OCEAN Challenge

The Challenger Society for Marine Science

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OCEAN Challenge

The Magazine of the Challenger Society for Marine Science

SCOPE AND AIMS

Ocean Challenge aims to keep its readers up to date with what is happening in oceanography in the UK and Europe. By covering the whole range of marine-related sciences in an accessible style it should be valuable both to specialist oceanographers who wish to broaden their knowledge of marine sciences, and to informed lay persons who are concerned about the oceanic environment.

The views expressed in *Ocean Challenge* are those of the authors and do not necessarily reflect those of the Challenger Society or the Editor.

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***Ocean Challenge* is sent automatically to members of the Challenger Society for Marine Science.**
For more information about the Society, see inside back cover.

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The cover image shows the global phytoplankton distribution. Phytoplankton concentrations are low in the central gyres (purple, deep blue), and tend to be high along coasts (yellow, orange and red). The images, which were made by processing thousands of individual scenes from the Coastal Zone Color Scanner, have been used by courtesy of Gene Feldmannn, NASA/Goddard Flight Center, Space Data and Computing Division, Greenbelt, Maryland 20771, USA.

The cover was designed by Ann Aldred Associates.

Forthcoming Events

Events in 1995

The Geological Evolution of Ocean Basins: Results from the Ocean Drilling Program (Joint Meeting of the Marine Studies Group and the Challenger Society). 18–19 October, Burlington House. *Contact* Dr Adrian Cramp, Marine Geosciences Research Group, Dept of Earth Sciences, UWCC, PO Box 914, Cardiff, CF1 3YE; Tel. 01222 874335; Fax: 01222 874326; Email: cramp@cf.ac.uk

Second MAST Days and EUROMAR Market (European Commission, in conjunction with the EUROMAR umbrella project, EUREKA). 7–10 Nov., Sorrento, Italy. The intention is to bring together scientists, engineers, administrators and managers to foster the exchange of ideas across disciplines, and to develop conceptual approaches to major issues in marine science and technology. Scientific sessions will concentrate on the major tasks of the MAST and EUROMAR programmes, while discussion meetings will address future challenges, such as those of operational oceanography, biodiversity, marine biotechnology and the Mediterranean Sea in the 21st century. Cost: 300 ecu. *To register, contact:* Mr J.P. Sceins, CEC CCAB 2/12, rue de la Loi 200, B-1049 Brussels; Tel. 00-322-295-0213/296 6317; Fax: 00-322-295-3736.

Coupled Atmosphere–Ocean Modelling (Joint Meeting of the Royal Met. Society and the Challenger Society). 15 Nov, Blackett Laboratory, Imperial College, London. *Contact* Dr Steve Foreman, Meteorological Office.

IGCP Project 367: 2nd International Meeting 19–26 November, Antofagasta, Chile. *Contact* Ian Shennan, Dept of Geography, University of Durham, Science Laboratories, South Rd, Durham DH1 3LE; Tel. 0191-374-2484 or 2466; Fax: 0191-374-2456 Email: ian.shennan@durham.ac.uk
See also the back of this issue.

Follow-up of the 4th North Sea Conference (North-East Atlantic Liaison Group). 27 November, 2.00 p.m., Palaeodemo Room, Natural History Museum, London. Speakers are: Mr Ben van de Wetering, Secretary, The Oslo–Paris Commission, Ms Alija Schmidt van Dorp, North Sea Officer, WWF, Mr Mike Burn, Dept of the Environment. *Contact* Dr Jean-Paul Ducrotoy, The Marine Forum, c/o University College of Scarborough, The University of York, Filey Rd, Scarborough, YO11 3AZ, UK; Tel. 01723-362392; Fax: 01732-370815.

Events in 1996

Marine Environmental Management: Review of Events in 1995 and Future Trends 24–25 January, School of Oriental and African Studies, Russell Square, London. Topics covered will include coastal zone management, water quality and pollution, marine nature conservation, and fisheries; the outcomes of the North Sea Ministerial Meeting and the *Brent Spar* controversy. *Contact* Bob Earll, Candle Cottage, Kempley, Glos, GL18 2BU; Tel./Fax: 01531-890415.

MSG Postgraduate Research in Progress 1–2 February, Southampton Oceanography Centre. *Contact* Dr Rachel Mills, Southampton Oceanography Centre, Empress Dock, Southampton, SO14 3ZH. Tel. 01703-595000; Fax: 01703-593059; Email: ram@uk.ac.southampton

From the North Sea to the Irish Sea – Quality Status Report: Different Approaches to Pollution? (North East Atlantic Liaison Group with the Irish Sea Forum). February/March, Palaeodemo Room, Natural History Museum, London. *Contact* Dr Jean-Paul Ducrotoy, The Marine Forum, c/o University College of Scarborough, The University of York, Filey Rd, Scarborough, YO11 3AZ, UK; Tel. 01723-362392; Fax: 01732-370815.

Mid-Ocean Ridges: Dynamics of Processes Associated with Creation of New Ocean Crust (Royal Society Discussion Meeting). 6–7 March, London. Organized by Prof. Joe Cann, Dr Harry Elderfield and Sir Anthony Laughton. *Contact* The Scientific Meetings Secretary, Royal Society, 6 Carlton House Terrace, London SW1Y 5AG. Tel. 0171-839-5561, extn 278; Fax: 0171-839-2170.

The Law of the Sea: Ratification and After (Marine Forum). March/April, Palaeodemo Room, Natural History Museum, London. *Contact* Dr Jean-Paul Ducrotoy, The Marine Forum, c/o

Preliminary Notice

UK Oceanography '96

will be held on

2–6 September, at the University of Wales, Bangor

All UK oceanographers are invited to offer contributions. The aim is to review progress and to present recent work in marine science. Papers on all aspects of oceanography and related topics are welcomed. Papers emphasising the interdisciplinary nature of the subject will be particularly welcome, and it is hoped to offer participants a broad perspective of the present state of oceanography in the UK.

Oceanographers from outside the UK are also warmly invited to participate in the meeting.

One of the objectives of the conference is to provide opportunities for young scientists, including research students, to present their work: The Norman Heaps Prize and the Cath Allen Prize will be awarded for the best verbal and best poster presentations by young scientists.

The meeting will be held in large-capacity lecture theatres on the main University campus in Bangor, a short walking distance from the new Hall of Residence complex where conference participants will be accommodated.

For more information, contact: Dr A.E. Hill (UK Oceanography '96), School of Ocean Sciences, Marine Science Laboratories, Menai Bridge, Gwynedd, LL59 5EY; Tel. 01248-382846.

University College of Scarborough, The University of York, Filey Rd, Scarborough, YO11 3AZ, UK; Tel. 01723-362392; Fax: 01732-370815.

The Humber Estuary and Yorkshire and Lincolnshire Coasts (Estuarine and Coastal Sciences Association Meeting). April, University of Hull. *Contact* M. Elliot, University of Hull.

Crustacean Biology (Special Meeting of the MBA, the SEB and ECSA, in honour of Professor Ernest Naylor). 1–3 April, University of Plymouth. *Contact* Malcolm Jones, University of Plymouth. Tel. 01752-232900.

Behaviour and Ecophysiology of Marine Oganisms (Estuarine and Coastal Sciences Association meeting). April, University of Plymouth. *Further details* will be available from D.S. McLusky, Department of Biology and Molecular Science, University of Stirling, Stirling FK9 4LA. Tel. 01786-467755; Fax: 01786 464994.

Climate Change Offshore NE Europe (Joint Meeting of the Society for Underwater Technology and the Challenger Society). 17–18 April, Aberdeen. *Contact* SUT Aberdeen Office, PTSI House, Exploration Drive, Offshore Technology Park, Bridge of Don, Aberdeen, AB23 8GX, UK; Tel. 01224-823637; Fax: 01224-820236.

Impact of Oil and Gas Exploitation (Marine Forum/Joint Nature Conservancy Council in conjunction with the Centre for European Research into Coastal Issues). May/June (2 days), venue to be arranged. *Contact* Dr Jean-Paul Ducrotoy, The Marine Forum, c/o University College of Scarborough, The University of York, Filey Rd, Scarborough, YO11 3AZ, UK; Tel. 01723-362392; Fax: 01732-370815.

Inauguration of the Marine Forum Information and Documentation Centre June/July, University College Scarborough. College of Scarborough, The University of York, Filey Rd, Scarborough, YO11 3AZ, UK; Tel. 01723-362392; Fax: 01732-370815.

Atmospheric Chemistry of Sulphur in Relation to Aerosols, Cloud and Climate (Royal Society Discussion Meeting). 3–4 July, London. Organized by Dr R.A. Cox, Dr C. Hewitt, Prof. P.S. Liss, Dr J.E. Lovelock, Dr K. Shine and Prof. B.A. Thrush. *Contact* The Scientific Meetings Secretary, The Royal Society, 6 Carlton House Terrace, London SW1Y 5AG. Tel. 0171-839-5561, extn 278; Fax: 0171-839-2170.

Joint Symposium of ECSA and the Estuarine Research Federation Sept. *Further details* will be available from D.S. McLusky, Dept of Biology and Molecular Science, University of Stirling, Stirling FK9 4LA. Tel. 01786-467755; Fax: 0786-464994.

ECSA-26 (Joint ECSA and ERF Meeting) 2–6 Sept, Middelburg, The Netherlands. *Local organizer:* Carlo Heip.

Jason VII Project Participate in live link-ups with Woods Hole Oceanographic Institution's remotely-operated *Jason/Medea* diving off the Florida coast. *Contact* Mr Eric Greenwood, Keeper of the Liverpool Museums and Galleries on Merseyside, William Brown Street, Liverpool, L3 8EN; Tel. 0151-207- 0001; Fax: 0150-478-3490.

Events in 1997

Suffolk and Essex Estuaries (Estuarine and Coastal Sciences Association Meeting). Details to be arranged.

Remote Sensing in Estuaries (ECSA-27) St Andrews, Scotland.

See also the final pages of this issue.

The Challenger Society for Marine Science

Remember: If you are organizing a conference or meeting on any aspect of oceanography, you can publicize it through *Ocean Challenge*. Details should be sent to the Editor at: The Dept of Earth Sciences, The Open University, Walton Hall, Milton Keynes, Bucks MK7 6AA, UK.

IOS and RVS Move to Southampton

September saw the long awaited move to Southampton of the Institute of Oceanographic Sciences Deacon Laboratory, from Wormley, and the NERC's Research Vessel Services, from Barry. They joined the University of Southampton's departments of Geology and Oceanography in the brand new Southampton Oceanography Centre (SOC) on Empress Dock close to Ocean Village, as part of a docklands redevelopment scheme. The SOC has for the past five years been the Government's largest building project in academia.

The SOC's principal thrust is the study of the Earth and its oceans as a system, using physics, chemistry, biology, mathematical modelling and engineering, with special emphasis on the interactions between these disciplines as they affect the system. Studies will be undertaken on whatever time- and space-scales are necesary to elucidate the processes of interest, from the microscopic to global, and from diurnal to geological.

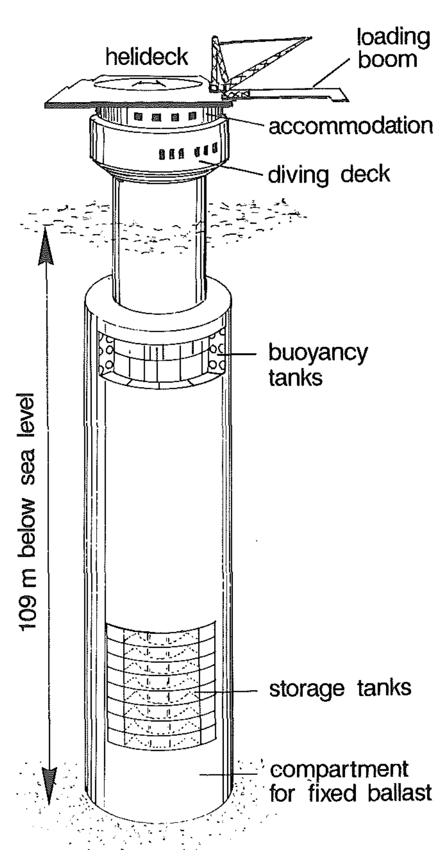
The SOC will be home to some 450 scientists, to a similar number of students, and to the fleet of Royal Research Ships, *Discovery*, *Challenger* and *Charles Darwin*. It is intended that it should become Europe's leading centre for oceanographic research and teaching as well as one of Europe's premier centres for geological research and teaching, especially for marine geological studies. Joint developments are expected between the SOC and adjacent maritime industries in the Portsmouth–Southampton–Bournemouth area, and with the several local defence establishments at Haslar and in the Portand area.

The address of the Southampton Oceanography Centre is: Empress Dock, Southampton, SO14 3ZH.

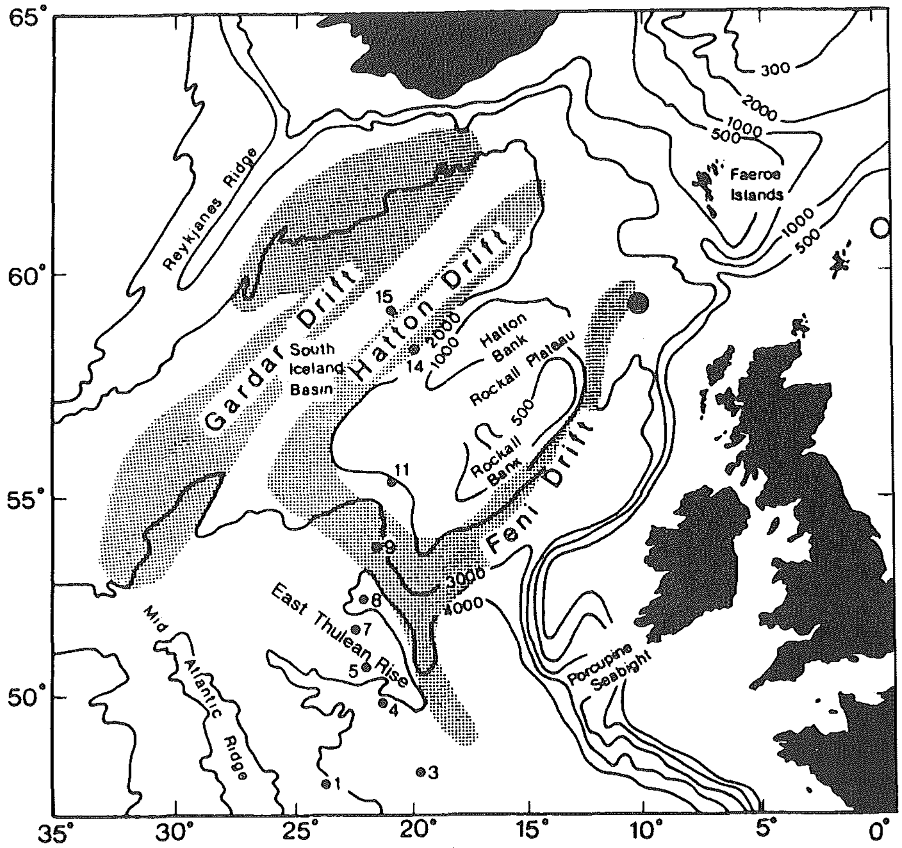
For further details, phone 01703-596-888, or fax 01703-595-107.

All change at *Brent Spar*

A week being a long time in politics, the *Brent Spar* controversy may be almost forgotten by the time you read this; but it's worth recalling, not least because the accompanying media circus featured no less an authority than Dr Tony Rice of IOS Deacon Laboratory, well-known to readers of *Ocean Challenge*. Just to refresh your memory, Shell announced in February of this year that the UK Government had approved their plan to dispose of the redundant oil storage platform, *Brent Spar*, in ~ 2350 m of water on the 'North Feni Ridge', 150 miles west of the Outer Hebrides. Greenpeace immediately called this proposal an environmental outrage and campaigned vigorously against it, as well as taking direct action: this involved running the gauntlet of water cannon from escort vessels, in order to occupy the rig as it was being towed from its original station (120 miles north-east of Shetland) to its intended final resting place.



The design of the* Brent Spar. *The oil-rich sludge is mostly in the storage tanks near the base of the structure, just above the haematite ballast.



Map to show the proposed dump site of the* Brent Spar, *at about 59° N, 11° W (●), and its previous position (○) east of Shetland. Shaded areas are low ridges of sediment deposited from bottom currents, and known as 'drifts'.

Greenpeace mobilised so much public opinion that motorists in Germany, Holland and Denmark, not to mention UK and Switzerland, boycotted Shell petrol stations – one or two in Germany even got bombed. They seem also to have persuaded the German, Dutch and Danish Governments to put pressure on Britain to halt the operation – pressure which the UK Government robustly resisted. Then suddenly in June, when the rig was half-way through its journey, Shell caved in and announced it would seek another disposal method. The Government was not amused. Greenpeace and their supporters were jubilant. On the face of it, a wicked multinational corporation had been prevented from fouling up the marine environment to save itself a few millions in decommissioning costs. And it made great television. But it's not so simple as that, because there is a surprising counter-intuitive twist to this tale: support for Shell's deep-water disposal option came from a number of marine biologists (including Tony Rice, see above), who understand the benthic marine environment better than most. More importantly, these experts had not previously been consulted by either Shell or Greenpeace. They gave their opinions independently, and only after the controversy had become widely publicised.

Is it possible that the outcome of the dispute between Shell and Greenpeace had more to do with politics than with science? Let us delve a little further back in history. *Brent Spar* is (or was) an oil storage platform some 130 m in height (109 m of it under water), weighing 14 500 tonnes, stationed originally in the northern North Sea off Shetland. Built in the mid-1970s, it became redundant in 1991, with construction of the direct pipeline from the Brent field to Shetland's Sullom Voe terminal. Shell claimed – and there is no reason to doubt them – that they spent three years weighing up the disposal options, which included both decommissioning (dismantling) on land and partial dismantling *in situ*, as well as dumping in deep water (see *Ocean Challenge*, Vol. 3 (2/3), 1993, pp.46–7). Partial dismantling *in situ* was ruled out, because of the requirement to leave at least 50 m of clear water above the remains – nearly two-thirds of the installation would have to be removed. Disposal on land (in the UK) was ruled out because the platform would have to be turned on its side for towing into shallow water – and the sheer size of the thing, weakened by battering by winter storms (and by damage sustained during installation), could cause it to break up, releasing its load of potentially toxic wastes into the North Sea. An added difficulty with this option is the ballast in the base (6 000 tonnes of haematite) placed there to ensure the platform stayed upright.

And what of the toxic wastes? Apart from some hundreds of kilograms of heavy metals forming part of the structure itself (in electrical installations etc.), our best information suggests there are some 100 tonnes of petroleum-rich sludge, apparently largely sand impregnated with bituminous residues. There are also about 30 tonnes of hard 'scale', which forms on pipes and tanks of all oil-processing facilities. The scale is contaminated by heavy metals (notably cadmium, mercury, zinc, lead, nickel and copper) and radioactive isotopes (including thorium-232, radium-226, lead-210 and polonium-210). These occur naturally in petroleum-bearing formations (i.e. in the oil itself as well as in sediments and associated brines), and they tend to become concentrated in the scale. However, metal concentrations in the scale are not particularly high, and the radioactivity is such that this would be classified as low-level waste by the nuclear industry.

Shell's argument was that as all these wastes are presently contained *within* the structure they would leak into the marine environment only slowly. Moreover, as stressed by Tony Rice and others, the northern end of the Feni Drift is very near the cold outflow of North Eeast Atlantic Deep Water from the Norwegian Sea. The water would take hundreds of years to return to the surface, by which time, anything leaking slowly out of the rig would be still further diluted.

It must be stressed, however, that the support of these independent scientists for the deep-sea disposal option is *for this case only*. It is not an automatic endorsement of the policy for other installations.

So what now? The latest development is an offer from Norway to help dismantle the rig. It would be towed, still upright, to a deep-water anchorage in a Norwegian fjord, pending a final decision as to its fate. Our latest information is that this has been done – the rig is now moored in a fjord near Stavanger. Could safe dismantling and disposal be achieved without contaminating the restricted waters of a fjord? We must await developments.

Meanwhile, there is a puzzle. Shell had the full support of the UK Government, and they found powerful (and unexpected) allies in a considerable line-up of knowledgeable scientists. Their original plan would have cost about £12 million, of which some £8 million would have come back to them in tax concessions. Now they have to find an estimated extra £35 million, on which there will be no tax refund. So why did Shell not stick to their guns, explain the contrasted hazards of the two options, stress that this is a one-off case, and so win back public opinion, both in UK and the rest of Europe? In the event, more recent press reports have suggested that Shell may even end up opting for the deep-sea option after all.

John Wright

And while on the subject ...

Readers may have seen coverage of this issue in *Nature* (29 June and 20 July) and those north of the border may also have read an article by Martin Angel (IOS Deacon Laboratory) in *The Scotsman* (6 June). These articles make the point that hydrothermal vents mainly (but not exclusively) on mid-ocean ridges pump out metals in annual quantities that are orders of magnitude greater than what is reported to be on *Brent Spar*. A few hundred (or even several thousand) kilograms of heavy metals leaking from a dumped platform are hardly likely to make much difference to deep-sea ecosystems. Added to which, the structure itself could provide an artificial 'deep-sea reef' environment for fish and benthos, just as sunken ships do. However, to suggest that 'the bacteria on the sea floor would have greeted the arrival of *Brent Spar* as if all their Christmases had come together', as the *Nature* editorial put it, is flagrant hyperbole. Marine bacteria are indeed capable of digesting petroleum, but they aren't really interested in heavy metals except as sulphides (though the physiology of other organisms requires them to take up trace amounts of certain metals) – and versatile though they are, even bacteria can't really cope with radioactive isotopes.

