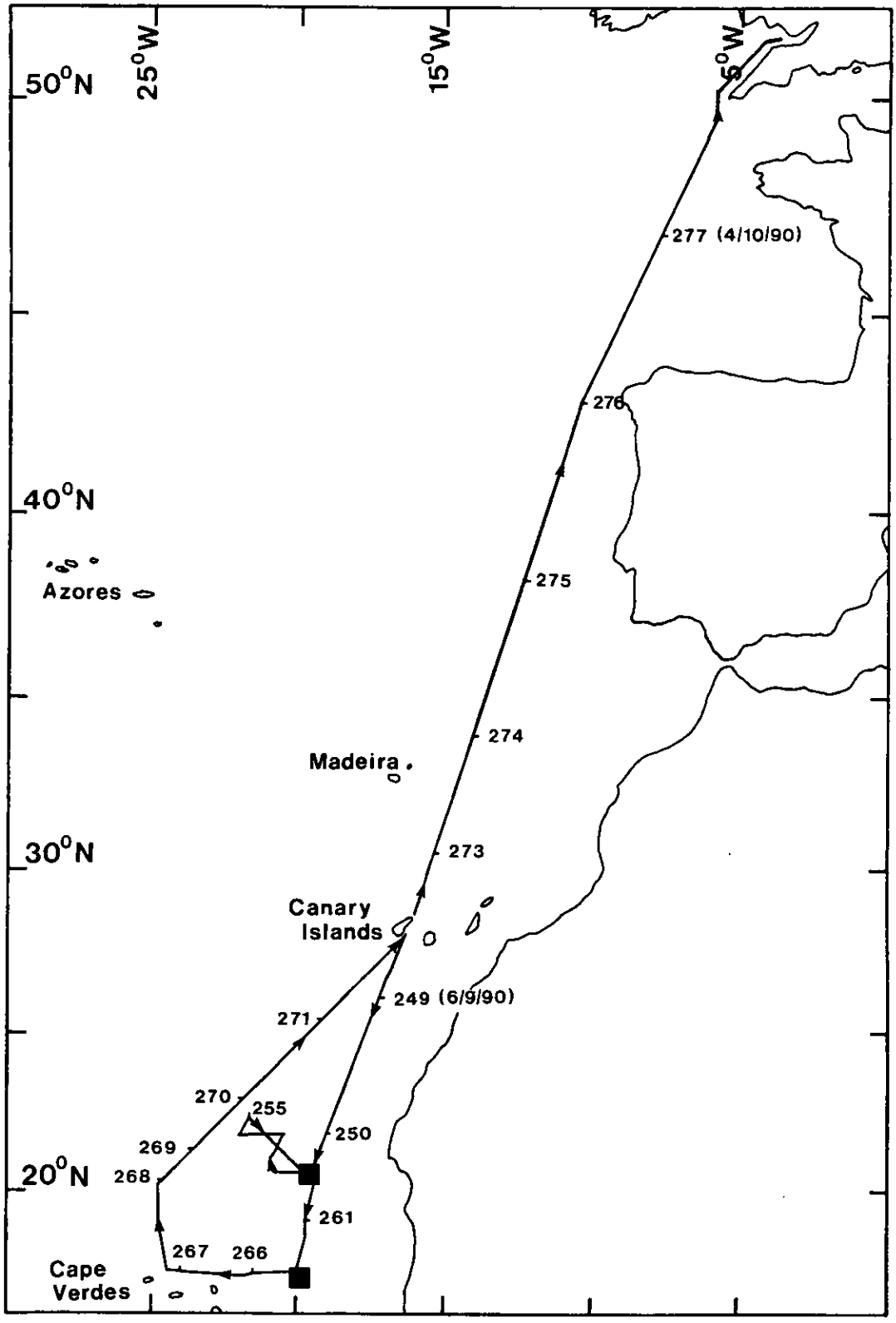

Figure 1. Track chart of *Discovery* cruise 195 5 Sep - 5 Oct 1990. Boxes indicate the two main work areas and the numbers indicate Julian days.