All the same, these articles do help to swing the debate back in favour of using the deep oceans for disposal of at least some industrial wastes. In this case they suggest that the best sites might be not on abyssal plains (where previous research has been focussed) but on or near mid-ocean ridges, where natural concentrations of heavy metals should be sufficient to accommodate most anthropogenic additions (we Europeans would have to go a long way to get to 'our' nearest ridge, unlike the Americans, who only have a short way to go to theirs, from the US west coast).

I'm still uneasy, though. I cannot help wondering why we keep on inventing technological fixes like this. Shouldn't we be trying to stop producing so much waste, instead of looking for new places to dump it? (Including deep-sea trenches again – did anyone spot the 'deliberate mistake' in that item? See below for the answer.) Anyway, as Nisbet and Fowler point out in their *Nature* article (29 June), a more fundamental and pressing environmental problem is overfishing, especially in the North Atlantic. Perhaps Greenpeace could be persuaded to focus on that, when they have finished their (this time praiseworthy) attempts to stop nuclear weapons testing in the Pacific.

Answer (See *Nature*, 20 July, p.208.) It would take 50 000 years or more, not 500 years, for the rig to „be carried into the mantle" – assuming an average plate movement of 5 cm per year the rig would move only 25 m in 500 years! Incidentally, this idea is not new. Readers with long memories may recall that Tim Francis made the same suggestion (also in *Nature*) some 20 years ago.

Plus ça change

In the middle of all the fuss over the *Brent Spar* (see the previous item), I have been putting together my contribution to the *Challenger* Legacy Symposium, held in Southampton from 17 to 19 September this year, to mark the opening of the new Southampton Oceanography Centre.

My almost impossible brief has been to kick off the symposium with something newish about the *Challenger* Expedition itself. I will probably fail. But in scratching about for inspiration I have come across a few published pieces that illustrate, yet again, the truth of the old – and rather distressing – adage that nothing changes very much. Since they are particularly relelvant to the situation of IOS with respect to *Brent Spar* (see pp.4–5), and of NERC with respect to industry in general, it seemed appropriate to share them with you now.

The first is a contemporary well-written and well-informed, but highly critical assessment of the *Challenger* Expedition, prompted by the appearance of the first volume of the official reports in 1880. The cutting was among the papers of P.H. Carpenter, but without attribution, and was reproduced in 1971 in Margaret Deacon's superb book *Scientists and the Sea 1650–1900* where, however, she points out that it was not typical of the reaction in newspapers such as *The Times*. Although the extract has been published at least a couple of times since, it is so interesting that I repeat it here:

The first volume recording the adventures of the Challenger yachting trip is now out, and the other fifty-nine volumes will be ready in less than a century. Everybody knows that Mr. Lowe sent a man-of-war away laden with Professors, and that these learned individuals amused themselves for four years. They played with thermometers, they fished at all depths from two feet to three miles; they brought up bucketfuls of stuff from the deep sea bottom; and they all pottered about and imagined they were furthering the grand Cause of Science. Then the tons of rubbish were brought home, and the genius who bossed the excursion proceeded to employ a swarm of foreigners to write monographs on the specimens. There were plenty of good scientific men in England, but the true philosopher is nothing if not cosmopolitan; so the tax-payers' money was employed in feeding a mob of Germans and other aliens. The whole business has cost two hundred thousand pounds; and in return for this sum we have got one lumbering volume of statistics, and a complete set of squabbles which are going on briskly wherever two or three philosophers are gathered together. I believe the expedition discovered one new species of shrimp, but I am not quite sure.

The second series of pieces is from a controversy that took place almost 100 years later. As *Scientists and the Sea* appeared, the technical journal *Hydrospace* (now metamorphosed through several intermediate existences into *Offshore*), was carrying a lively series of exchanges about where British marine science and technology should be going, and the government's role, if any, in determining this. It had begun in the April 1971 issue of *Hydrospace* in which the editor, Robert Barton, had written an item under the title "CMT is Three Years Old".

The Committee on Marine Technology had been established under the Wilson Government in 1968 with representatives from the DTI, the MoD (Navy) and NERC. Its terms of reference were to review activities in marine technology and to identify economically promising projects; to stimulate users to define their technological needs; and to recommend technological programmes to meet these needs. The gist of Barton's article was that the CMT had so far done nothing worthwhile and that it was about time it announced imaginative plans for the future, comparable with those existing in France under the guidance of CNEXO.

The August 1971 issue of *Hydrospace* carried a response from a 'Businessman' pointing out that there had been a recent change of Government and that the policy of the Heath administration had been clearly defined – "to allow industry to decide what is worth doing, and then let industry get on with it". The 'Businessman' thought this was the correct policy and guessed (and clearly hoped) "that we shall probably never hear from it [the CMT] again".

Barton's reply was a long editorial spelling out in more detail his criticism of CMT and its associated Marine Technology Support Unit (MATSU). First, he suggested that 'Businessman's' view of the role of government was oversimplistic, claiming that "for the wellbeing of the nation ... it is Government's responsibility to work with industry to supply those essentials that industry alone is unable to supply". He accepted that although some of the types of projects he was thinking of might be tackled by industry anyway, "they would be tackled at a time and at a speed dictated by the purely economic criteria of commercial organisations: in other words, market forces." (Where have I heard that phrase more recently?)

What was needed, thought Barton, was for the Government to identify a number of major oceanic projects which it intended to support, so that industry could develop, and eventually market, some of the required technology. He suggested a way forward, including the immediate scrapping of CMT and its replacement by a Commission of Enquiry headed by someone "capable of making and implementing forthright and bold decisions", and proposed a number of possible general areas for the major projects.

Some of these, such as fisheries and fish farming, have a somewhat hollow ring in the 1990s, but others, including deep sea-bed prospecting, environmental monitoring and manned submersibles, are as relevant today as they were then. Throughout the document, Barton compared the situation in the UK unfavourably with that in other nations, particularly the US, France, Germany and Japan.

Barton's editorial apparently caused something of a stir. As a result, in the December 1971 issue of *Hydrospace* he published the *Challenger* criticism that he had just seen in Margaret Deacon's book, so that "Those who felt the lash can perhaps take comfort from the fact that criticism of British marine technology is by no means new."

He might equally have referred to an editorial article published in *Nature* in June 1872, almost exactly 100 years before his own and which I have just come across anew after many years. Headed 'The tides and the Treasury' it addressed the general question of government support for marine science, and had been prompted by a recent exchange between the British Association and the Treasury (of Gladstone's first Liberal administration of 1868–74) on the subject of tidal research.

The BA had for some years been undertaking tidal observation, analysis and prediction supported by tiny amounts of money from the Association's own very restricted coffers. Encouraged by the results, particularly in view of their importance to a largely maritime economy, in November 1871 the Council had resolved to apply to the Treasury for financial support to continue the work. Accordingly, in May 1872 they asked for the princely sum of £150 (about £10K now) to supplement the £600 already provided by the BA "to secure the continuance of the investigation".

The reply to this memorial (wrote the *Nature* author) *is such that, unless printed in extenso, many persons would, we feel certain, refuse to believe that such a document could have been issued with the sanction of a civilised Government. We therefore now append it:-*

> *"Treasury Chambers, June 3, 1872*
>
> *Sir, – The Chancellor of the Exchequer has referred to the Lords Commissioners of Her Majesty's Treasury the memorial of the British Association for the Advancement of Science forwarded to him with your letter of the 21st ult., praying for Government assistance in connection with tidal observations.*
>
> *I am to state that their Lordships have given their anxious attention to the memorial, and that they are fully sensible of the interesting nature of such investigations; but that they feel that if they acceded to this request it would be impossible to refuse to contribute towards the numerous other objects which men of eminence may desire to treat scientifically.*
>
> *Their Lordships must, therefore, though with regret, decline to make a promise of assistance towards the present object out of public funds.*
>
> *I am, Sir, your obedient servant,*
> *William Law"*

Resisting, but not very successfully, the temptation to treat this response with sarcastic indignation, the *Nature* editorial goes on to broaden the issue to address what they describe as "the great question which England must soon solve":

"What is the scientific work which the Government is bound to perform for the benefit of the community at large; and what is the scientific work which cannot be performed by State agency so well as by private enterprise?

So long as individuals, and bodies of individuals attempt to do what should properly devolve on the State, so long will a Government, destitute, like ours, of a particle of the scientific element, neglect its legitimate duties. We therefore strongly counsel the British Association, at their next meeting, to take measures for classifying science under the two great heads of Public and Private, to supply the Government with a full statement of all comprehended under the first head, and to refuse a single penny of its funds to any object not distinctly appertaining to the second. This will bring on a crisis – and we want a crisis.

As to the Government, what can we say? Poor Mr. Law's letter speaks volumes. It [the Government] plaintively confesses its total inability to grasp any State scientific problem lest it should have to deal with all. We have no heart to spurn a prostrate form so lowly and humble; but can we not raise it? Can we not introduce into our Administration a source of knowledge on which they can rely to guide them in the choice of scientific objects really profitable to the nation, and officials able to insure a proper system for the attainment of such objects?"

Though he must have been fully aware of it, the *Nature* author does not mention the fact that only two months earlier, in April 1872, the Government had given its final approval for the *Challenger* Expedition, including a commitment to an expenditure of some thousands of pounds in addition to the normal naval expenditure of keeping the ship in commission. Margaret Deacon suggested (*Scientists and the Sea*, p.334) that the difference between the two situations was that while the *Challenger* Expedition was a 'one-off', involvement in tide research might result in a long-term commitment.

In the event, the total cost of the *Challenger* venture, including the publication of the results over more than twenty years, turned out to be relatively enormous, estimated at close to £200K then and equivalent to well over £10 millions now. Perhaps Gladstone's Liberal administration, which authorised it, failed to appreciate this financial commitment. Or perhaps they assumed that any future unforeseen costs would have to be borne by a future administration. As it happened, Disraeli's Tory Government was elected in 1874 while the *Challenger* was still away, to be replaced by Gladstone's Liberals once more in 1880 – just as the costs of publication must have been building up nicely!

I leave it to you, dear reader, to draw any parallels with present-day Government White Papers or the arrangements for major new oceanographic laboratories. But I will draw your attention to one aspect of science funding of which *Brent Spar* has made me acutely aware. Throughout the affair, and in the face of contrary views, including inuendos by *Private Eye*, IOS Deacon Laboratory and NERC have claimed independence of both the oil industry (Shell in particular) and the Government. This status seems to suit both organisations and, I suspect, is grudgingly respected by Greenpeace. But how are we to retain it? Although we continue to receive some government funding via the science vote, as with all government research laboratories, this source of finance has declined significantly in recent years; in our case, we get less than half our funding by this route. The shortfall has to be obtained from other sources – government departments, the European Union, industry or virtually anyone else who will pay. But if, in this particular case, we had been successful in obtaining a contract from, say, Shell, to carry out a pre-disposal survey or post-disposal monitoring, who would still believe that we were truly independent, no matter what the contract might say about putting the results in the public domain? If we don't try to get our hands on such contracts, and the Government continues to be so parsimonious, how will we survive? And if we don't survive, to whom will the Government, or anyone else, turn for a truly independent, but properly informed, opinion. I don't have any answer, except to suggest some form of levy on the offshore oil industry to be used to fund deep-sea research, but not under the control of the industry. I can see all sorts of problems with this solution, but the problem needs urgent attention.

As the *Nature* editorial said in 1872, *'Can we not introduce into our Administration a source of knowledge on which they can rely to guide them in the choice of scientific objects really profitable to the nation, and officials able to insure a proper system for the attainment of such objects?'*

Tony (A.L.) Rice
Institute of Oceanographic Sciences Deacon Laboratory

Rarity: a biological conundrum

Until a few months ago I understood what it meant if a species was said to be rare; now I am not so sure. On *Charles Darwin* cruise 72 we caught a striking isopod which I happened to photograph and whose picture subsequently appeared on the cover of *NERC News* in October 1993. It turned out to be a specimen of *Xenuraega ptilocera* – only the seventh ever caught. Most people would agree that it is rare, but is it merely rare in collections, or is it really rare in nature? If it is really rare, is it because it is a species that is on the road down to extinction? Or because it is on the way up from speciation? Or is a characteristic of its ecology that it *has* to be rare?

It might be argued that because it has been caught so infrequently, it *is* rare. But how much of the volume of the ocean has ever actually been scientifically observed, i.e. has been filtered through a net, so that the presence of this species might be detected? Throughout the history of biological oceanography maybe 200 km^3 or so have passed through scientists' nets. At IOS, our largest sampler, the RMT 8, filters about 25 000 m^3 per hour of fishing at our normal towing speed of 2 knots. So to filter just one km^3 takes 400 hours of fishing, which is about what we achieve in three research cruises!

During the nearly 30 years I have worked on oceanography at IOS, we have probably filtered less than 10 km^3, and most of this effort has probably been outside the isopod's distributional range. Although the total range of the species may extend through quite a small percentage the ocean's total volume of about 1 368 million km^3, its habitat may be in excess of a million km^3 so that its global population may be far larger than some terrestrial animals with more restricted distributions which are considered to be quite common! Even within its range, like nearly all pelagic species it probably has a very patchy spatial distribution, perhaps in time as well, increasing the chances of not catching it! So can we really claim that this species is rare? The chances of catching a truly rare pelagic species in the deep ocean with a population of just a few thousands may be so small that, if such a species can persist, then it will probably remain unknown to science. Even if it gets caught there is a good chance that a rare species will not be recognised. A very large species, like the Megamouth shark, will be noticed, but a single specimen of a rare copepod in amongst several tens or even hundreds of thousands of others, is very likely to remain unobserved. If the sample is collected as part of a programme to study processes, as most are nowadays, then only the dominant species will be identified. Even if it is part of an ecological or distributional study, only a fraction of the sample is likely to be analysed, because of time and resource constraints. Even if it happens to be in the fraction analysed, then as a single oddity it is most likely to get consigned to an unidentified category, unless that even rarer animal, the experienced taxonomist, happens to be around. Luckily these rare species do tend to be aggregated in areas where sorting and identification of species is going on! My own expertise in the taxonomy of halocyprid ostracods is now unique in the world – not a boast but a sad comment on the way biology is being subverted away from taxonomy, that area of study which is fundamental to all other biological and multidisciplinary research.

In terrestrial environments, many rare species have very restricted distributional ranges, and yet within those ranges they may be quite abundant. The inhabitants of oceanic islands are an obvious example, and the dynamics of selection associated with native (endemic) species on islands is very readably described in Weiner's recent book on the finches of Galápagos (see Further Reading). For many of these island species, straying off the island means certain death, and so many lose their ability to disperse – birds and insects tend to lose their ability to fly. In the oceans, similar island situations occur associated with life on the sea-bed in the vicinity of hydrothermal vent and cold seep systems, and on the tops of guyots. Guyots, in terms of evolutionary time-scales, are permanent features, so may well be directly analogous with islands above the water. Hydrothermal vents are ephemeral, and the initial hypothesis that vent inhabitants may have lost their powers of dispersal is being proved wrong. These species have had to retain their dispersive abilities, since every few tens of generations they are having to colonise a new vent as the flow of their present system is stemmed.

Another deep-sea benthic example of rarity expressed as very scattered patches of abundant animals, is seen in the highly localised aggregations of the sponge *Pheronema*, found by Tony Rice and his colleagues in the Porcupine Seabight to the south-west of Ireland (see also pp.16–17 of this issue). Not only are the sponges distributionally 'rare', but they also play host to several other species, including a spider crab and some ophiuroids, whose life-styles seem to be totally dependent on the sponges, and so these associates are similarly 'rare'.

In the pelagic environments of the open ocean, currents and turbulent mixing result in all species having relatively broad ranges, so rarity in these circumstances is expressed in another form by species being very wide-ranging yet always in very low abundances. On land, these are often species which are well on their way to extinction: they are losing the battle for survival, either because they are facing competition from other species, or because climate is changing their habitats faster than they can adapt.

However, many species cannot help but be rare, because of the ecological niche they occupy. There are top predators which have to range over immense areas to find enough food. There can only be a few hundred lions on the whole of the Serengeti Plains because of the limited carrying capacity of that ecosystem to support a lion population. So, in this sense, the great white shark has always been rare and will always remain so. Likewise, the physiological demands of large whales may limit the maximum size of their populations, so that despite their immense size and tendency to form obvious aggregations, ecologically they have always been rare. However, such large animals will almost certainly have a substantial top-down influence on the ecology of the habitats they occupy. Consequently, the fact that they are rare does not necessarily mean that their continuing survival is a side-issue with little or no ecological relevance. If this is true of large animals, perhaps it can also be true for the smaller, inconspicuous species as well?

There are species that have both small ranges and small populations and these must be the most vulnerable to sudden changes in their habitat caused by climate change or anthropogenic impact. These are often inhabitants of special or extreme environments: for example, the relict faunas found in caves and lava tubes, or some of the shallow-living benthic species found on the summits of isolated guyots in mid-ocean.

Other species have evolved ploys which rely on rarity to ensure survival. These include the species that pretend to be what they are not – the mimics of distasteful or venomous species which advertise their nastiness with bright colours and blatantly overt displays. If the mimics which display the same colours and overt behaviour become relatively too common, then the predators never really learn to avoid the exhibitionists, and both mimic and mimicked get eaten.

There are also the species that exploit ephemeral habitats. In terrestrial environments, so much of what we see around us is highly disturbed by human activity so that the commonest species are the opportunistic and normally ephemeral weeds that only proliferate wherever there is a disturbance. However, when Fred Grassle first carried out recolonisation experiments on the deep sea bed, the first animals to arrive in vast numbers were species of polychaete worm which proved to be new to science.

Even in the open ocean our activities have favoured substantial increases in some of these inhabitants of ephemeral habitats. Goose barnacles must have become far more abundant over the last few centuries because the amounts of floating flotsam and jetsam have increased substantially since ocean voyaging became commonplace. Similarly, even rarer natural substrata will have increased in frequency, like logs either found floating or waterlogged on the seafloor, which are almost without exception being consumed by wood-boring molluscs and amphipods. Carcasses of large fish and whales are consumed by hosts of scavenging amphipods which seldom get collected in nets and trawls. Despite such habitats being extremely infrequent, the rapidity with which a log floating in the ocean is colonised by ship-worms (*Teredo*), gribble and goose barnacles means such species cannot really be described as rare.

Rarity can be statistical. In a sample or a collection of samples, those species which constitute a very small proportion of the catch – say contributing <0.1% of the specimens in a collection – are often considered to be rare. In 1974 we carried out some repeated sampling in the North Atlantic to the north-west of Cape Finisterre (44°N, 13°W), at depths of 100, 250, 450 and 600 m – collecting a total of 96 samples. Howard Roe worked up the calanoid copepods, and I have re-examined his data which are held in the IOS Deacon Laboratory biological database. Numerically, over 90% of the catches in the macroplankton net (RMT 1) were copepods. Nearly 95% of all the 520 142 copepods identified, belonged to just three species, so the samples showed low diversity in terms of dominance. Another 15 species each contributed between 0.1 and 1% to the total (making up another 4.11%), 35 species each contributed 0.1 to 0.01% (another 0.85%), and the remaining 53 species each contributed <0.01% (the remaining 0.06%). There were 23 species represented by <4 specimens. These were rare in the samples, but are they really rare in the ocean?

For some of the species, the bathymetric range covered by the samples was recognisably unrepresentative. Others may have been expatriates; for example the three specimens of *Calanus finmarchicus* were clearly at the southernmost margin of the species' geographical range. Sixteen of the species are known from off the Canary Islands, and six of these also occur in the Mediterranean. There are just four candidates for true rarity, but only an indeterminate species of *Arietellus* seems finally to qualify. Even so, the majority of known oceanic species never appear to occur abundantly. So what contribution are they making to the ecology of the oceans? Should we care about whether they survive or not? How do they manage to persist in the face of apparently overwhelming competition from the dominant species? I have no answers to such questions, and that worries me.

Thus the rarity of a species in a collection may be because it is on the fringes of its geographical or bathymetric range, or because its seasonal peak in abundance was missed. Least likely of all, is that the species truly is rare. I remember the excitement, when we were first starting to sample at great depths, of catching a specimen of a very strange fish, *Monognathus*. At that time less than ten had ever been collected, but now we know that they occur consistently (although never abundantly) in the abyssopelagic pelagic zone at depths greater than 4000 m. Its rarity in earlier collections was the result of our inability to sample its remote habitat.

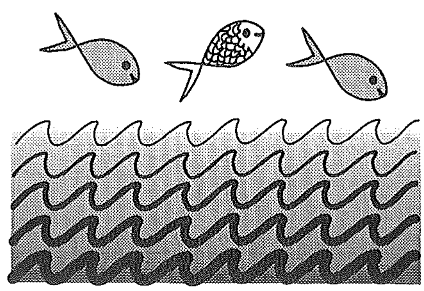
At a time when the Biodiversity Convention is focussing attention on the need to conserve species, and rare species in particular, it behoves us to understand rarity (real or apparent) more clearly. Is the apparent rarity of a species just a sampling artefact? Is the species rare because of its ecology? Or is it a new emerging species, or one well down the road to extinction? Perhaps most importantly, do the vast majority of species that never appear to be abundant play any sort of ecological role? Should we really put so much effort into the conservation of rare species, or should we be more concerned about those species that are dominant in driving ecological processes?

Martin Angel
IOS Deacon Laboratory

Further Reading

Gaston, K. (1994) *Rarity*, Chapman and Hall.

Weiner, J. (1994) *The Beak of the Finch: Evolution in Real Time*, Jonathan Cape.



Professor Ray Beverton CBE, FRS Fisheries Biologist, 1922–1995

The name of Ray (R.J.H.) Beverton is famous to fisheries biologists all over the world, but his administrative and teaching abilities were evidently as considerable as his scientific talents. He came to fisheries biology almost by accident, his scientific education having been interrupted (like that of many others) by the outbreak of World War II. At that time he had just completed Part I of his Natural Sciences Tripos at Downing College, Cambridge, and he became a 'boffin' in the Operational Research branch of the Services, where – among other things – he worked on the development of polystyrene and latex for coaxial cables used in radar systems.

In 1945, he was persuaded to spend a year with the Government Fisheries Laboratory at Lowestoft, allegedly to "do something practically useful" before resuming his academic career – a curious perception, if true, of someone who had just spent five years on what could justifiably be considered very "practically useful" research! Be that as it may, Beverton was immediately sent to the Arctic on a commercial trawler to help in the design of a new fisheries research vessel (the *Ernest Holt*). It seems he was a poor sailor, suffering so badly from sea-sickness that he felt obliged to write no less than three letters of resignation. Fortunately, none of them was ever posted, because it was during this period that he had begun to formulate his ideas on the exploitation of fish stocks. He now (1946) returned to Cambridge, completing Part II of his Tripos with the top First of his year, winning the Smart Prize for Zoology in the process, as well as gaining a Blue for soccer. Being, in addition, a lover of music, he was also an accomplished pianist.

He went back to Lowestoft after graduating, and was joined by S.J. (Sydney) Holt, both of them having been recruited as biologists with a knowledge of mathematics. Together they developed Beverton's early ideas on the dynamics of fish populations, and spent several periods at sea, studying plaice, cod and other commercial species (unfortunately, Holt suffered even more from sea-

sickness than his colleague and had to resign after a few years). The result of their researches was the publication in 1957 of a classic work of ecological literature: *On the Dynamics of Exploited Fish Populations*, widely held to be the most cited work of all time in fisheries research. Despite this acclaim, it seems that Beverton's conclusions have since been all too frequently ignored, through political indifference and in the interests of short-term expediency. *Plus ça change.*

He left the Fisheries Laboratory in 1965 (by which time he had become its Deputy Director*), and took on a new challenge: helping to set up NERC, as its first Secretary. This task involved bringing together institutions as diverse as the Nature Conservancy, the Geological Survey, the British Antarctic Survey, the National Institute of Oceanography, and the laboratories of the Development Commission. As NERC's executive head, he subsequently supervised the move of the headquarter's offices from London to Swindon. During this period he was appointed CBE (1968) and elected FRS (1975).

Resigning from NERC in 1980, he held part-time teaching and research posts at Bristol and Southampton, and in 1983 became honorary professorial fellow at the University of Wales Institute of Science and Technology (UWIST), where he much enjoyed supervising student field courses at the university's field centre near the River Wye. His many other activities now included editing a journal of marine science and advising foreign organisations on matters such as conservation of minke whales and development of fish stocks in Lake Malawi, as well as serving on numerous committees. Thus, he was chairman of the management committee of Millport Research Station, head of the British delegation to the IOC, chairman of the Natural Sciences Advisory Committee of UNESCO, president of the Fisheries Society of the British Isles, and a trustee of the WWF.

In 1984 he became Professor of Fisheries Ecology, head of the Department of Applied Biology in 1987, and in 1988 (after the merger of UWIST with University College, Cardiff), he was appointed to head the School of Pure and Applied Biology at the newly created University of Wales College of Cardiff. This post involved integrating four separate departments and establishing new degree schemes and research groups. He retired again in 1989, at the age of 67, but went on delivering lectures and keynote addresses throughout the world, and published several more research papers, deemed by many to be as important as any he had produced in the preceding 40 years. He continued to enjoy fishing and sailing, and playing and listening to music, though deafness in his later years somewhat dulled his appreciation.

Ray Beverton was a courteous and gentle man, who was very supportive of the Challenger Society in general and *Ocean Challenge* in particular, both during as well as after his time as President of the Society (1990–92), and he will be sadly missed. Members' sympathies are extended to his wife, Kathy, and his three daughters.

* Additional details of Beverton's career at MAFF can be found in A.J. (Arthur) Lee's book, *The Directorate of Fisheries Reaearch: Its Origins and Development*, published by MAFF in 1992.

News and Views

'Goldrush Begins Beneath the Waves'

I wonder how many readers of these columns view the idea of deep-ocean mining with unalloyed enthusiasm and optimism. The mineral potential of the deep oceans is attracting more media attention nowadays, some of it very bullish, promoted in part by recent publications such as the Marine Technology Directorate review described below, and by discoveries such as those reported in the last issue of *Ocean Challenge* (Vol. 5, No.2, pp. 16–17).

The headline above came from a two-page spread in the *Daily Telegraph* (March 26), which highlighted phrases like "... marine mineral riches open up a world of opportunities" and "An undersea mineral 'mine' is growing at a rate of 10 million tonnes a year," this last being a specific reference to manganese nodules. There are estimated to be of the order of 10^{12} tonnes of nodules on the deep Pacific floor alone, but potential entrepreneurs may not realise that the growth rate of '10 million tonnes a year' represents incremental sub-micron layering on individual nodules, not new nodules appearing fully formed. I can just see a boardroom meeting at which it is decided that an annual nodule-mining rate of, say, 8 million tonnes would provide a comfortable sustainable yield.

Manganese nodules form a layer roughly one nodule thick, covering great areas of the sea-bed on abyssal plains, where they can reach concentrations of 25 kg m^{-2}. Even in a rich nodule field, therefore, to get a good bulk carrier load of, say, 250 000 tonnes of nodules, you need to 'hoover' some 10 km^2 of sea-bed, comprising nodules and surrounding abyssal plain sediments, which would be washed back into the sea. 10 km^2 is an area greater than that of most large land-based open-pit metal mines that have been operating for decades, yielding millions of tonnes of ore annually. You'd need a lot of sea-bed to achieve that sort of production. How many people realise that the deep sea can no longer be dismissed as a barren desert largely devoid of life, where nothing much happens; that it is in fact rather inhomogeneous with high biodiversity (*Ocean Challenge*, Vol. 4, No.1/2, pp.19–20)?

With respect to polymetallic sulphide deposits formed in hydrothermal systems associated with sea-floor volcanism, the article says "deposits gathered around sea volcanoes may be mined by drilling vertically down through the flanks of the volcano and then tunnelling outwards towards the deposits" (cf. the following review). Where mineral deposits (nodules or sulphides) lie in international waters (beneath the high seas) it may be presumed that the International Sea-Bed Authority will exert pressure (under the Law of the Sea) on mining consortia to operate with minimal damage to the marine environment. Nations with deep-sea deposits within their exclusive economic zones, however, may be less squeamish and could see immediate economic gain as being more important that protection of marine ecosystems.

"Oceans might literally be gold mines (each cubic mile containing dissolved gold worth about £10 000) ...'. Not really. That's about 2 kilograms of gold in 6 km^3 of seawater, and you'd have to assume 100% recovery. Seawater mining of gold and other metals seems to be a non-starter, unless you are already processing large volumes of water, as in desalination plants or OTEC (Ocean Thermal Energy Conversion) installations. The latter also feature in the article as a means of generating pollution-free electricity from the temperature gradient across the thermocline (the operating principle is the same as that of air conditioners or fridges). Trouble is, the efficiency of conversion is so low, you'd need power stations bigger than *Brent Spar* to yield the power output of conventional fossil-fuel or nuclear stations (10^3 MW). The options for siting such power stations could be a bit limited, given that the electricity would presumably be needed for industrial conurbations.

If history is any guide, we may expect exploitation of the sea's physical resources to increase rather than diminish, and to move into progressively deeper waters. Perhaps by the time deep-sea nodule mining starts (early next century?) oceanographers will have found a way to minimise any damage to the marine environment. What do you think?

The next item reviews a new publication on sea-bed mining.

Potential Mineral Wealth from the Oceans (Review)

As the depletion of land-based mineral resources continues apace, there is growing interest in the deposits, now becoming increasingly well documented, on the ocean floors. Recent discoveries in the equatorial Atlantic, described in the last issue of *Ocean Challenge* (pp. 16–17), are just one example.

Long-term research in Imperial College's Marine Minerals Resources Programme, under the direction of Dr David Cronan, is helping to define the most promising areas for exploitation for the metals cobalt, copper and nickel. Results of this research are summarised in a 20-page illustrated booklet *Evaluation of Marine Minerals in EEZs.** The booklet concentrates on two types of marine mineral deposit, manganese nodules and polymetallic sulphides deposited by hydrothermal activity. Manganese nodules consist mainly of iron and manganese oxides, but contain larger than normal proportions of trace elements, such as nickel, cobalt and copper (4% or more combined). Work has focussed on evaluating the resource potential of manganese nodules in the exclusive economic zones of some Commonwealth South Pacific Islands, but it should be applicable to other nodule deposits world-wide.

The most important factor in any such evaluation is the grade, expressed as combined percentages of nickel + copper + cobalt. The research has established a pattern in the variability of grade and has helped to explain the underlying causes. In the region of the Cook and Line Islands, the highest-grade nodules lie at latitudes 3–4° S, which has been related to the high biological activity of equatorial waters. The decay of organic matter promotes chemical reactions which concentrate nickel, copper and other metals in the nodules. The precise latitude of the peak concentration depends on the extent to which these reactions are affected by the dissolution of calcium carbonate at depth, and by the presence of biogenic silica.

'Black smokers' – hot plumes associated with volcanic activity in deep water – can deposit massive

continued >>

Potential Mineral Wealth cont.

polymetallic sulphides containing iron, copper and zinc, and sometimes silver, lead and gold as well. Several of these deposits exposed on the ocean floor are of such size and content that they will one day be considered as mineable resources, for example in the Red Sea.

The booklet describes investigations of deposits formed at convergent plate margins around islands in the south-western Pacific, and also estimates the likely occurrence of valuable polymetallic sulphide deposits around Pitcairn Island and in the eastern Mediterranean and the Caribbean. Sea areas near land-based gold deposits would be a good place to start looking, and indeed gold-rich sulphide deposits have recently been discovered in the Lau, North Fiji and Woodlark basins. For the south-western Pacific, Dr Cronan suggests that the best prospect for sea-bed polymetallic sulphide mining would be submerged slopes of volcanic islands, where they could be reached by tunnelling out from land.

The exploitation of marine minerals has been partly restrained by legal problems of mineral rights over the sea bed. Where countries have declared exclusive economic zones, they have sole mineral rights over an area of sea-bed up to 200 nautical miles from their coasts. With the UN Convention on the Law of the Sea (UNCLOS) now in force (since November 1994), mineral development is likely to be encouraged in the International Sea Bed Area more than 200 nautical miles from land.

Further information about MTD:
The Marine Technology Directorate Ltd (MTD) is based at 19, Buckingham Street, London WC2N 6EF, Fax +44 (0)171-930-4323; Tel. +44(0)171-321-0674.

MTD is a UK-based association with international membership. Members have significant interests and capabilities in ocean-related technology, and come from industry, government, research establishments, academic institutions, the UK Engineering and Physical Sciences Research Council, and the Royal Academy of Engineering. MTD operates programmes with a total value of £8M a year in the broad areas of research and development, and technology transfer.

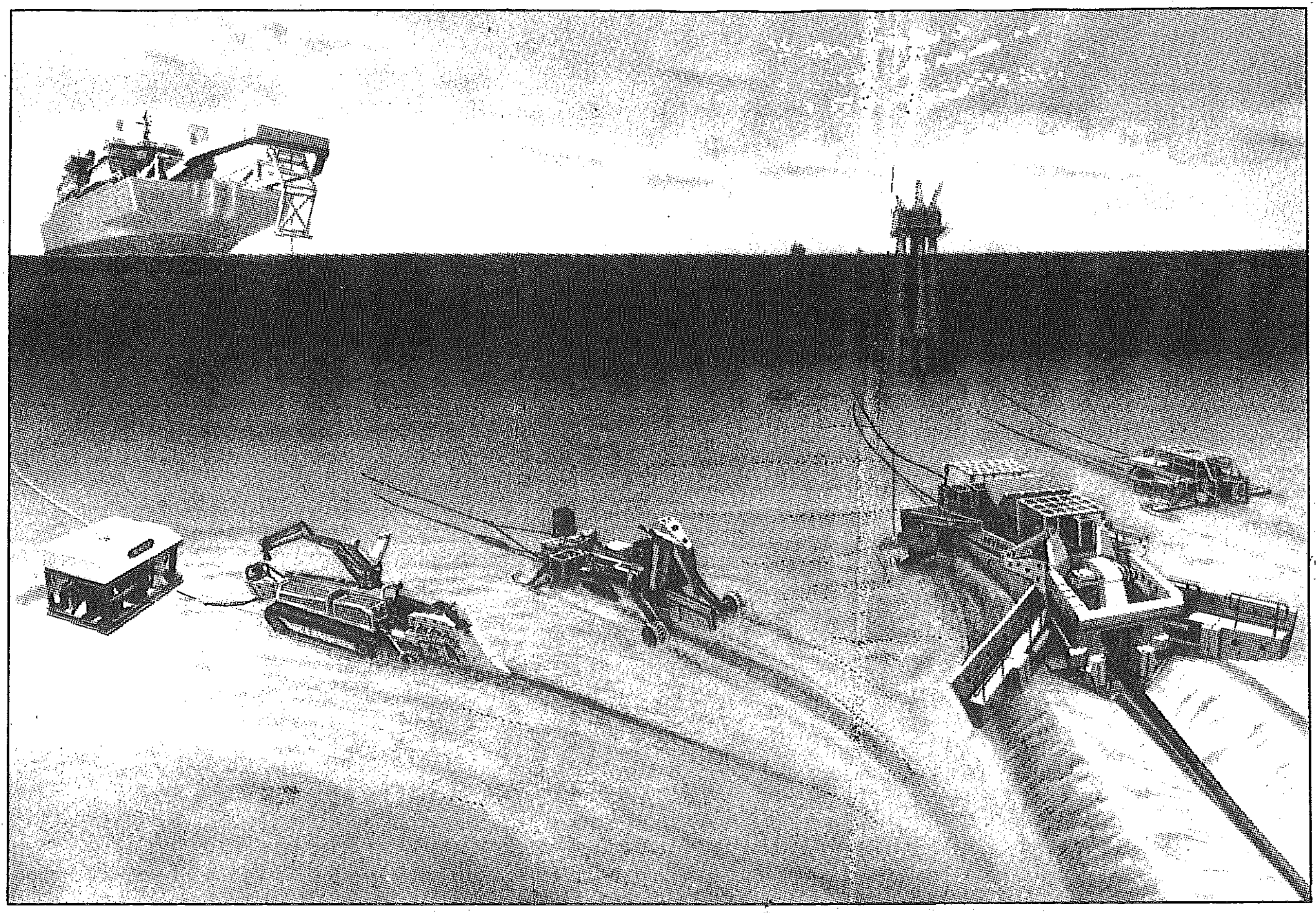
The Marine Research Review series was established with support from the DTI's Oil and Gas Projects and Supplies Division (OSO). The first five titles are: Structural Integrity Monitoring for the Offshore Industry; Automated Scene Interpretation for ROVs; Vision Systems for Subsea Robotic Tasks; Intelligent Control of ROVs and Manipulators; Acoustic Communications for ROVs.

**Evaluation of Marine Minerals in EEZs, Marine Research Review 6,* ISBN 1-870553-20-9, price £15, is available from the Publication Sales Department, MTD.

Ploughing the Sea-bed

The network of submarine cables criss-crossing the world's oceans is being up-graded as high capacity fibre-optic cables replace the older copper-cored variety (which could thus become available for use by scientific institutions for research; *Ocean Challenge*, Vol. 2, Winter 1991, pp.6–7). So, more than a century after the first trans-Atlantic telegraph line was laid on the sea-bed, underwater cable technology evidently continues to thrive.

Below: Artist's impression of the underwater ploughs that lay fibre-optic cables across the Atlantic
(By Joanna Walters; The Guardian *©)*



Cables must be buried to protect them from disturbance by fishing gear and currents, or from fouling (or damage) by marine organisms. The same requirement applies to oil and gas pipelines on the sea-bed, and the number of these will grow as the offshore petroleum industry continues to expand worldwide.

A small company on Tyneside – Soil Machine Dynamics (SMD) – has roughly 75% of the highly specialised and lucrative world market in submarine cable-laying and pipe-trenching ploughs, which can cost over £1M, because each machine is a custom-built one-off model.

The remotely controlled ploughs are towed by surface ships along the sea-bed, digging furrows and burying communication cables or oil and gas pipelines. The company's submarine earth-movers have been towed across the floor of all three major oceans. In 1994, SMD finished burying over 1500 km of cable for a multimedia communication service linking Canada with four European countries, a project costing more than £200 million. They also won the 1994 Royal Academy of Engineering MacRobert Award for innovation in engineering.

Mediterranean Turtle Watch

In 1992, Glasgow University was invited by the Society for the Protection of Turtles to conduct a survey of the marine turtle nesting beaches on the coast of Northern Cyprus. Each year since, a team of students and staff from Glasgow University have been helping to monitor the nesting and hatching activities of the endangered green (*Chelonia mydas*) and logger-head (*Caretta caretta*) turtles. In the Mediterranean there are estimated to be only 300–500 green and 2000 loggerhead females nesting annually. With such low numbers it is crucial that all remaining nesting beaches are monitored and protected so that these endangered species avoid extinction.

According to the preliminary report of the 1994 Glasgow University Turtle Conservation Expedition, the 1994 turtle season was by far the most successful since the project began in 1992. Over 80 beaches in North Cyprus were monitored from the end of May to the beginning of October. It is estimated that in 1994, 154 green turtles and 173 loggerheads nested on the shores of North Cyprus, representing approximately 30% of the green and 9% of the loggerhead turtles in the Mediterranean. North Cyprus is therefore an extremely important nesting site for both species, in particular the green turtle. Successful hatchlings were recorded in only about 40% of the nests. Of the rest, about 30% were predated and 30% did not hatch because of unsuitable incubation conditions. Several nests were transplanted because of unsuitable nesting conditions (e.g. laying too close to the water which may lead to flooding of nests), and they subsequently hatched successfully. Over three thousand hatchlings were liberated into the sea. Hatchlings not yet vigorous enough for the sea were kept in follow-on accommodation until fully developed.

One of the main successes of the 1994 Expedition, with the help of officers from the Department of the Environment, was the closure to the public of the two main nesting beaches at Alagadi between the hours of 8 p.m. and 8 a.m. These beaches were sites for night-time work, recording morphometrics and behaviour, and tagging of nesting females. At Alagadi, a high level of human activity impinges on a prime nesting habitat, and education and public awareness were a major part of the work. Educational leaflets and children's books were handed out every weekend when beach usage was at its highest. Expedition members also gave talks to schoolchildren, officials, and members of the public, concerning the threats to marine turtles, and possible remedial measures.

The 30% of nests being predated represent a real problem that needs to be addressed. One of the students conducted a successful investigation into caging methods of protecting nests. There are plans to set up a new base on the west of the island where a hatchery can be established, and areas of the beaches can be caged off to prevent dogs and foxes reaching the nests.

Continuation of this work is crucial for the protection of marine turtles nesting in North Cyprus. The plan is to work closely with local authorities and volunteers with the aim that in future years they will be in a position to run this project unaided.

For further information, contact:
Brendan Godley and Annette Broderick, Department of Veterinary Anatomy, Glasgow University Veterinary School, Bearsden Road, Glasgow G61 1QH, Scotland. Tel. 0141-339-8855, extn 6910; Fax: 0141-330-5715.

Aegean: Sea of Troubles

In reference to the article 'Battle in the Aegean: not many dead ... yet', I respectfully would like to point out that your comment misses the essence of the matter. The problem is not mainly one of geographical division and territorial waters. Most islands shown on the map are populated and they have a right to feel safe, especially in an area where conflicts, wars and invasions have not been rare even in the recent past. International Law (as indeed any form of law) is especially helpful in such areas as it provides a 'standard' for sorting out differences which otherwise may be sorted out in unwanted ways.

Allow me also to point out a few other facts: (1) all the nations in the Black Sea, including Russia, face a similar problem to Turkey but none has described this situation as *casus belli* (reason for war) as Turkey did; (2) all the Black Sea states have to sail through the Dardanelles (regulated by Turkey) without having any other passage to the Mediterranean (with the exception of Russia), while Turkey has of course its extensive southern coast in the Mediterranean and, as you correctly point out, its 'median line' territorial water to sail from the Black Sea to the Mediterranean, if that is the problem; and (3) Turkey has already exercised its right to extend its territorial water to 12 miles in the Black Sea.

Faithfully yours

Michael N. Tsimplis
Proudman Oceanographic Laboratory
Bidston Observatory
Merseyside

IRONEX: Was Science Really Highjacked?

John Wright's piece on IRONEX ('IronEx and the hijacking of science', on p.20 of the last issue) gives the impression that the experiment went ahead because funding agencies were tripping over themselves to give money to an idea touted by the scientists as a 'techno-fix' cure for global warming. Now, normally I too would subscribe to the view that our political masters are power-mad despots who are just waiting for a chance to implement some madcap scheme to eco-engineer the planet. However, I'm afraid that in this particular instance the reality was rather different. The scientists involved have consistently tried to pour water on the eco-engineering idea, regarding it as, at best, irrelevant and, at worst, downright dangerous. However, the techno-fix implications of the experiment also made the funding agencies very shy of it, so that it nearly did not go ahead at all.