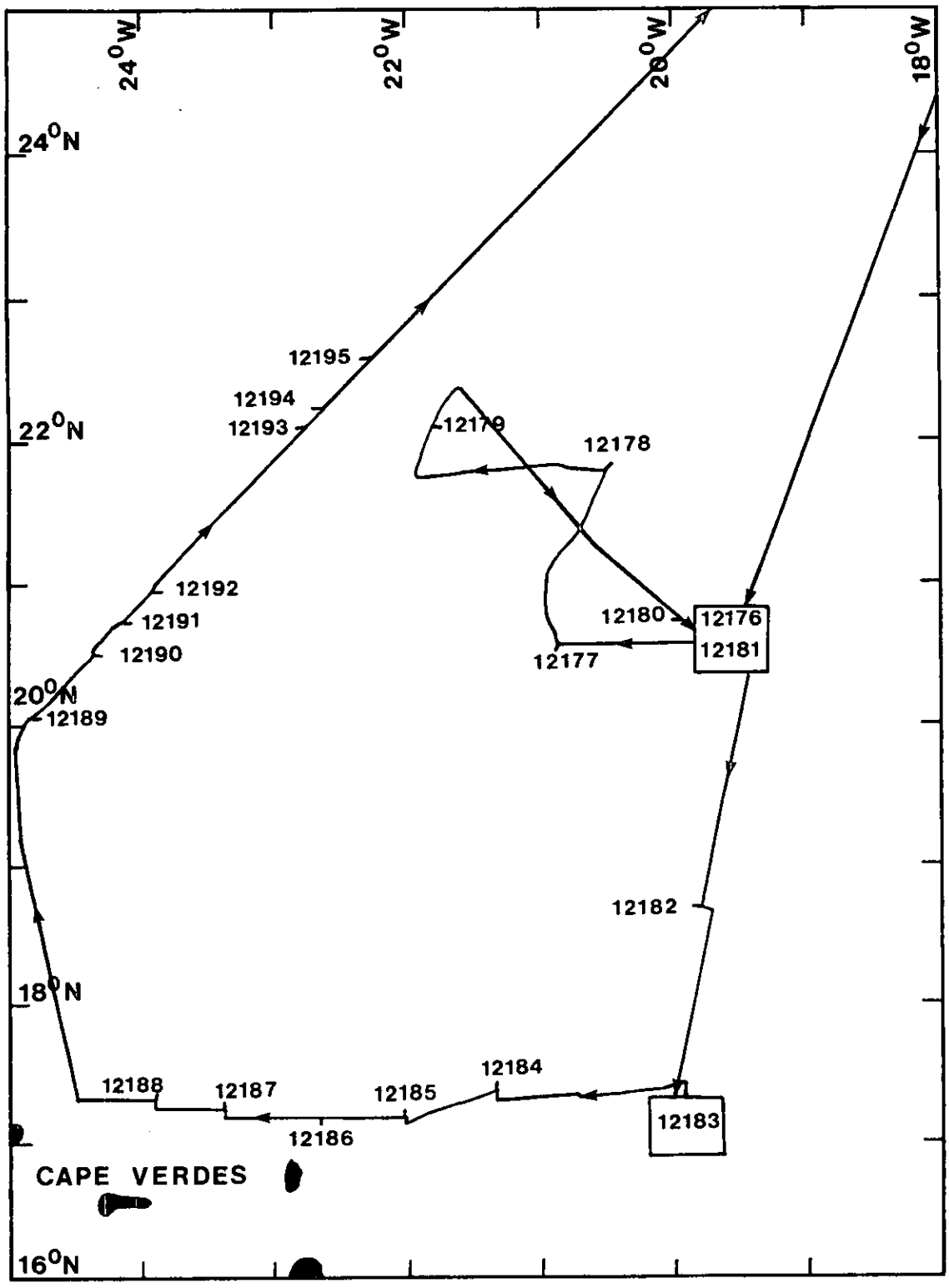

Figure 2. Track chart of the more southerly work area with the station positions indicated.


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