IronEx, you'll remember, was an experiment to test the idea that in some parts of the ocean (the equatorial Pacific and the Antarctic in particular), availability of iron limits the productivity of the plankton. In these regions, the more traditional nutrients (nitrate and phosphate) are present in substantial quantities in surface water, so they can't be the limiting factor. The idea that iron might be limiting in some circumstances has been around since the thirties and the work of Harvey at Plymouth, though in recent years it has been John Martin at the Moss Landing laboratory in California who has been associated with it. The idea of a small release to test the iron hypothesis in the open ocean became a real possibility only very recently, with the development of the SF_6 tracer technology needed to track a small parcel of water and follow the changes in it.

The original suggestion that we (that is, humankind) might fertilise the oceans with iron in order to make the plankton soak up carbon dioxide from the atmosphere was put forward more or less as a joke: it was suggested by the science writer John Gribbin in: 'Scientific correspondence' to *Nature* and subsequently popularised by John Martin. Although it is technically feasible, it never did seem a particularly attractive option. Marine scientists, including all those associated with the IronEx experiment, have repeatedly pointed out that such a strategy carries potential risks to the global environment and probably would not work in any case. It would be very foolish to start monkeying around with the biogeochemistry of the planet before we were confident we could answer some simple questions. These would include: "What would happen to marine emissions of other greenhouse gases such as methane and nitrous oxide?"

The reason that the IronEx experiments were proposed had nothing to do with the idea of techno-fixing the CO_2 problem. It was simply to test the hypothesis that iron limits productivity. I have yet to meet anyone (scientist, representative of a funding agency, or politician) who showed any enthusiasm at all for the idea of fertilising the ocean on a global scale. IronEx was in fact very poorly funded (at least by comparison with 'straight' science such as JGOFS or WOCE cruises). This is, one suspects, precisely because such a fuss was made by the media about iron fertilisation. The funding agencies therefore feared their motives would be misinterpreted in just the way John Wright has done!

In his article, John expressed satisfaction that the first IronEx did not show a very large change in CO_2 consequent on the iron addition, saying: "Oceanographers should be relieved that the IronEx results do not encourage large scale tampering with marine ecology to cool the climate." If that is the case, then it's time to start worrying again, because there were *two* IronExes scheduled. Just why the second one, just completed, gave such different results from the first is not fully understood, but in this case a *huge* effect on CO_2 was observed ...

Andrew Watson
Plymouth Marine Laboratory

POL Open Day a Great Success

On 14–15 June, the Proudman Oceanography Laboratory opened its doors to the public. Apart from visiting VIPS, over the two days, about 500 schoolchildren and several hundred adults explored the old Observatory building and the main laboratories. Instrumentation on show included sea-bed monitoring equipment and deep-sea tide gauges; visitors could call up the data held by the British Oceanographic Data Centre, find out about how the GEBCO charts are made, talk to researchers about their projects, and much, much more. Sadly, POL's next Open Day won't be until 1998.

Sudden Death of David Graham Jenkins

Dr Graham Jenkins, a micropalaeontologist and biostratigrapher of extraordinary vigour died sudddenly on 6 August this year. His outstanding studies on Cenozoic foraminifera, in particular, will remain as a lasting trubute. Oceanographers will remember his work on *Guembelitria stavensis* which helped fix the timing of the opening of the Drake Passage, and hence of the initiation of the Antarctic Circumpolar Current.

Following a distinguished career in Australia, New Zealand and England, Graham returned to his native Wales in 1990, and continued his research as an Honorary Research Fellow at the National Museum.

In addition to his 120 or so individually authored and joint scientific publications, Graham also wrote evocatively about life in rural Wales in the early and middle years of this century.

Australian Poisoned Pilchard Puzzle

While we were all preoccupied with the battle between Europe and Canada over halibut stocks on the Grand Banks, a few short sparse news items recorded that millions of sardines (called 'pilchards' Down Under) had been found dead off much of the southern part of Australia: all the way "from Western Australia to eastern Victoria, northern Tasmania and New South Wales". Mass mortality on this scale has not hitherto been recorded from Australia, and the cause remains a mystery. Press reports that "it doesn't seem to have affected the food chain" serve only to deepen the mystery – and must surely be treated with some scepticism. However, it is also reported that "seagulls are not taking the dead fish", which is at least consistent with the only explanation so far offered. This suggests that an influx or upwelling of cold nutrient-rich water caused an algal bloom which suffocated the fish. That's a pretty big bloom, but some sort of large scale event is surely implicated. Could it have anything to do with the so-called Indian Ocean Dipole which was recently described in *New Scientist* (13 May 1995) and is thought to be linked to ENSO events in the Pacific?

Hebridean Adventure

by a visitor to Scottish seas

To American eyes there could hardly be a more exotic place than the Sea of the Hebrides. To heighten the feeling of other-worldliness, I saw this region from a Scottish fisheries research vessel, the *Clupea*. We sailed from Mallaig on an afternoon with a clear sky, but a strong south-westerly wind, one that would put us abeam of the waves as we crossed the water to reach our night's harbour at Castlebay. As we passed the island of Eigg huge sea cliffs appeared, complete with crashing waves. It was easy to see where Mendelssohn got his inspiration for 'Fingal's Cave', or the Hebridean Overture. Kevin Horsburgh introduced me to the fulmars then following the ship. These birds are marvellous fliers and seem to have no need to flap their wings at all. They made turns like fighter aircraft do, with 90 degrees of roll. As the waves got up to 10 foot height, it felt better to watch the horizon now and then, to help get some 'sea legs'.

The exotic nature of the trip only increased as my American ears strained to absorb the speech of the crew. Most of them hailed from near Fraserburgh on the east coast, so my brief exposure to west coast Scottish accents did me no good. But Captain George Geddes and I both worked on our communications and succeeded well enough with a few repetitions thrown in.

A few nights later we stopped at the Isle of Tiree. This permitted an expedition to the local pub. We set out in fair weather with plenty of daylight left, or so we thought. The pub turned out to be not so local, requiring a forced march through the Tiree countryside. Apart from a few scattered houses, this was empty of all but sheep. Just as we despaired of locating the pub, it came into view. After a fine pint of Caffrey's Ale, I thought I would make my way alone back to the ship. It was now pitch black outside, however. Just staying on the road was a challenge, though I had some luck in navigation from adjacent sheep, that made a dull bright spot in the gloom. Finally, I made the last correct turn and found the pier. It was quite an adventure. Indeed, the whole trip was an adventure I will always remember.

Rich Garvine
Harrington Professor of Marine Sciences, University of Delaware

Professor Garvine has been on sabbatical leave as the Sir Kirby Lang Fellow in the School of Ocean Sciences, Menai Bridge, where he and Ed Hill have been making drifter observations of circulation in the Irish and Hebridean Seas.

NOW There's a FUNNY THING...

Full many a gem ...

Thomas Gray's *Elegy*, '*wrote*' (in the original) *in a Country Churchyard*, is surely one of the most beautiful poems in the English language. My woefully late introduction to it came when, as a student in 1956, I read Alister Hardy's then newly published New Naturalist volume on *The Open Sea – the world of plankton*, still the best general plankton text ever written. Hardy himself wrote beautifully, and in one passage his child-like wonder at the prospect of totally unknown organisms being brought to the surface in oceanic plankton nets reminded him of one of Gray's most emotive couplets:

Full many a gem of purest ray serene
The dark unfathom'd caves
of ocean bear

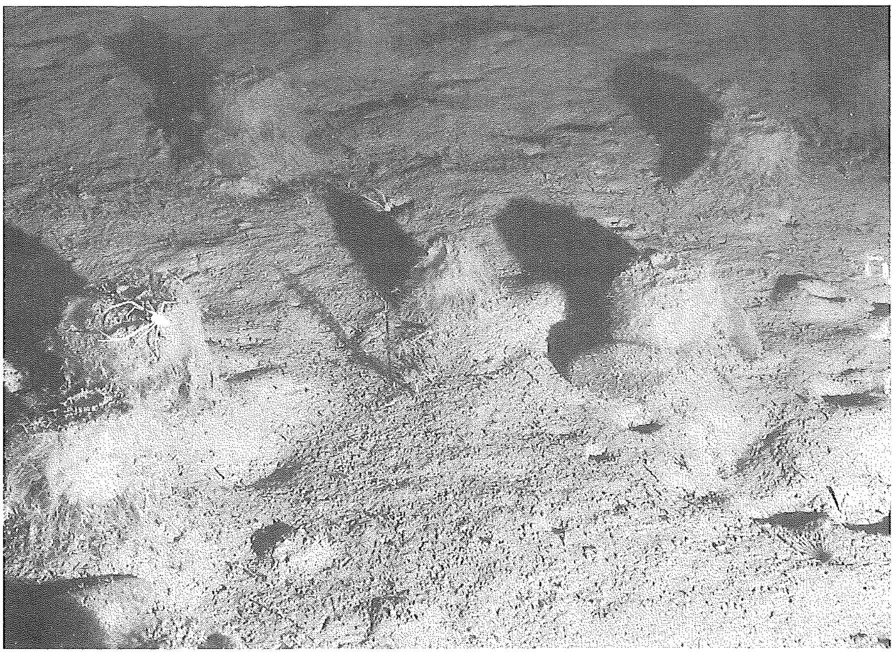
Years later, when I also shared the excitement of the arrival on deck of nets from thousands of metres beneath the ship's keel, I too was struck by the aptness of Gray's words. Consequently, I used them many times to introduce talks on deep sea biology to a wide range of audiences. But never did anyone point out to me that I was consistently misquoting the poem. For until no more than three or four years ago I had conveniently mis-remembered the quotation, substituting the (from my point of view) more appropriate "depths" for Gray's "caves".

I was reminded of this boob by a short article in a recent issue of *Deep-Sea Research* by three French biologists reporting the animal life in a recently discovered 120 m long submarine Mediterranean cave (see Vacelet *et al.*, 1994). Gray's "gem" referred, of course, to mineralogical rather than biological treasures, for when the *Elegy* was published in 1751 the possibility of life existing in the deep ocean probably never occurred to him or to anyone else. Even the depth of the ocean was still a total mystery, while the very first serious deep-sea biologist, Edward Forbes (1815–1854) (see *Ocean Challenge*, Vol.5, No.2), wasn't yet a twinkle in his grandfather's eye! In any case, almost a century later, when Forbes eventually carried out his classic series of dredgings in the Aegean in the 1840s, he concluded that the dramatic decrease in animal abundance which he encountered with increasing depth pointed to a deep ocean totally devoid of life. This would have confirmed the view, held more or less intuitively by anyone who gave the matter a second thought since Gray's time and before. Poor old Edward was fooled by the fact that he had been working in a sea where, although animals do occur in the very deepest regions, the depth-related decrease is much more abrupt than in most other areas. Nevertheless, the resulting so-called 'azoic theory' of the deep ocean held sway for almost 30 years until the 1870s when the cruises of the *Lightning*, *Porcupine* and *Challenger* dispelled it.

Apart from the recently discovered hydrothermal vent communities, most of the wide variety of animals that we now know inhabit the deep ocean are adapted for life at very low, and remarkably constant, temperatures. For the vast majority of the oceans are extremely cold, less than 4 °C at depths below 1000 m or so, even in tropical regions. The deep oceans are also, of course, perpetually pitch black apart from the odd flashes of bioluminescence. So the communities living there are dependent for their existence on food imported from the overlying sunlit surface waters. Shallow-water caves may also be totally dark and therefore not support plant growth, including phytoplankton, but here the resemblance to the deep sea usually ends. For animals living in such caves are subjected to much lower pressures than their deep sea counterparts and, probably much more importantly, to much higher, or at least much more variable, water temperatures. Consequently, although some normally deep-living species have been found in shallow caves, these occurrences are rare and are usually restricted to fairly mobile animals tolerant of a rather wide range of conditions.

Two features of the Mediterranean cave situation combine to make this a very special case. First, the whole of the Mediterranean has a curious temperature structure, the deeper parts hovering around 13 °C even down to 4 000 m or more. Second, this particular cave, near La Ciotat on the French coast, slopes downwards from its entrance whereas most Mediterranean caves slope upwards. Because of this peculiarity, during the winter storms the shallow (about 15 m deep) 'sill' of the La Ciotat cave traps cold water

***The hexactinellid sponge* Pheronema carpenteri *photographed at a depth of about 1200 m in the Porcupine Seabight to the south-west of Ireland.* Pheronema *has the same basic form as* Oopsacas *described opposite, but is much larger (the size of a big grapefruit) and is anchored into the soft mud by long silica 'roots'. Here it is accompanied by the squat lobster,* Munida tenuimana.**



which then undergo an extremely small seasonal temperature variation between 13 and 14.5 °C.

It was, perhaps, therefore not too surprising that Jean Vacelet and his co-workers found that the cave harbours an unusual abundance of animals not normally met with in caves exposed to the normal temperature range of the surrounding surface waters. These included foraminiferans, ostracods, arrow-worms and lamp-shells, either previously undescribed or known only from much deeper waters. But the most remarkable cave inhabitant was a representative of an almost exclusively deep-sea group, the hexactinellid sponges.

Also known as 'glass sponges' because their supporting skeleton is made up of needle-like spicules of pure silica, the hexactinellids include the Venus' Flower Basket whose beautiful and intricate skeleton, cleaned of all traces of the sponge's living tissue, is displayed in many museums around the world. Although a few hexactinellids have been found at relatively shallow depths, these records are restricted to cold-water regions on the Antarctic continental shelf and off British Columbia and New Zealand. The discovery of dense populations of glass sponges in the La Ciotat cave, as many as 100 individuals per square metre on the walls and roof, was therefore very exciting. They all apparently belong to a single species, *Oopsacas minuta*, a rather small form consisting of fragile white urn-like bodies, up to only about 6 cm long, attached loosely to the rocky substrate. Prior to its discovery in the cave, the species was known only from two minute specimens collected at a depth of 924 m at the Mediterranean end of the Straits of Gibraltar. This locality is exposed to the outflow of the western Mediterranean Deep Water at a temperature of 12.8 °C, very similar to that inside the cave.

Since the cave seems to have been submerged only some 7 000 years ago, Vacelet and his colleagues suggest that its colonization by *Oopsacas* has been quite recent – and from a relatively nearby source, probably the Cassidaigne Canyon about 7 km away. They go on to suggest that the species is probably widely distributed in the Mediterranean, but that its preferred habitat of vertical or even overhanging rock faces, normally in rather deep water, explains why it has been collected so rarely before.

So the cave discovery is interesting for at least two reasons. First, there may be other so far undiscovered caves, similar to the one near La Ciotat, harbouring other deep sea 'gems' that are difficult, if not impossible, to collect from their 'normal' habitat. Second, such caves provide an opportunity to study the *in situ* behaviour of these species and to collect fresh and undamaged material for histological and physiological analysis, almost never possible on specimens subjected to the ravages of deep sea trawls and the long ascent to the surface.

But I am pleased for a much more personal reason. Ignoring the disciplinary switch from mineralogy to biology, I feel that I can continue to use Gray's words for my original purpose, but now quoted correctly. Biological gems are to be found in both dark unfathom'd caves *and* depths and sometimes they are identical! I am sure Thomas Gray would be delighted. In fact, dare I suggest that if he had known *then* what we know *now* he might have used "depths" in the first place!

Tony (A.L.) Rice
IOS Deacon Laboratory

Reference

Vacelet, J., Boury-Esnault, N. and Harmelin, J-G. (1994) Hexactinellid cave, a unique deep-sea habitat in the scuba zone. *Deep-Sea Research*, **41**, 965–73.

Post Script

Since this article was written, Vacelet and Boury-Esnault have published an account of an even more remarkable sponge find from the same cave (*Nature*, **373**, 333–35, 1995). This sponge is an undescribed species of the cladorhizid genus (*Asbestopluma*), which also includes the deepest recorded sponges – from almost 9 000 m. But this group is also remarkable for having lost the aquiferous canal system typical of filter-feeding sponges, in favour of specialised carnivory – presumably an adaptation to the nutrient-poor deep-sea environment in which the sponges are normally found. As in the case of the glass sponge, the accessibility of the cave populations provides a unique opportunity to study the morphology and behaviour of this strange organism.

Legibility in Lecture Theatres

In the last issue of *Ocean Challenge* we remarked on the great improvements in standard of presentation of papers at UK Oceanography 94, relative to that experienced two years earlier (Vol. 3, no. 2/3, p. 23). Here is a further helpful snippet to guide presenters to future meetings, wherever held.

One of the criteria essential to good presentation is legibility of overheads and slides. To be sure, 'information density' is part of this problem, and the extent to which slides are perceived to be overcrowded with information is to some extent subjective. But difficult decisions about how much to put on an overhead can to some extent be alleviated by bearing in mind the following rule of thumb:

For someone 15 m from the front of a lecture theatre (which is fairly normal size), the height of lettering on the screen should be not less than about 9 cm (90 mm) for normal reading standard. This in turn means that lettering on the overhead transparency itself should be about 7 mm high, assuming a normal projector-screen distance of a couple of metres or so.

Mathematically gifted readers keen to pursue this matter in more detail are referred to *Nature*, **370**, p.423 (11 August, 1994).

Vacancy at SUT

The position of Executive Secretary for the Society for Underwater Technology, based in the Memorial Building at 76 Mark Lane, London, will become vacant on the retirement of David Wardle at the end of January 1996. This multi-disciplinary learned Society brings together individuals and organisations with a common interest in underwater technology, ocean science and offshore engineering. For further details, contact SUT on 0171-481-0750. The closing date for applications is 17 Nov. 1995.

Book Reviews

The Admiralty Chart – British Naval Hydrography in the Nineteenth Century by Rear Admiral G.S. Ritchie (1994). The Pentland Press, 444pp. £19.50 (hard cover, ISBN 1-85821-234-0)

Every mariner, whether on a naval warship or a yacht, on a supertanker or on a small fishing trawler, automatically turns to a chart to find his way over the oceans. Charts are the road maps to the seas, delineating the coastlines, giving warning of hazardous shoals, and supplying the necessary framework for navigation, whether by celestial observations, radio methods or satellite. It is easy to take it for granted that charts have always been available to navigators and that the role of Hydrographic Offices has been a mundane one in supplying them. Steve Ritchie's book quickly dispels such ideas.

The book belies its rather uninspiring title: it describes a century of high adventure, of considerable danger and hardship and, most important of all, of the utmost dedication of a small band of surveyors who explored and surveyed hitherto unknown coastlines all over the world. This book, which was first published in 1967, has been rewritten in the light of new research into the archives of the Hydrographic Office in Taunton, with the assistance of Lieutenant Commander Andrew David, formerly responsible for the Sailing Directions, who has also contributed an introductory chapter.

By the end of the eighteenth century, the refinement of the theodolite, the development of station pointers and hand compasses and, most important, the invention of an accurate marine timekeeper, later to be known as a chronometer, enabled surveyors to navigate with relative accuracy all over the globe. The nineteenth-century surveyors exploited these newly available tools to discover and to map the unknown coastlines of Australia, South America and Africa, and of the Arctic Ocean. The names of the surveyors, who often became Hydrographers to the Navy, are familiar to many in the place-names on maps today and have been commemorated in the names of ships of the surveying fleet – Dalrymple, Vancouver, Flinders, Beaufort, Fitzroy (who was captain of the *Beagle* in Darwin's expedition) and Wharton, to mention just a few.

Ritchie describes the challenges of exploration imposed on these pioneers, and the considerable hardships that they had to face. Often confronted with hostile natives, operating from small sailing boats working for weeks away from their mother ships in waters with unknown hazards, undertaking dangerous land expeditions to establish key surveying points on local mountains, facing unknown tropical diseases for which no remedies were known, at times shipwrecked, and without the rapid communication which we take for granted today, the expeditions required, and generated, the highest level of personal leadership and dedication.

The growth of global trade and the development of the British Empire created the demand for reliable navigational charts on a worldwide basis, and the British Admiralty chart became a symbol of high quality and reliability throughout the world. In the middle of the century, the search north of Canada for a north-west passage to the Indies and China, triggered numerous expeditions from both the Atlantic and the Pacific Oceans and resulted in many dangerous, and – in the case of Franklin – fatal, journeys in ice-packed water, sometimes involving enormous distances over land covered with snow and ice.

Towards the end of the nineteenth century, hydrographers played a key role in the foundation of oceanography. Increasingly, surveyors were undertaking scientific work in addition to charting. The Royal Society wanted measurements of the magnetic field; governments wanted to lay cables across the Atlantic floor and to know the nature of the bottom, currents and marine life; regular measurements were being made of water temperature and chemical composition; and scientists wanted the answers to questions about the sea on a global scale. The famous expedition of HMS *Challenger*, mounted by the Hydrographic Department, "brought to an interested world the knowledge that the floor of the ocean was a complex of abyssal plains carpeted with ooze, divided by deeps, rises and even rocky submarine ranges; that life in some crude form ... existed even at a depth of five miles; and that a vast circulation of water took place within the oceans, the redistribution of nutrients playing a vital role in the massive life cycle of this newly discovered world". The collaboration between the Hydrographic Department and oceanographers has remained strong throughout the present century.

The book is written with authority – as befits an author who was such a distinguished successor to the nineteenth-century Hydrographers – as well as with style and humour. Ritchie describes in detail some of the evolving techniques for surveying, and relates the newly found features to today's maps. There are charming illustrations from the surveyors' original sketches, and maps to help the reader to follow the narrative. My enjoyment was considerably enhanced, however, by having a modern world atlas in front of me to help visualise the details of the explorations.

I recommend this book unreservedly to all who enjoy adventure, who want to get a feel for the difficulties faced by the early surveyors, and who are curious about the origins of marine science and the role played by the UK Hydrographic Department during the last century.

Anthony Laughton
Chairman, Joint IOC/IHO Guiding Committee for GEBCO,
formerly Director of the Institute of Oceanographic Sciences, UK

Sediment Transport and Depositional Processes (1994) edited by Kenneth Pye, Blackwell Scientific Publications, 397pp. £32 (hard cover, ISBN 0-632-03112-3)

There is something in this book for everyone with an interest in sediment transport and deposition, whatever their level or background. The book is wide-ranging, with chapters on fluvial, lacustrine, aeolian, marine and volcanic clastic processes (amongst others). Each is written by an expert in the field, and most readers, from whatever sedimentary background, will recognise many of the contributing authors. The style and content of each chapter seems to have been left to individual authors, resulting in considerable variety in format and quality, but the general approach is quantitative while not mathematical, with emphasis on the processes underlying the environmental observations.

The variety of content can be judged from the chapter titles: Properties of sediment particles by K. Pye; Fundamental properties of fluids and their relation to sediment transport by J.R.L. Allen; Hillslope sediment transport and deposition by M.J. Selby; Fluvial sediment transport and deposition by I. Reid and L.E. Frostick; Sedimentary processes in lakes by P.G. Sly; Estuarine sediment transport and deposition by K.R. Dyer; Beach and nearshore sediment transport by J. Hardisty; Deep sea processes of sediment transport and deposition by D.A.V. Stow; Aeolian sediment transport and deposition by R. V. Fisher and U.-U. Schmincke.

With a book containing such diverse topics, it is inevitable that many readers will find some chapters too simplistic for their needs, while others will find progress too rapid. This is not a book for experts who want to advance their own speciality but is remarkably good for anyone wishing to broaden their knowledge of sediment transport processes. I personally found more interest in the contributions describing areas of sedimentary transport and depositional processes with which I was less familiar, and I suspect others will find the value of this book to lie in the unfamiliar rather than the well known. It is a good starting point for new graduate students as most chapters contain a wealth of references to guide the reader onwards. Undergraduates will also find much that is useful when reviewing taught material or for alternative perspectives on processes.

Because I have my own particular specialisation it would not be appropriate to pick out any particular chapter for detailed comment. However, I did find the contribution from J.R.L. Allen on fluids and sediment transport a delight to read: it is not easy to summarise the important fluid processes in relation to sediments in a manner which is clear and interesting yet free from complex mathematics, but Allen manages it. I will certainly be recommending it as essential reading to all my students who find my own lectures on the subject less than illuminating!

Chris Vincent
School of Environmental Sciences
University of East Anglia

Regional Oceanography: an Introduction by Matthias Tomczak and Stuart Godfrey (1994). Pergamon Press, 422pp. £23 (flexicover, ISBN 0-08-041020-0)

This book was developed from undergraduate lectures in marine science designed for students majoring in marine geology, biology, chemistry and geography, as well as physical oceanography. Consequently, the advantage for many students is that the text does not require a previous knowledge of mathematics and theoretical physics. However, a general description of ocean circulation is of little use in advancing the science of oceanography unless it conveys an understanding of the physical principles which drive the ocean. In this respect, the authors have tried, in the first five chapters of the book, to give an introduction to the basic physical principles and their consequences, primarily as a reference for the remaining fifteen chapters.

These first five chapters are particularly informative to the non-specialist. The first chapter introduces the major external influences on ocean circulation and gives a brief account of air pressure and wind fields, solar radiation and heat flux, and freshwater flux and evaporation. The second concentrates on the basic temperature, salinity and density structure and the consequent oceanic pressure field; the third deals with the Coriolis force, geostrophy, Rossby waves and western boundary currents; the fourth with Ekman transport and pumping and the Sverdrup balance; and the fifth with water mass formation and subduction and the oceanic heat budget.

Since no science can be done without mathematics, these chapters do incorporate equations (I hear a number of students sigh mournfully) but the reader is taken through them sympathetically and certainly no-one should feel daunted by the approach. It is intended to be helpful, and I think the authors have achieved a happy balance in getting the basic message across without going into the more theoretical aspects of physical oceanography. Yes, there may be readers who say these five chapters don't go far enough into the theory, but this is not the intention of the book as a whole. There are a number of other texts which describe the detailed theory very well but, personally, I think the inclusion of the five introductory chapters in an otherwise descriptive volume is the forte of the book.

The following eleven chapters are studies of the world's oceans, commencing with the polar oceans and working through the Pacific, Indian and Atlantic Oceans and their marginal seas. The descriptions of the Antarctic and Arctic oceans are each confined to a single chapter whereas the other three have three chapters each. For each ocean there is an account of bottom topography, wind and current regime, fresh-water flux and evaporation, and water mass characteristics, the text following a similar format for each ocean. The one thing I found curious was the order in which the oceans were discussed. Understandably, North Atlantic Deep Water is introduced in Chapter 7 on Arctic Oceanography, but Chapter 8 then discusses the Pacific Ocean and it is not until Chapter 14 that the reader returns to the Atlantic Ocean. In view of the modern idea of the 'oceanic conveyor belt' it would seem more logical to deal with the Atlantic after the Arctic Ocean, and work through the Indian to the Pacific – but then the Atlantic is on my back door-step while the Pacific is home waters to the authors of the text.

My first impression of the book was that it was not much different in approach from that of *Descriptive Regional Oceanography* by Tchernia (Pergamon Marine Series, Vol. 3), even though Tchernia's book is now 15 years old (and out-of-print). However, the science has moved on, and this new book brings in many of the new concepts in physical oceanography. In particular, it tries to give the reader a basic understanding of how ocean circulation is involved in climate change. The last three chapters are related to 'climate issues', with discussions of 'The oceans and the world's mean climate', 'El Niño and the Southern Oscillation (ENSO)' and 'The ocean and climate change'. When I had finished reading, I realised that the similarities to the Tchernia volume were in fact superficial and that the great advantage of this text as a general introduction to the subject lay in the first five chapters and the last three.

I should add that the book is clearly written with a large number of figures which are an integral part of the text. To gain the maximum benefit, the reader should spend as much time looking at the figures as reading the text.

Finally, the authors admit in the preface that there were aspects of physical oceanography that had not got the attention they deserved, and (I quote) *"Much can be learned about the oceanic circulation and the life cycle of the various water masses by combining information from CTD and current meter data with information on oxygen, nutrients and other chemical tracers. Unfortunately marine chemistry has always been among the authors' weak points, and the treatment of chemical tracers in this book is below acceptable level – it cannot even be called elementary."* They go on to say that if the book is a success then the first improvement in a revised edition would be more detailed coverage of all chemical tracers. As a tracer chemist, myself, I find this admission rather amusing, and perhaps on that note I should stop writing this review and contemplate writing something on chemical tracers.

Denise Smythe-Wright
James Rennell Centre
for Ocean Circulation,
Southampton

Principles of Oceanography (7th edition) by M. Grant Gross (1995). Prentice-Hall, 230pp. £17.95 (flexicover, ISBN 0-02-347981-7)

I am disappointed. This is the latest version of a series of student textbooks on introductory oceanography, which Grant Gross has been putting out for the last 25 years or so. The previous six editions went under the title *Oceanography: A View of the Earth*, which at least had a certain resonance. The new title and content are pedestrian by comparison with the old ones.

I have only the first and fourth editions (1972 and 1987), but I believe the fifth and sixth editions to have been similar and with the same aim: "to introduce students to the ocean and how it works ... A high-school level in science and mathematics is assumed." In the seventh edition there is a subtle change, and the book is "... intended ... as an ... introductory course at either high school or college level, or as a supplemental text on other [science] courses. ... It assumes only high-school-level scientific knowledge *and no mathematics*" (my italics).

The author claims that he has rewritten the text to emphasise fundamental processes controlling the ocean, the ocean basins, and ocean life, with new text and new figures. Additions included recent advances in many branches of science that contribute to our understanding of the Earth and its oceans.

Hmmm, I'm not so sure it works. This 'rewriting' has reduced the length from 406 large-format pages down to 230 of A5 size, and replaced many attractive two-colour diagrams with less appealing and rather stark black-and-white ones; and the colour plates have gone. The price has stayed the same, though. What's more, I get the feeling that 'fundamentals' have tended to be sacrificed to 'recent advances', by which it seems the author means current issues like the greenhouse effect, El Niño, energy and resources, satellite technology and Law of the Sea. There is less on oceanic processes to make space to retain these topics (which were also in earlier editions), so tides no longer have amphidromic systems, geostrophic currents get about a page, and ocean chemistry gets short shrift, to give but a few examples. Is it possible that the author was persuaded by his publishers to make the material 'easier' so that it could be used in general environmental courses by students with little science background?

This is no better than any other introductory general oceanography text you could buy, and a good deal less good than some, especially those that have more attractive illustrations and give you the same or more information and explanation for little if any extra cost. I concede that one or two diagrams are useful, even novel, and the book does have end-of-chapter summaries and questions (though *no* answers), plus a glossary. None of that is new – lots of other books do the same these days. Verdict: If there's no other introductory text in the shop, you could buy this one; otherwise, you might find one of the alternatives better value. What a shame. Earlier editions of the Grant Gross *oeuvre* were by way of becoming classics.

John Wright

Marine Pollution (3rd edition) by R.B. Clark (1992). Oxford University Press, 172pp. £18.95 (flexicover, ISBN 0-19-854686-6)

Given the recent furore over the *Brent Spar*, it seems appropriate to draw readers' attention to a very readable, well-illustrated and informative book on this topic, packed with examples and case studies.

I urge anyone interested in protection of the marine environment to get hold of it, particularly as there seems to be little evidence of any overall decline in levels of pollution resulting from human activities, although there have of course been local improvements – such as decreased discharges of radioactive wastes from Sellafield to the Irish Sea. The book is suitable for students at any level, provided they have a bit of basic chemistry and biology and understand something of coastal processes. Most pollution still occurs along coasts and in shallow seas, and that includes atmospheric inputs, which are very important in enclosed shelf-sea areas such as the Baltic.

Marine pollution is an emotive issue and one of the author's reasons for preparing this new edition is his conviction that discussions and policy decisions relating to pollution must be based upon sound science. He reminds us also to bear in mind that most anthropogenic inputs to the sea are not a whole lot different from natural inputs – halogenated hydrocarbons and derelict drift nets being two obvious exceptions. Most of our polluting activities in fact merely increase rates of supply of materials that already enter the seas and oceans naturally. Even the effects of radioactivity from nuclear wastes, and excess heat from power stations, differ in degree rather than in kind from their natural counterparts. In effect, humans are competing with volcanoes, hydrothermal systems, oil seeps, erosion of metal-rich rocks and ores, hydrocarbons produced by plants (both marine and terrestrial), and redistribution of soils and sediments by wind, rain, rivers and storms. These processes have been going on throughout the Earth's history, and problems arise only when *our* additions raise concentrations – especially on a local scale – to levels that may be harmful to life. That is what we perceive as pollution. More decades ago than I care to remember, my Granny defined dirt as 'matter out of place'. I have never been able to improve on that succinct phrase, and it serves as a pretty good general definition of pollution too.

The author also suggests that the apparent spread of contamination (pollution) of the marine environment by industrial civilisations may be more a matter of increased sampling and monitoring and of improved analytical techniques, than of real changes in the quantity of 'manufactured' pollutants entering the sea. In any case, some polluting practices have ceased or been greatly curtailed in certain regions, e.g. incineration at sea off Europe, marine dumping of metal-rich dredging spoil from harbours in the southern North Sea, and disposal of nuclear wastes at sea. International legislation, agreements and conventions have helped both to moderate the extent of pollution and to encourage good practice in waste disposal. However, you can't legislate against accidents; furthermore there remain plenty of unscrupulous organisations, and even governments, who 'couldn't care less' about marine pollution, illegal dumping and the like. Ignorance of the effects of anthropogenic wastes on the marine environment must also be a factor in less developed regions of the world, where local populations are inevitably less well educated and informed than they might be elsewhere.

By far the greatest quantities of wastes that enter the sea are either biodegradeable (chiefly sewage, but also petroleum products), or essentially inert (mainly dredging spoil, which may, however, be contaminated with metals, but also quarry wastes of various kinds). On the whole, it is the *rates* at which these substances enter marine environments that cause most of the damage: either deoxygenation of the water, or the smothering of benthic communities.

It's not as simple as that, of course: the lighter fractions of petroleum – especially when refined and particularly the aromatic (benzene-based) hydrocarbons – are highly toxic. They are also the most volatile fractions and won't persist long, but after they are lost by evaporation, the remaining oil has a physical effect (coating surfaces, clogging sediments, especially in low energy environments), and uses up oxygen. (I am left wondering just what happens to those toxic volatile fractions circulating in the atmosphere, though; I guess they are so heavily diluted and so widely dispersed that when they reach the surface again they do little harm and are rapidly degraded.)

I didn't realise that oil spills actually have rather little effect on plankton populations, and it seems that the public perception of sea-birds as the chief victims of oil spills is in fact correct. Nor did I know that the chief source of marine oil pollution associated with offshore production is not in fact pipeline accidents or rig blow-outs but oil-saturated drill chippings dumped on the sea-bed beneath drilling platforms (though it seems that this practice is being phased out).

Metals vary considerably in their toxic effects, depending on the metal(s) and the organism(s) concerned, the form in which the metal(s) occur(s) and so on. As noted on p.5 in connection with the *Brent Spar*, considerable tonnages of metals are being continuously spewed into the oceans by hydrothermal vents, and the seawater solution contains all the known elements anyway. The capacity of many marine organisms, especially shellfish, to accumulate metals to levels orders of magnitude above seawater concentrations is also well established. Again, it is not the metals themselves that are specifically the problem; what matters is the rates at which they are introduced into the sea.

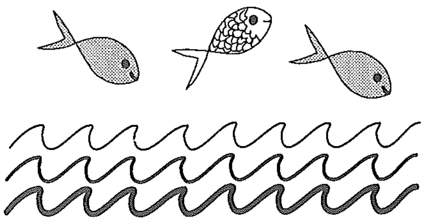
Halogenated hydrocarbons (DDT, PCBs etc.) constitute a more serious threat to the health of seas and oceans than anything else, chiefly because they are wholly synthetic, having no natural counterparts. They are now global in their distribution, they are not biodegradeable, they are highly soluble in animal fats, and (like many metals) they are readily adsorbed on particulate matter. So they accumulate in fatty tissue and in sediments. Incidentally, I note that the author classifies metals and halogenated hydrocarbons as conservative pollutants, not in the sense that we generally understand the term in oceanography, but in the sense that, not being subject to bacterial or other breakdown, they are in effect permanent additions to the marine environment. I also learned that it is difficult to distinguish between the effects of adsorption and those of ingestion of these 'conservative' pollutants on micro-organisms: adsorption is not directly harmful, but may affect higher trophic levels, while ingestion could be toxic both to the organism itself and to anything else that eats it.

A chapter entitled 'The state of some seas' briefly reviews a number of shelf-sea regions and makes fascinating reading, rapidly dispelling any possible complacency about present levels of marine pollution worldwide. Some sections appear to be based only on pre-1980s information, and if recent trends are any guide, the situation in the Mediterranean and Caspian Seas, to name but two, is if anything worse than described in the book. The author was not able to benefit from the North Sea Project results, but these would probably not affect the summary significantly. He makes the telling point that '... the practices of the fishing industry have a dominating influence on the size of exploitable fish stocks in the North Sea. Against this background, it is impossible to detect any effects that pollution may have had on the fishery.' (See also Tim Jickells' report on the 1993 *North Sea Quality Status Report* in *Ocean Challenge*, Vol. 5, No.1.)

The last chapter, 'Assessing pollution damage', could be the most controversial in the book, as the author himself recognises. Here's a snippet to get you going: When the *Torrey Canyon* was wrecked off Land's End in 1967, it was decided to try and clean up the beaches rather than the oil slick at sea, because while the slick might damage fisheries worth £6 million, the beached oil would damage tourism worth £60 million. There is a lot of environmental jargon, with terms and phrases like: Polluter Pays Principle, Environmental Impact Assessment, Precautionary Principle, and BATNEEC (Best Available Technology Not Entailing Excessive Cost). Even so, it is a very useful overview of the problems that bedevil attempts to pin down the effects of pollution. The author also makes the valuable point that *natural* fluctuations in reproduction and recruitment of coastal and shallow-water animal populations can be so great as to mask any possible changes attributable to pollution.

You will enjoy this book, I promise, and there don't seem to be too many typos either. I saw at least two pictures that I intend to use in assessment exercises for our Open University oceanography students.

John Wright



The Oceanography of the Eastern Mediterranean Sea

Michael D. Krom

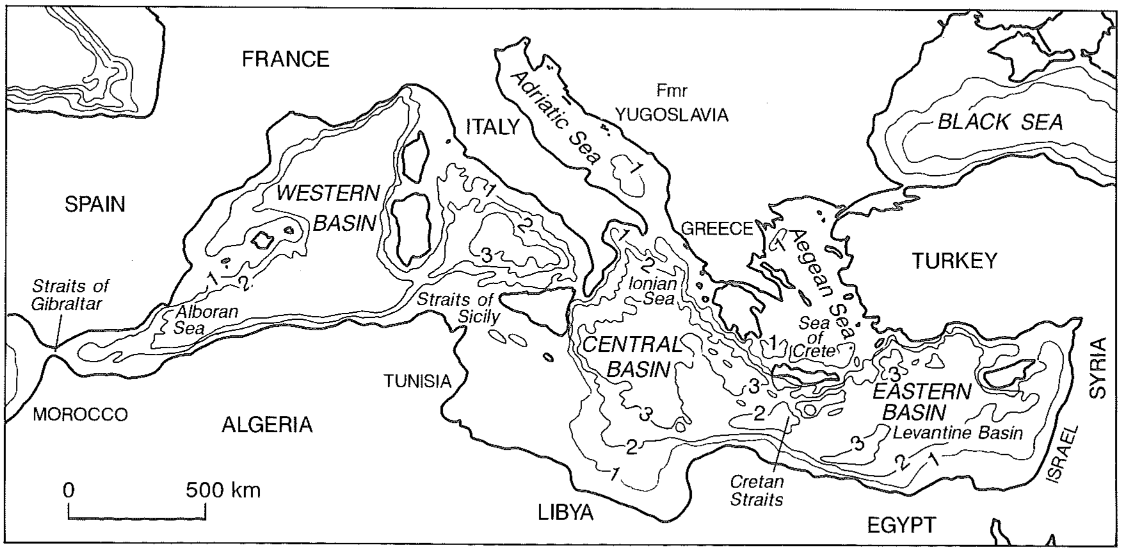
For many years the oceanography of the Eastern Mediterranean has been relatively neglected, yet it has several characteristics that make it an unusual sea and one worthy of detailed study. It is the source of Mediterranean outflow water, which is one of the important water masses in the North Atlantic. It has low primary and secondary productivity (i.e. it is ultra-oligotrophic), as well as unusually low species diversity, particularly in its deeper waters. Recent studies have also shown it to be the largest body of water in the world in which the primary productivity is unequivocally limited by the availability of phosphate. What are the characteristics of this special part of the world's oceans? And why are its physical, chemical and biological properties so unusual?

The Mediterranean Sea is an ocean basin that is gradually closing as the African Plate moves north and collides with Europe. In the comparatively recent geological past (Late Miocene, 7.5–5 million years ago), there were periods when the basin all but dried out. This resulted in the extensive deposits of salt that underlie much of the sea-bed of the present-day Mediterranean. Most authors argue that during the Holocene and Pleistocene (400 000 to approximately 7 000 years ago), circulation within the eastern Mediterranean became so restricted at times that all of the deeper waters became anoxic, as in the Black Sea today. These periods are represented by a series of deposits of organic-rich sediments called sapropels. This history of drastically changing water column chemistry caused periodic extinctions of the native fauna, particularly in deeper water. As a result, the deep-water fauna of the basin is much less varied than in, for example, the adjacent Red Sea.

The Mediterranean Sea can be divided into three basins (Figure 1): the Western Basin comprises the region west of Sicily, while the Adriatic and Ionian seas in the Central Basin are separated from the Aegean Sea and the Levantine Basin in the Eastern Basin by the Sea of Crete and the Cretan Straits. In this review I will deal with the oceanography of the Eastern Basin, particularly the physical and chemical oceanography of the smaller Levantine Basin within it.

Figure 1 *The bathymetry and geographical setting of the Mediterranean Sea.*

The basins of the Mediterranean are separated by the Cretan Straits and the Straits of Sicily



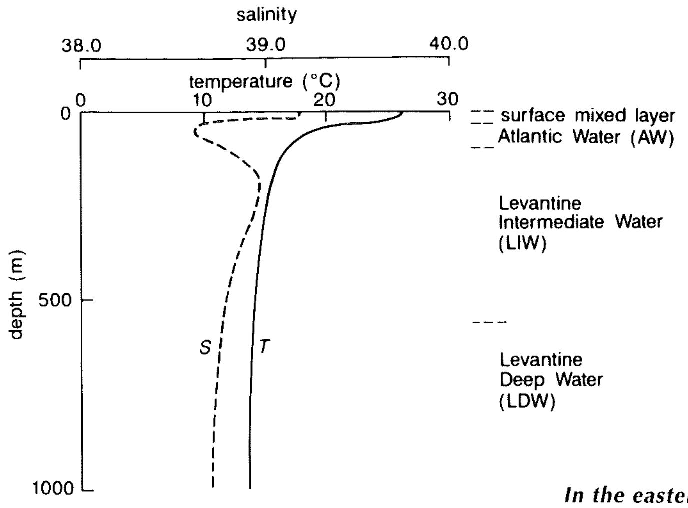
Water Masses

The only significant input of 'new' seawater into the eastern Mediterranean is from the Atlantic Ocean. This Atlantic Water (AW) flows in at the surface through the straits of Gibraltar (see Figure 3). Part of this inflow reaches the Eastern Basin via a sinuous eastward path, more-or-less parallel to the north coast of Africa. It is found immediately below the summer mixed layer (Figure 2), and can be recognized in the water column by its low salinity relative to the waters above and below. The other major water mass flowing into the Eastern Basin is the Levantine Deep Water (LDW). This water mass has a characteristic salinity of 38.7 and a temperature of ~13.5 °C.

LDW is formed in winter in the northern Adriatic by cooling and evaporation under the influence of cold dry winds. After sinking, it flows as a relatively narrow jet of water along the western side of the Adriatic and out into the eastern Mediterranean where it makes up the deep water in the Levantine Basin (Figures 2 and 3). Wolfgang Roether has estimated, on the basis of tritium and Freon measurements, that LDW has a residence time of 50–100 years before it is mixed with intermediate water and flows out of the basin.

The Levantine Basin is the principal site for the formation of Levantine Intermediate Water (LIW; Figures 2 and 3) whose characteristic temperature and salinity are 15 °C and 39 repectively. This is an important water mass: having formed in the Eastern Mediterranean, it flows at intermediate depths across the Central Basin and out through the Straits of Sicily, joining with Riviera Intermediate Water (RIW), and eventually becoming the major component of Mediterranean Outflow Water (MOW) (Figure 3). It has been suggested that LIW forms mainly in the northern part of the Eastern Basin, south of the Turkish coast; also that its formation may be connected with the eddies and gyres present in the area.

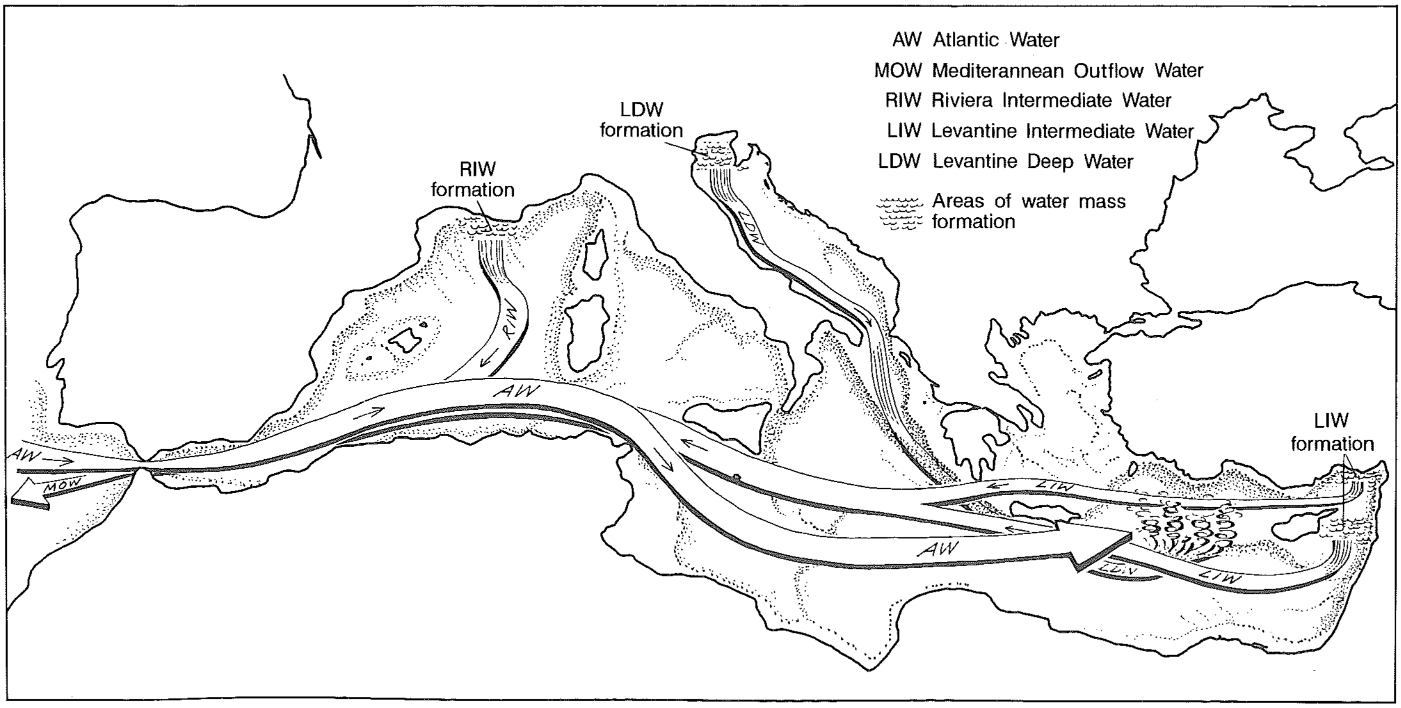
Figure 2 *Summer temperature and salinity profiles from a sampling station in the eastern Mediterranean considered typical of the region.*



In the eastern Med, Levantine Intermediate Water lies between Atlantic Water and Levantine Deep Water

Figure 3 *Schematic diagram showing the areas of formation and the main flow patterns of the major water masses in the Mediterranean Sea.*

The interleaving flows of water masses within the Mediterranean



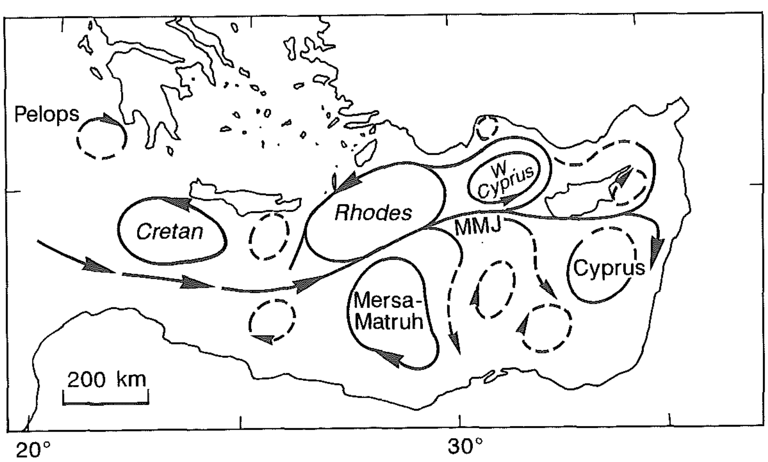
Current Patterns

The earliest measurements of physical properties in the water of the Levantine Basin were made from the Norwegian ship RV *Thor* in 1910. On the basis of these data, the circulation in the upper and intermediate layers of the Levantine basin was depicted as a simple basin-wide cyclonic gyre. Water flowed in along the North African coast and flowed out along the Turkish and Greek coasts. Data collected subsequently by the American RV *Atlantis* in 1948, the French RV *Calypso* in 1956, and various Soviet vessels in the late 1950s through to the early 1970s, supported this picture of the large-scale circulation.

In 1985, a multinational programme was initiated to study in more detail the Physical Oceanography of the Eastern Mediterranean (POEM). This POEM programme, which is still continuing, is a cooperative effort involving scientists from Croatia, Cyprus, Egypt, France, Germany, Greece, Israel, Italy, Turkey, and the United States. As a result of the work of this programme, we now know that the current patterns in the eastern Mediterranean are more complex than originally thought (Figure 4). There is a complex system of persistent sub-basin-scale gyres interconnected by meandering currents as well as an energetic mesoscale field consisting of warm- and cold-core eddies. Because the scale of the gyres is similar to that of mesoscale eddies, the terms 'gyres' and 'eddies' are often used interchangeably by researchers working in the Eastern Mediterranean. For example, a persistent warm-core eddy off the Egyptian coast is commonly called the Mersa Matruh Gyre, and the Rhodes Gyre is a cold-core eddy south-east of the island of Rhodes; a warm-core eddy south of Cyprus is variously called the Shikmona Gyre or the Cyprus Eddy.

The system of interconnected gyres in the eastern Mediterranean

Figure 4 *General circulation pattern in the Eastern Mediterranean showing the principal eddies and jets in the region; the Mid-Mediterranean Jet (MMJ) is the principal carrier of Atlantic Water into the Eastern Basin (cf. Figure 3). The circulatory features labelled in italic are cyclonic and have cold cores; the others are anticyclonic and have warm cores.*



Eddies are important because they can entrap, transport, and disperse chemicals, particulate matter, small organisms, heat, and so on. They also significantly modify the vertical mixing patterns in an area, creating, among other phenomena, zones of upwelling and downwelling which in turn can have a major effect on the biological productivity. In the world's oceans in general, most of the eddies so far studied in detail are actually 'rings' which have formed from frontal currents, flowing along the boundaries between bodies of water with contrasting temperature and other physical and chemical properties (Gulf Stream rings are, of course, the best-known of this type of mesoscale eddy). However, mesoscale eddies are not only found in the vicinity of such frontal regions, but occur throughout the world's oceans. For large areas of ocean, they are considered to be an important reason for the observed patchiness in chemical properties and biological productivity.

The quasi-stationary eddies (gyres) in the eastern Mediterranean, which are located comparatively close to shore, appear to have many of the features of mid-ocean eddies, including the fact that (as recent studies have shown) they are formed by physical processes within a single body of water. My co-workers and I have studied in detail the chemical, physical and biological properties of the warm-core Cyprus Eddy while Kamal Saydam and co-workers have carried out similar studies on the cold-core Rhodes Gyre (Figure 4).

Chemical Properties

The Eastern Basin of the Mediterranean has a higher salinity (~39.5) than any other part of the world's oceans except the Red Sea, as a consequence of high evaporation rates and low freshwater inputs. Recent studies have revealed that abrupt, significant and apparently irreversible changes in the characteristic salinity of the surface and intermediate waters have occurred over the past several years. These changes are probably due to diversion of fresh water that used to flow into the basin. As in many parts of the world, rivers which once flowed into the ocean have been diverted and are now used almost entirely for industry or agriculture. One of the most dramatic examples of this is the River Nile which until 1965 discharged 50–60 × 10^9 m^3 of water every year into the Eastern Basin of the Mediterranean, and now discharges only about 10 × 10^9 m^3 yr^{-1}. Another example is the flow into the Levantine Basin from Israel: 96 per cent of the water which falls on the country is diverted for human use, and as a result not a single river or stream now has a permanent flow of natural fresh water to the sea.

The deep waters of the Eastern Mediterranean have unusually low concentrations of nutrients when compared to deep waters in

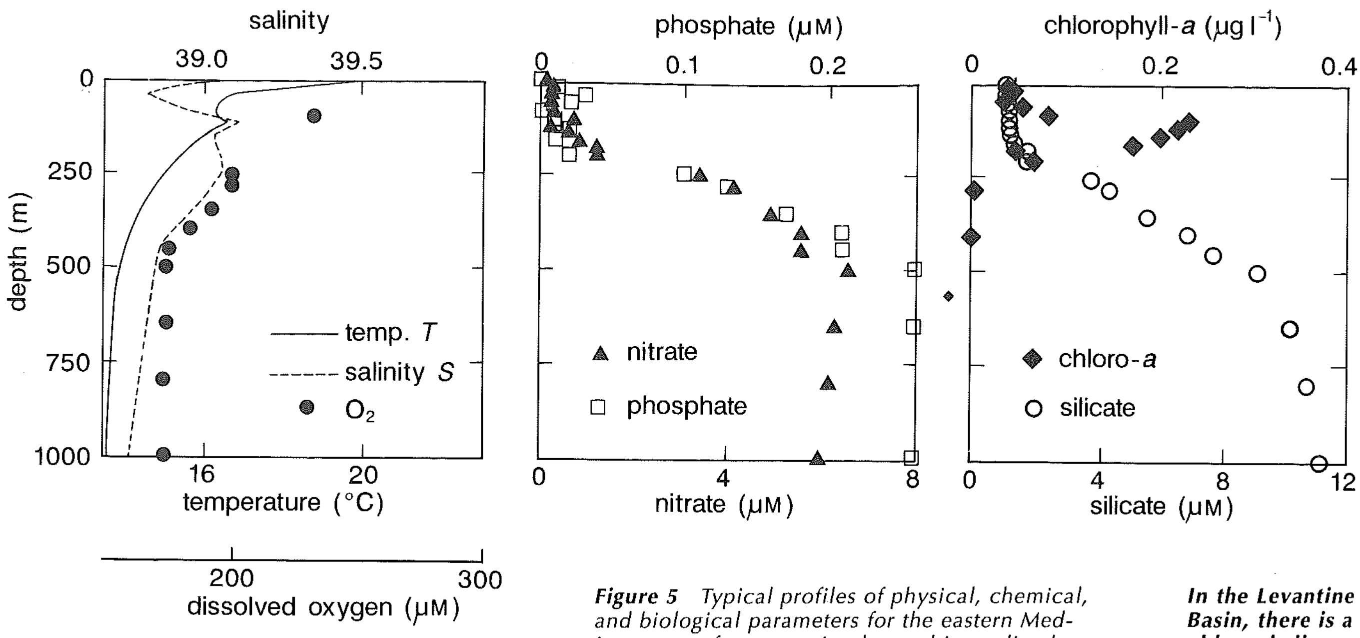


Figure 5 Typical profiles of physical, chemical, and biological parameters for the eastern Mediterranean, from a station located immediately north of the Cyprus Eddy, in early summer. (μM ≡ μmol kg^{-1})

In the Levantine Basin, there is a chlorophyll maximum but no oxygen minimum layer

other oceans. LDW typically has 6 μmol kg^{-1} nitrate, 0.25 μmol kg^{-1} phosphate, and 10–12 μmol kg^{-1} silicate (Figure 5). By comparison, waters of similar depth in the Atlantic Ocean have dissolved nitrate, phosphate and silicate concentrations of 20, 1.8 and 20 μmol kg^{-1} respectively. The primary reason for the low nutrient levels in LDW is the very low net supply of nutrients to the Levantine Basin. The Atlantic waters flowing into the Mediterranean at Gibraltar are nutrient-depleted surface waters, while the intermediate waters which flow out of the basin are relatively enriched in dissolved nutrients. In addition, there is very little natural input of nutrients from the adjacent land masses, particularly the Sahara Desert to the south.

It is not yet certain what effect anthropogenic changes have had on the nutrient budget of the eastern Mediterranean. The large increase of population in the regions around the basin (including the influx of tourists) has resulted in large amounts of sewage effluent, which contains dissolved organic and inorganic nutrients and particulate organic matter, being discharged directly or indirectly into the basin. There is also an increased flux of nutrients into the basin via the atmosphere, from pollutant sources in Europe. As noted above, however, many of the rivers which used to flow into the Levantine Basin are now diverted for industrial, agricultural or domestic needs, and do not reach the basin at all, and their flux of natural and pollutant nutrients has been cut off. For example, the construction of the Aswan dam in 1965, and the subsequent 'turning off' of the River Nile, has resulted in the collapse of the local sardine fishery. As outlined later, my co-workers and I have suggested that the increase in wind-blown dust to the basin as a result of agricultural practices in the area may also be reducing the overall productivity in the region by removing phosphorus from solution in LDW.

Primary Productivity in the Levantine Basin

Because of the low nutrient content in the deep water, when it is upwelled or mixed into the photic zone it is only able to support a very low primary productivity. Away from the direct influence of eddies, summer levels of chlorophyll-*a* are typically 0.25 μg l^{-1} at the chlorophyll-*a* maximum (which is at ~120 m) and 25 mg m^{-2} for the entire water column (Figure 5). This is similar to levels in mid-oceanic regions like the Sargasso Sea and the central Pacific gyre, and ~ 1/30 of levels commonly found in coastal and shelf waters like the North Sea. For oceanic waters, transparency has an inverse relationship with productivity. Because of the clarity of the water, the Eastern Mediterranean has one of the deepest euphotic zones known (in 1985, Tommy Berman and co-workers claimed a world record Secchi disk depth of 53 m in the Levantine Basin off the Israeli coast). Low phytoplankton productivity is one of the reasons for the deep blue colour so characteristic of the Mediterranean (which helps to make it so popular with tourists). Low primary productivity also affects the vertical distribution of dissolved oxygen (Figure 5). There is only a relatively small decrease in oxygen with depth, and there is no observable oxygen minimum as there is in most of the rest of the world's oceans, possibly as a consequence of relatively low respiration in the water column.

The surface waters of the eastern Mediterranean have a very large proportion of small phytoplankton with high chlorophyll contents: more than 90 per cent of the chlorophyll is confined to particles < 10 μm and more than 50 per cent is found in organisms < 2 μm. The proportion of chlorophyll in

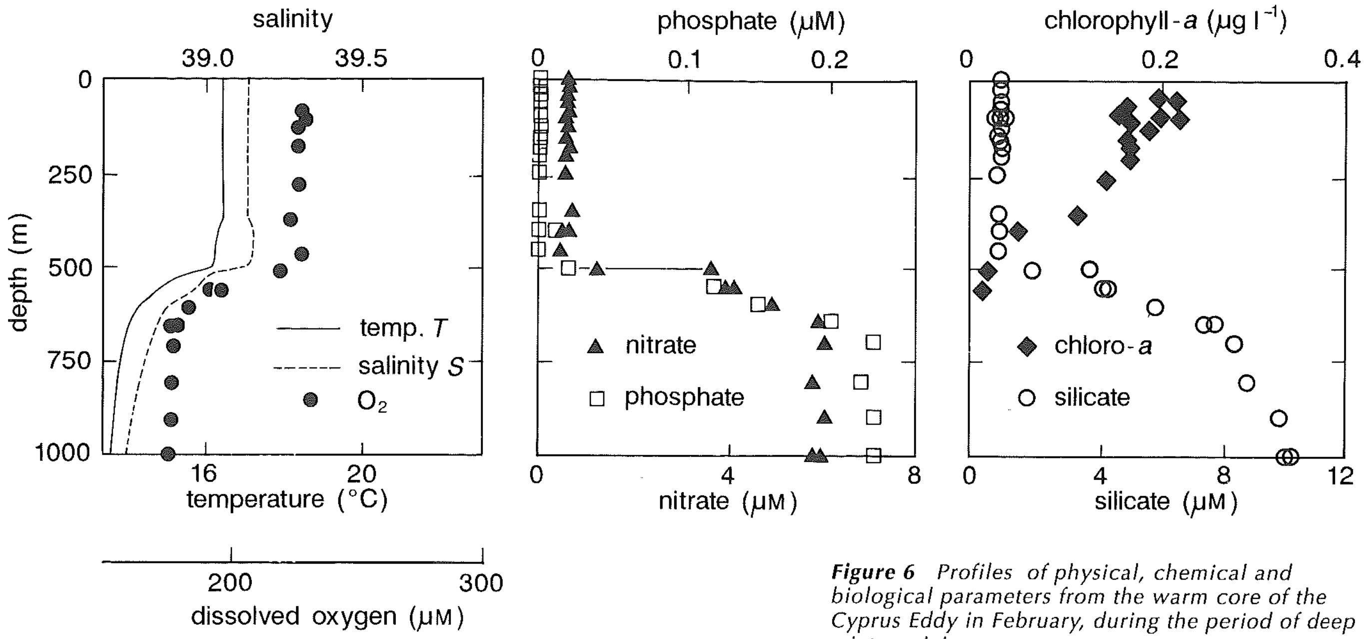


Figure 6 Profiles of physical, chemical and biological parameters from the warm core of the Cyprus Eddy in February, during the period of deep winter mixing.

Only phosphate concentrations are reduced to zero by phytoplankton growth

particles < 2 µm increases with depth and can exceed 70 per cent in the chlorophyll-*a* maximum at 90–120 m, while viable phytoplankton are routinely found to a depth of 200 m (Figure 5), even in winter when constant plankton concentrations are found throughout the 200 m mixed layer. In the extreme case of the warm core of the Cyprus Eddy, during the winter bloom we have measured chlorophyll-*a* down to 500 m, the entire depth of active winter mixing (Figure 6).

There are types of picoplankton (< 2 µm) found in the eastern Mediterranean that appear to be capable of harvesting sufficient light to grow at light levels very much less than 1 per cent of that at the surface. Tamar Zohari and Yosef Yacobi have suggested that the chlorophyll maximum may be significantly deeper than the biomass maximum, i.e. that the phytoplankton at depth in the eastern Mediterranean are adapted to growing at very low light levels by having unusually large amounts of chlorophyll per cell so that they can harvest the maximum amount of light possible. This phenomenon is the subject of further active research at the National Institute of Oceanography, Haifa, Israel.

Phosphorus-limitation of Primary Productivity

As far as most of the world's oceans are concerned, nitrate is generally considered to be the main nutrient limiting primary productivity. Both nitrate and phosphate are depleted in the Mediterranean Sea compared with the adjacent Atlantic Ocean. My co-workers and I have shown that the eastern Mediterranean is phosphorus-limited and is probably the largest body of seawater in the world that is so limited. This conclusion was based on several independent strands of evidence. We found that during winter, when both nitrate and phosphate are mixed from deeper layers into the photic zone, phytoplankton grew until phosphate concentrations were below detection limits, whereas a small but measurable amount of nitrate remained (Figure 6). In a series of experiments, water from the area was put into glass bottles together with added nutrients, and incubated to see which nutrients or combination of nutrients would stimulate phytoplankton growth. Only those bottles to which phosphate was added showed increased plankton growth.

In most parts of the ocean, the molar N : P ratio of deep water is very close to 16 : 1, the ratio in which these elements are taken up in phytoplankton growth (known as the Redfield ratio). In the eastern Mediterranean the N : P ratio in deep water is closer to 29 : 1. Furthermore the data suggest that the degree of phosphorus-limitation increases eastwards across the whole Mediterranean Basin: the N : P ratio increases from 15.2 : 1 in the eastern North Atlantic to 22.5 : 1 in the western Mediterranean, to 24.3 : 1 in the central Mediterranean south of Crete, to 28.9 : 1 in the Levantine Basin (Figure 7, opposite). In other words, there is either more nitrate or less phosphate in the water column, as one passes from west to east across the basin.

A number of possible explanations have been put forward to explain this phosphorus-limitation and its geographical pattern. Jean-Pierre Bethoux and co-workers have suggested that seagrasses such as *Posidonia* may fix large amounts of nitrogen from the atmosphere, which would be released back into the water when the plant dies. This would have the effect of increasing the amount of nitrogen available for photosynthesis in the water relative to phosphorus. However, while there may be large areas of seagrasses in the western Mediterranean, there are relatively

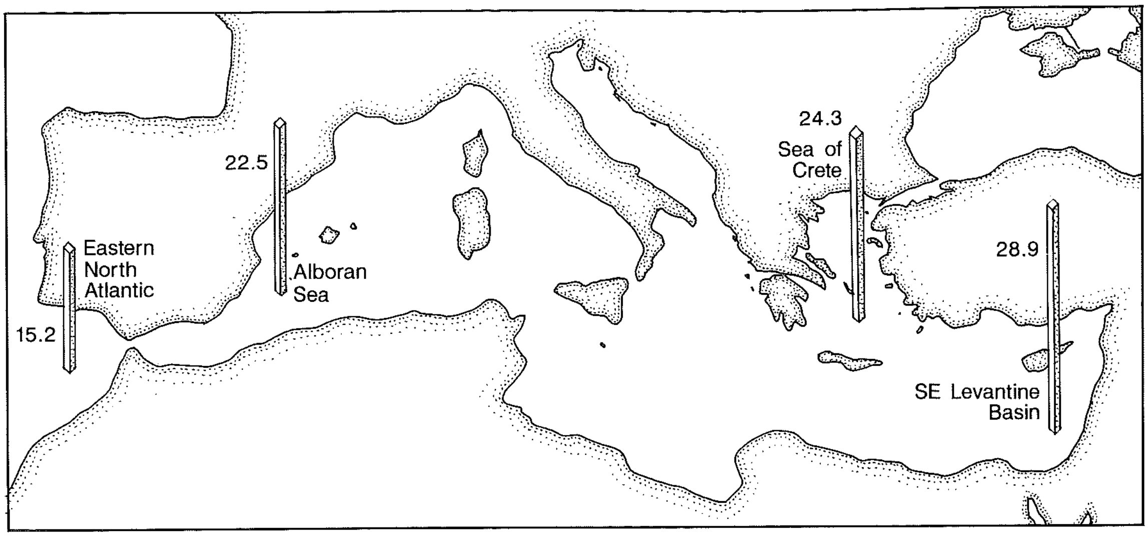


Figure 7 Geographical distribution of the molar N : P ratio in the deep water.

The molar N : P ratio in deep water increases eastwards across the Mediterranean

few such areas in the Levantine Basin. More recently, Bethoux has suggested that the nutrient inputs of some rivers may be depleted in phophate. Another explanation is that the atmospheric input of nutrients may be enriched in nitrogen relative to phosphate. This effect may be enhanced by pollution: NO_x is a major atmospheric pollutant which is transformed into nitric acid and deposited downwind of the industrial areas of western Europe. There may also be some deposition of anthropogenic ammonia.

We have proposed another hypothesis, namely that Saharan dust is scavenging phosphate from the water column – thus accounting for the low phosphate content of LDW mentioned previously. This area has a greater flux of dust than almost anywhere else in the world, and the dust contains a high proportion of iron oxyhydroxides which are known to scavenge phosphate from the water column. (The dust input would explain why the region is not iron-limited.) If this explanation is verified it has important implications elsewhere, as one of humanity's effects on the environment is to increase the amount of wind-blown dust and particulate matter eroded from soils. It is also known that during the last glacial period the amount of dust in the atmosphere was significantly greater than it is now. Could the world's oceans at that time have been phosphorus-limited?

Estimates of New Production

New Production (NP) is a widely used concept in oceanography. It is defined as the primary production in the euphotic zone that results from the supply of nutrients from outside that zone, as distinct from the primary production that occurs as a result of recycling processes in the water column. Jean-Pierre Bethoux calculated the NP of the whole eastern Mediterranean basin by estimating the total flux of nutrients into and out of the basin. The value he obtained was 150 mmol N m^{-2} yr^{-1}. We found that the waters of the Cyprus Eddy were essentially isolated from surrounding waters for periods in excess of one year. We calculated NP in the euphotic zone to be 300 mmol N m^{-2} yr^{-1} in the eddy core and 210 mmol N m^{-2} yr^{-1} for the rest of the basin. Within the limits of error, these values are similar to those of Bethoux, and to those found in other ultra-oligotrophic areas of the ocean, such as the central Pacific gyre. However in making this calculation we found that only ~30 per cent of the values quoted above correspond to *real* NP, supplied by nutrients from outside the eddy (from the atmosphere and lateral advection) – most of the nutrients were actually derived from decomposition of the previous year's production (i.e. it was recycled production) – implying *real* NP values of perhaps only 50–100 mmol N m^{-2} yr^{-1} in this region. This result highlights a potential problem in the definition of NP, which needs to be addresed by the oceanographic community.

The core of the Rhodes Gyre, the principal cold-core eddy in the eastern Mediterranean, is a site of upwelling and thus a location for enhanced biological productivity. Perhaps surprisingly, the principal site for enhanced primary productivity in the warm-core Cyprus eddy is also the core (Figure 8, overleaf). This enhancement is due to deep winter mixing of the water column to hundreds of metres, which brings significant amounts of nutrients into the euphotic zone. The 'upwelling' boundary of the Cyprus Eddy shows no evidence of enhanced biological productivity. This contrasts with the situation at the boundaries of oceanic warm-core rings where there *is* enhanced productivity – but that appears to have more to do with the temperature contrasts at the boundary than with upwelling.

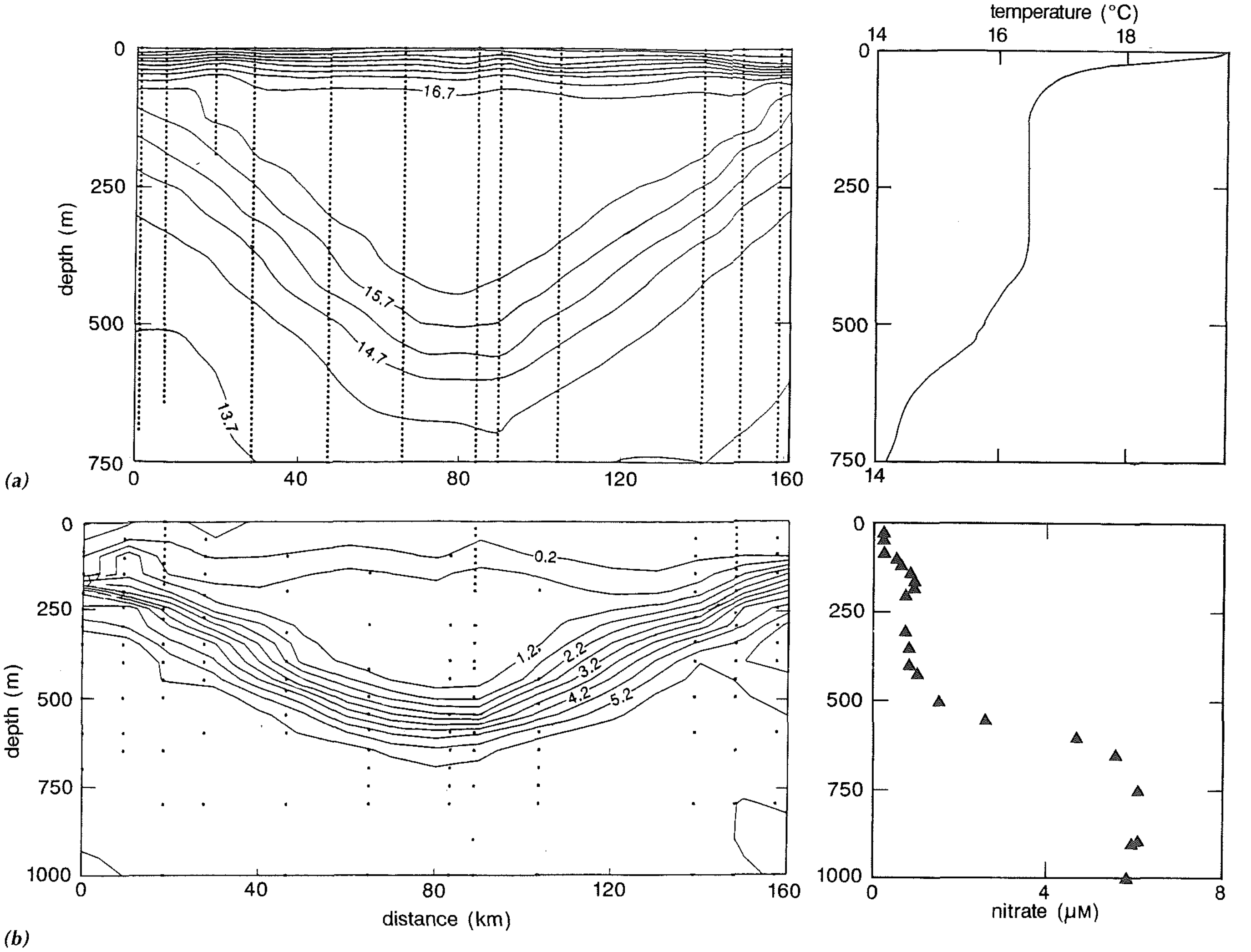


Figure 8 Cross-sections of ***(a)*** *temperature and* ***(b)*** *nitrate for the Cyprus warm-core eddy in May. Accompanying profiles are for the centre of the eddy. Sections and profiles show that high productivity extends from the stratified surface layer down to about 500 m in the core of the eddy.*

Future Studies

The second phase of the POEM programme is now underway, and one of its aims is to integrate biological and chemical measurements with a comprehensive set of physical measurements. The participating researchers hope to find out more about what controls the nutrient cycling and hence the primary productivity in the region, about the ways in which human activities have affected those cycles, and the cause of the unusual phosphorus-limitation in the region. Studies will also be undertaken to find out how the phytoplankton species have adapted to grow in the very clear, oligotrophic waters of the eastern Mediterranean. Within POEM, they also hope to learn more about the sources of LIW in the Levantine Basin. The lessons learnt from these studies will be important to the future prospects of this unique region, already greatly affected by human activity. The studies also represent a special opportunity to increase our knowledge of important oceanographic processes which are difficult and expensive to study elsewhere.

Further Reading

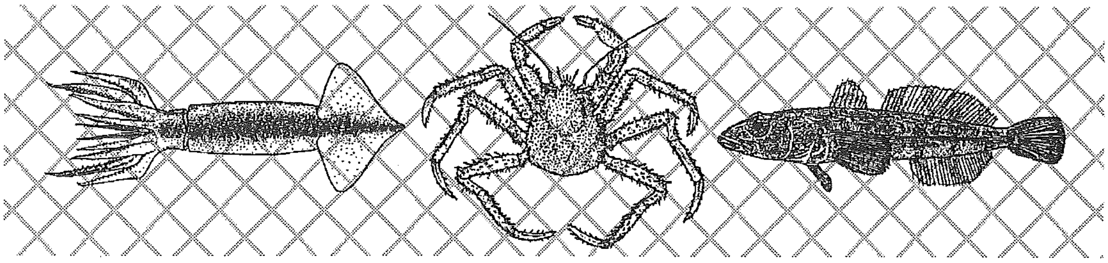
The physical oceanography of the eastern Mediterranean is reviewed in a series of papers brought together in a volume of 'Topical Studies in Oceanography', edited by A.R. Robinson and P. Malonote-Rizzoli, *Deep-Sea Research* (Part II), **40**, No. 6, 1993. The papers describe results from the first phase of the POEM programme mentioned in this article.

Acknowledgements

I would like to acknowledge the help and support of my friends and former colleagues at the National Institute of Oceanography, IOLR, Haifa, Israel. In particular, I would like to thank the director, Dr Yuval Cohen and my co-workers in studies of the eastern Mediterranean: Drs Nurit Kress, Steve Brenner, Amir Neori and Lou Gordon.

Michael Krom moved to Israel in 1982, working initially at the National Mariculture Centre in Eilat, studying water quality in marine fishponds. After moving to the National Institute of Oceanography, he worked on the chemical oceanography of the eastern Mediterranean and marine pollution. He took up his present position as lecturer at the Dept of Earth Sciences, Leeds, in 1991.

SOUTHERN OCEAN Fisheries



present status and future prospects

Paul Rodhouse   Martin White   Inigo Everson

The most abundant species of large animal (>40 kg) on the planet is the human, estimated population about 5.7 billion and currently growing at an annual rate of 1.7%. The UN predicts that the population could reach ~10 billion by 2050. Although there is widespread belief, not discouraged by the fishing industry, that the oceans will make an important contribution to future human food requirements, it appears we are currently exploiting fish and other seafood at about the upper limit that stocks can support, and even in the remote seas of the Antarctic some species have been effectively driven to commercial extinction. With respect to traditional fisheries it would appear that the carrying capacity of the planet has been already been reached.

Global Context

In 1990 the total world catch of marine fish showed a decline, finally reversing a trend of 20 years or so of increasing catches. Total landings dropped some 3% to 83 million tonnes. It is significant that in the years leading up to 1990, catches of high value species had been decreasing – in some cases since the 1960s – and the upward trend in total catch had only been maintained by increased targeting of alternative, lower value resources. Increasing investment in, and effort by, fishing fleets globally, at a time of declining catches of higher value species, has meant that the total catch has remained more or less stable at ever increasing cost. The UN Food and Agriculture Organization (FAO) estimates that the capacity of the world's fishing fleets grew at about twice the rate of the total marine catch between 1970 and 1990. Annual subsidies totalling $54 billion encouraged this investment and now result in the industry operating at an estimated loss of $22 billion per year at a time when the total value of the catch is $70 billion. Last year's so-called 'tuna war' in the Bay of Biscay and the recent dispute over Greenland halibut on the Grand Banks of Newfoundland are symptoms of a deep problem and it seems certain that such events will become more frequent in future as the competition for resources increases.

Aquaculture currently boosts global fish production by ~15 million tonnes per year and this could quadruple by 2025. However, there may be constraints imposed by shortage of water and land and problems of pollution and disease. Even if aquaculture develops according to the most optimistic scenario, there is undoubtedly going to be a continuing reliance on capture fisheries for a major proportion of the world demand for seafood. Furthermore, aquaculture depends heavily on pelleted food, much of which is manufactured from fish meal from the capture fisheries of 'trash species'. Clearly the problem facing fishery managers is not one of how to increase the global catch but how, at best, to sustain catches at present levels without doing irreversible damage to the marine environment.

Despite the size of the world's oceans, covering some 70% of the surface of the planet, marine fish production is largely limited to regions where there is high productivity at the base of the food chain. Composite global ocean colour images showing chlorophyll concentrations (as on the cover of *Ocean Challenge*) indicate regions of high phytoplankton standing stock and highlight regions of high productivity. Such images show that much of the world ocean is effectively desert, especially in the tropics, while conspicuous regions of high chlorophyll levels in the North Sea, the Saharan Banks and the Benguela upwelling system correspond to locations where fisheries have been historically pursued. It has been estimated that in these areas 20–40% of the primary productivity is used either directly, or indirectly via the food chain, to sustain fish catches.

Southern Ocean Fisheries

The Southern Ocean is a huge region comprising some 10% of the total world ocean. A composite ocean colour image of the Southern Ocean indicates the major regions of high productivity. Levels of primary production are generally of the same order as elsewhere in the world's oceans but the growth season for phytoplankton is short. Strikingly high densities of chlorophyll are visible close to the ice shelves of the Weddell and Ross Seas and off the Antarctic continent in the Prydz Bay area. However, these are highly seasonal environments with sea-ice cover for much of the year. Primary production by phytoplankton during the short intense growth season in these high latitudes mostly sinks to the sea-bed where it is consumed by dense populations of long-lived suspension-feeding sponges, echinoderms, hydroids and ascidians, which have no value as human food. Elsewhere, productivity is high in the Scotia Sea, the Bellingshausen Sea and locally in the vicinity of the Sub-Antarctic Islands such as South Georgia, the Kerguelen Islands and Heard Island. It is in these regions, especially the Scotia Sea and the Kerguelen Plateau, that the Antarctic fisheries are pursued. There are also areas of high productivity in some sectors of the Antarctic Polar Frontal Zone where the potential for commercial fisheries has not been fully explored.

In the past, the Southern Ocean has been the setting for massive exploitation of homiothermic ('warm-blooded') species, especially whales but also seals and penguins. The collapse of the whale stocks in the 1960s and their subsequent failure to recover, together with the shift in public opinion in the intervening years, means that future exploitation of homiotherms is unlikely. However there are a number of poikilothermic ('cold-blooded') species that are either the subject of current fisheries or are likely to be exploited in the future.

The major poikilothermic Antarctic marine living resources and their status are listed in Table 1. The majority of the commercially valuable fishes belong to the sub-order Notothenioidei, the rock-cods. Most exploitation has been at South Georgia, the Kerguelen Islands and the South Orkney Islands/Antarctic Peninsula region. The major stocks have been over-exploited and are currently much below their virgin biomass levels. The history of the Antarctic fin-fishery since its inception during the late 1960s shows clearly that total catches have declined to about 10% of their original values (Figure 1). It is also evident that the fishing industry has transferred its attention from one stock to another as each has been depleted below commercially viable levels. Initially the nototheniids were the mainstay of the fishery, then as these quickly declined, the fishing fleets turned to catching channichthyids (ice-fish), until these stocks also failed during the mid-1980s.

Table 1 *The major Antarctic marine living resources: the species and their current status.*

Fish (target species only)

Notothenia rossii (southern rock cod)
- South Georgia: over-exploited
- Kerguelen: over-exploited

Champsocephalus gunnari (mackerel ice-fish)
- South Georgia: over-exploited
- South Orkneys/Antarctic Peninsula: over-exploited
- Kerguelen: over-exploited?

Lepidonotothen squamifrons (grey rock cod)
- Kerguelen: over-exploited

Dissostichus eleginoides (Patagonian toothfish)
- South Georgia: not known
- Kerguelen: over-exploited?

Electrona carlsbergi (lanternfish)
- South Georgia: under-exploited

Crustaceans

Euphausia superba (Antarctic krill)
- Under-exploited

Paralomis spinosissima and *P. formosa* (Antarctic king crabs)
- Under-exploited

Molluscs (squid)

Martialia hyadesi (seven star flying squid)
- Under-exploited

The total catch of Antarctic fin-fish has declined by 90% in 20 years

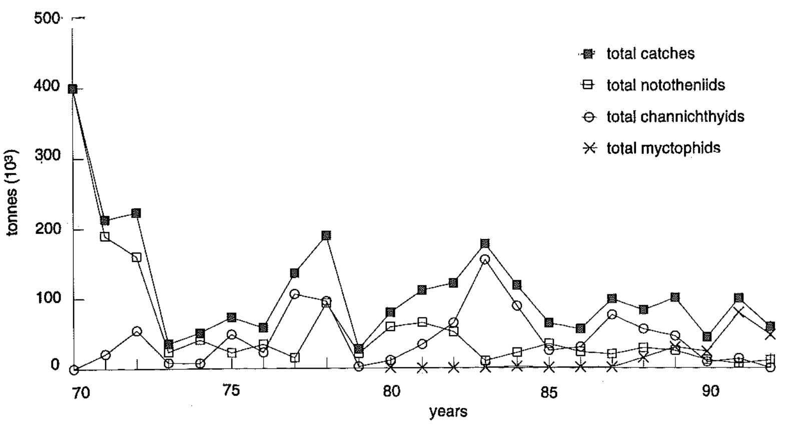


Figure 1 *Total catches of fin-fish in the Southern Ocean*

Recently, one of the largest fin-fish fisheries in the Southern Ocean has been for myctophids (lanternfish), for example *Electrona carlsbergi* (Figure 2). There are large, but little known, stocks of lanternfishes in the productive sectors of the Antarctic Polar Frontal Zone. These are lightly exploited at present fishing levels, are of low commercial value and have mostly been used for the production of meal for animal feed. The decline of fin-fish stocks in the Southern Ocean has led the fishing industry to diversify its techniques to exploit new species in an attempt to maintain the value of the fishery. This has lead to the development of a long-line fishery by Chile, Korea and Russia to exploit the high value Patagonian toothfish, *Dissostichus eleginoides* (Figure 3), in the vicinity of South Georgia and adjacent seamounts. Even though this fishery only contributes a small amount to the total annual fin-fish catch, little is known about its stock size and biology, so control over the fishery is being exercised to prevent it declining in the same manner as the previously exploited species.

Although of moderate value compared with other crustaceans, in terms of biomass, Antarctic krill, *Euphausia superba* (Figure 4), is the single largest harvest from the Antarctic. In spite of a circumpolar distribution, the most important fishing areas are South Georgia and the South Shetland and South Orkney Islands in the Atlantic sector. Catches have tended to fluctuate as Russian vessels have switched between targeting fin-fish stocks, when abundant, and then krill when fish stocks declined. Recent reduction in fishing effort by Russia, since the advent of a market economy and the withdrawal of unprofitable vessels, has led to a greatly reduced and more stable level of exploitation, mostly by the Japanese. In the overall context the krill stock is underexploited but because fishing often takes place in areas that are locally ecologically sensitive there is a need for careful management.

Stocks of king crabs, *Paralomis spinosissima* (Figure 5) and *P. formosa* are known to occur in the Antarctic but these have not been surveyed and their biology is poorly understood. These are high value species but it is likely that they grow and reproduce at slow rates. They would therefore be susceptible to over-exploitation, and so sustainable levels of exploitation would be low. An Alaskan king crab vessel recently spent a season fishing for *P. spinosissima* and *P. formosa* at South Georgia and despite strict limitations on gear, which was confined to use of pots, and restrictions concerning minimum size and gravid females, a large catch was reported. Subsequently, market conditions for king crab in the US have discouraged a return but this fishery is likely to be developed in the medium term.

Species that have been subject to recent commercial exploitation in Antarctic waters

Figure 2 *Lanternfish (myctophid)* Electrona carlsbergi *(maximum size ~ 9 cm).*

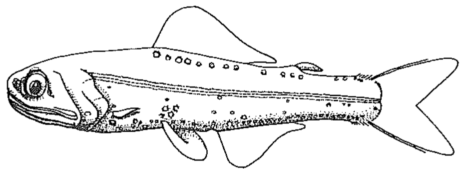


Figure 3 *Patagonian toothfish* Dissostichus eleginoides *(maximum size ~ 215 cm).*

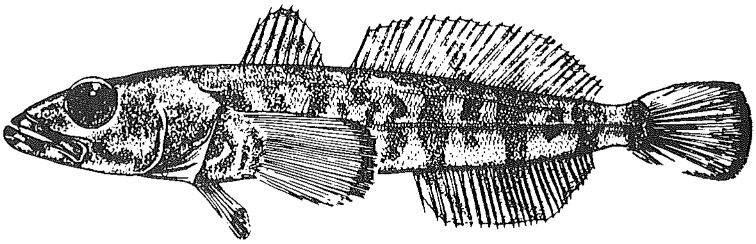


Figure 4 *Antarctic krill,* Euphausia superba *(maximum size ~ 7 cm).*

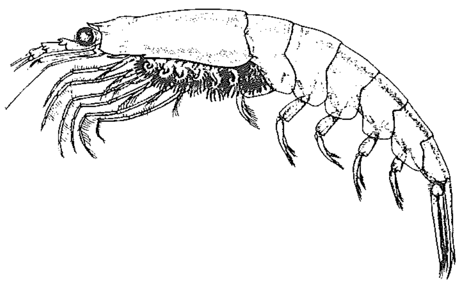


Figure 5 *Antarctic king crab,* Paralomis spinosissima *(maximum size ~ 16 cm).*

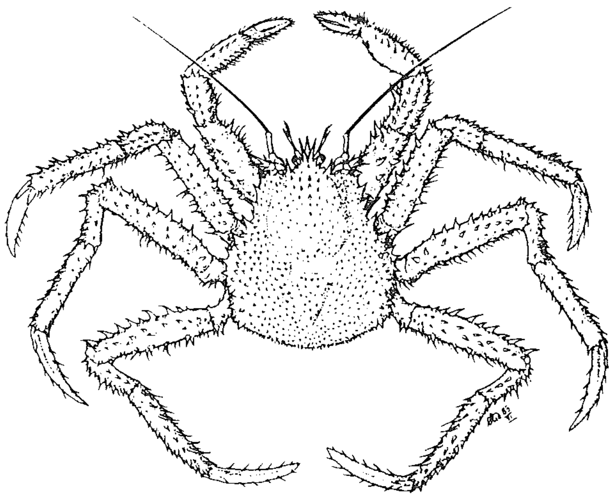
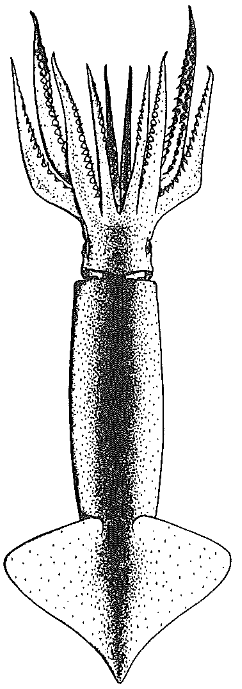


Figure 6 Seven star flying squid, Martialia hyadesi *(maximum size ~ 45 cm).*



Antarctic squid may be the next group to be targeted by fisheries in the Southern Ocean

Cephalopods, i.e. squid and octopus, are short lived, generally of high value, and in many areas of the world ocean have become important alternatives to traditional stocks where these have declined. Major international fisheries for squid are pursued on the Patagonian Shelf around the Falkland Islands and exploratory fishing has been carried out at South Georgia and in the Polar Frontal Zone of the Scotia Sea. The most likely candidate for commercial exploitation in the short to medium term is the seven star flying squid, *Martialia hyadesi* (Figure 6). Information from predator gut contents suggest that large stocks are present, at least in the Atlantic sector, and possibly elsewhere, but any future fishery is likely to have consequences for the seabirds and seals that rely on this species, especially during the sensitive breeding season.

Areas of the Southern Ocean are often subject to the administration of more than one authority

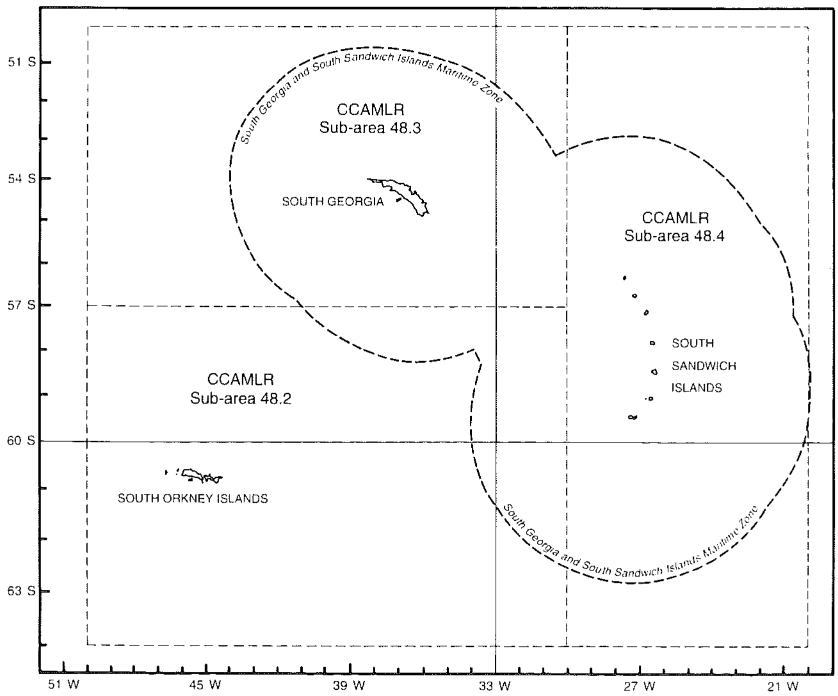


Figure 7 South Georgia and South Sandwich Islands Maritime Zone (heavy dashed line); also shown are CCAMLR statistical sub-areas, used in data analysis.

Management

Since 1982, the Commission for the Conservation of Antarctic Marine Living Resources, CCAMLR, has been the international body responsible, under the auspices of the Antarctic Treaty, for the management of marine fisheries in the Southern Ocean. The Commission meets annually to establish provisions for the management of exploited species but in contrast to fishery conventions elsewhere it also goes much further. Stocks are managed on the principle that harvesting should not reduce stocks below a level that (1) that ensures their stable recruitment, (2) compromises the maintenance of stable ecological relationships between harvested, dependent and related populations of Antarctic marine living resources and (3) causes changes in the ecosystem that are not potentially reversible within two or three decades. In other words, the Commission sets out to manage the fisheries in the context of the ecosystem, especially the vertebrate predator populations (seabirds and seals). In spite of these laudable aims, many stocks of the most valuable fish species were severely depleted prior to the establishment of CCAMLR and much of the Commission's efforts have been directed at reinstating stocks. As with other Antarctic Treaty provisions, the Convention is difficult to enforce and relies on voluntary compliance by the governments of the signatory countries.

In 1993 the UK government claimed a 200 nautical mile maritime zone around South Georgia and the South Sandwich Islands (SGSSI) (Figure 7). The SGSSI government accepts CCAMLR regulations for the management of stocks but may impose more stringent regulations if this is considered necessary. The benefit to CCAMLR of the SGSSI Maritime Zone is that much better catch statistics and assessment data will be available upon which to base regulations. In addition major ecological research programmes on resources and higher predators are carried out by the British Antarctic Survey in the area, so there is considerable potential for the future sustainable management of stocks.

Table 2 An indication of the potential contribution of Southern Ocean fisheries to world catch.

Resource	Potential annual catch
Nototheniods (rock cods and ice-fish)	Total: 100 000 tonnes South Georgia: 35 000–50 000 tonnes
Myctophidae (lanternfishes)	Not assessed
Euphausia superba (Antarctic krill)	>1.5 million tonnes
Martialia hyadesi (seven star flying squid)	Not assessed

The Future

Antarctic fisheries are currently undergoing a period of change. The major nations involved in the fishery have been the former Soviet Union, Poland, the former GDR, Bulgaria, Japan, Korea and Chile. The collapse of communism and the advent of market economies in eastern Europe, as mentioned previously, has led to a decline in fishing effort, but there are reports that Russia is currently planning to invest $1 billion in a modern fishing fleet. Given the pressures of human population growth and demand for quality protein it is inevitable that attention will be once again focussed on the Southern Ocean, a region still perceived by many to be largely unexploited.

An indication of the potential annual yield of Southern Ocean fisheries is shown in Table 2. It has been estimated that if depleted stocks can be restored the maximum annual yield that could be attained from the notothenioid fishes of Antarctic shelf waters is about 100 000 tonnes, of which some 35–50 000 tonnes would come from around South Georgia. The potential yield of krill has proven to be very difficult to estimate, largely because of the difficulties of estimating stock size in a population with a patchy distribution over extremely large areas of remote ocean. However, a precautionary catch limitation of 1.5 million tonnes per year has been set by CCAMLR, with a limit within any sub-area (cf. Figure 7) of 620 000 tonnes. This is higher than any annual catch to date. Standing stock of king crabs at South Georgia is estimated to be in the region of 48–78 000 tonnes. Annual yield would be considerably less. Squid stocks are also extremely difficult to assess. In the Scotia Sea some 350 000 tonnes of *Martialia hyadesi* are estimated to be consumed annually by vertebrate predators. When a fishery starts it will be necessary to proceed with extreme caution if this potentially valuable and ecologically important resource is not to be wantonly destroyed in the way that the fragile fish stocks were two decades ago.

In spite of the global crisis in exploitation of many marine species, there are still some stocks, notably of Antarctic krill and squid, that could sustain increased catch rates. However, in view of the problems that have been created by over-exploitation elsewhere it is imperative that these under-utilised resources be carefully managed to ensure a sustainable fishery and the maintenance of ecological relationships. The slow growth and reproductive rate of most Southern Ocean species means that stocks are slow to recover from the effects of over-exploitation.

The UK, represented by the British Antarctic Survey, is a major contributor to research on marine living resources in the Antarctic and the ecological systems that depend on these resources. The Survey's Marine Life Sciences Division supports research programmes on the dynamics of the plankton, large-scale modelling of the Southern Ocean and studies on higher predators that underpin research on the living resources. The Survey makes a major contribution to the work of CCAMLR in the areas of fish stock assessment, estimates of krill standing stock, inspection of commercial vessels fishing in the CCAMLR area and the CCAMLR Ecosystem Monitoring Programme (CEMP). Commissioned research is also undertaken of behalf of the Falkland Islands Government on the life-cycle biology and recruitment processes of the commercial squid stocks on the Patagonian Shelf.

Acknowledgements

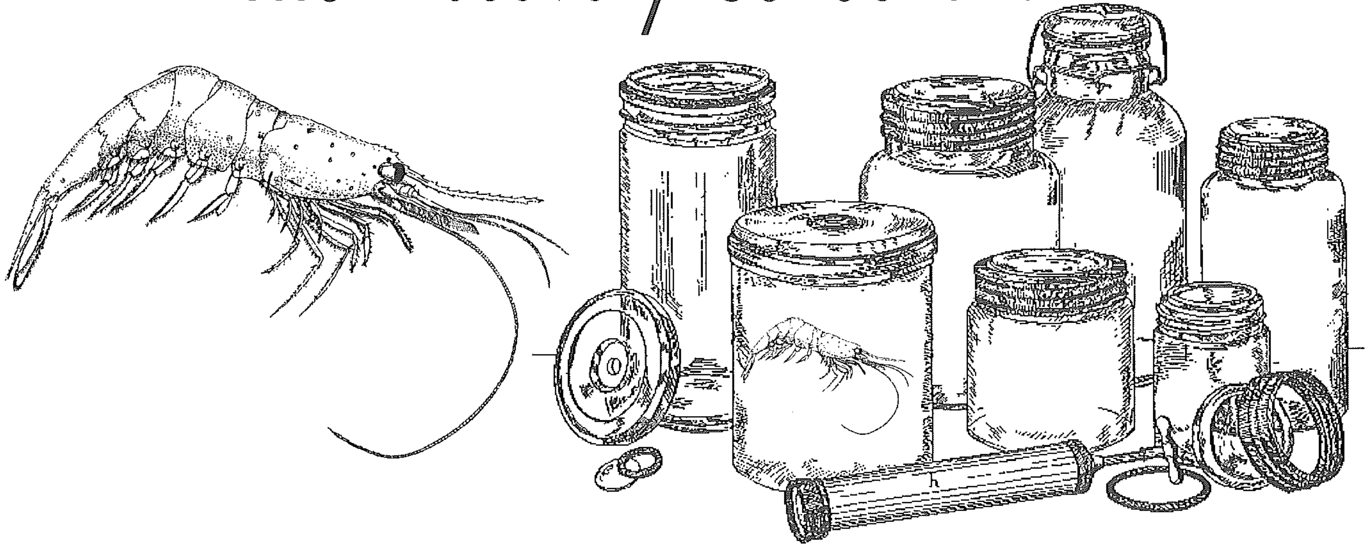
Figure 2 is reproduced from Miller, R.G. (1993) *History and Atlas of the Fishes of the Southern Ocean*, Foresta Institute for Ocean and Mountain Studies.

Figure 3, 4 and 5 are reproduced by permission of the Food and Agriculture Organization of the United Nations, from Fischer, W. and Hureau, J.C. *Species Identification Sheets for Fishery Purposes, Southern Ocean*, Vols. I and II.

Figure 6 is reproduced from Rodhouse, P.G. and Yeatman, J. (1990) *Bull. Br. Mus. Nat. Hist. (Zool.)*, **56**, 135–143.

Paul Rodhouse, **Martin White** and **Inigo Everson** are biologists in the Marine Life Sciences Division at the British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, UK. Their research focusses on the biology of the marine living resources of the Southern Ocean.

The *Discovery* Collections



70 years of sampling the ocean's fauna

Martin V. Angel

The first programmes of systematic sampling of the marine environment were initiated in the early 1900s, chiefly as a consequence of concerns about the uncontrolled manner in which the fishing and whaling industries were eating into the living resources of the ocean. This widespread increase in awareness that stocks of any marine species – fish as well as marine mammals – need to be scientifically managed led to the establishment of ICES (the International Commission for Exploration of the Seas) to collect and coordinate data on catches and the status of stocks and the marine environment in the North Atlantic. In 1904, W.L. Allardyce, the Governor of the Falklands, introduced the first regulations to restrain the slaughter of whales in the Falklands and its Dependencies. The regulations sought to restrict the numbers of shore-based stations, factory ships and whale-catchers, as well as banning the killing of cows with calves.

The early history of whaling as described by Sydney Harmer in 1928 is a sorry story of greedy and ignorant over-exploitation. The first whales to be hunted had been the Biscayan right whales – 'right' because when killed they floated – which Basques started exploiting some time in the 10th or 11th centuries. Between 1517 and 1561, at least 700–1000 whales were taken from the Spanish coast; this proved enough to drive the whales away, forcing the Basques to go progressively further afield. By 1578 there were already reports of 20–30 ships whaling off Newfoundland. These early whalers included the Icelanders, who had started whaling in the 12th century, concentrating solely on right whales. But in 1865 Svend Foyn introduced the harpoon gun which allowed the exploitation of rorquals. Foyn began by hunting blue whales off Norway: very soon the stocks were exhausted and the whalers began to look elsewhere.

The first whalers to visit the Southern Ocean (in 1893) were from Dundee; they were equipped only to hunt right whales and returned empty-handed. The Swedish Antarctic Expedition, which began in 1901, included Captain C.A. Larsen who, excited by what he saw during the expedition, founded a whaling company in Buenos Aires on his return. On 24 December 1903, a whaler *Anderssen* killed a humpback whale, the very first whale ever to be taken in the Southern Ocean: the Antarctic whaling industry had begun.

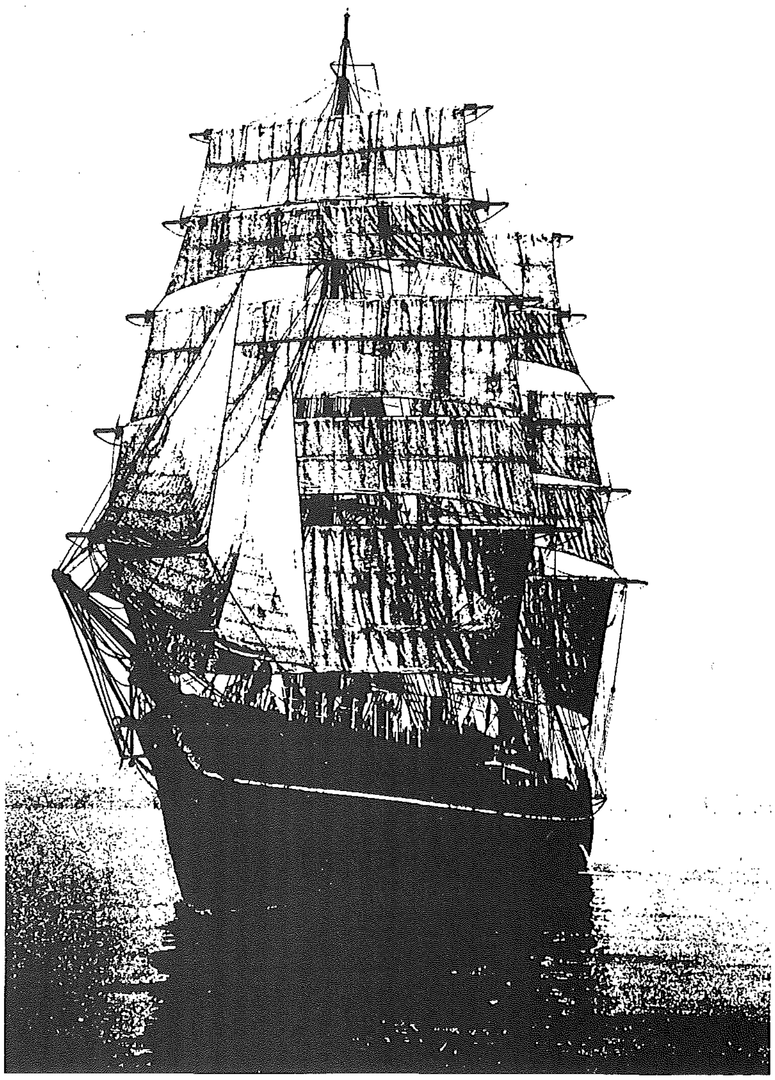
Larsen returned to Norway in 1904, reporting large concentrations of whales off South Shetlands, South Orkneys, South Sandwich and South Georgia. It was he who established the whaling station at Grytviken, South Georgia, in July 1904. In 1908, Norway recognized British jurisdiction over the islands. Initially, the Southern Ocean whaling industry concentrated on humpbacks, with nearly 6 200 being taken during 1910–11. By 1912, twenty-one whale-catchers were already operating from shore stations in South Georgia and thirty-two from the South Sandwich Islands.

During 1910, J.A. Mörch, a Norwegian chemical engineer attached to the whaling industry, wrote to Sidney Harmer at the Natural History Museum proposing that a licensing system should be established whereby catch data should be compiled, and that a proportion of the licence fee should be set aside for scientific research. Following pressure from the Trustees of the Museum, in October 1913 the Colonial Office sent Major G.E.H. Barrett-Hamilton, an Irish zoologist, out to South Georgia on a fact-finding mission. Barrett-Hamilton measured whales for two months before he suddenly died on 17 January 1914. However, his data were used by an Interdepartmental Government Committee on the whaling industry, in which Martin Hinton reported that "on its present scale and with its present wasteful and indiscriminate methods, whaling is an industry which, by destroying its own resources, must soon expire".

This first Committee was disbanded because of the War, but a second was set up at the very end of 1917 to decide how best to regulate the whaling industry when hostilities were over. In its final report, published in 1920, the Committee identified the urgent need to study not only the biology of the whale but also its whole environment, in order to provide a scientific basis for regulating the catches.

In 1924, an Executive Committee was set up under the chairmanship of Rowland Darnley of the Colonial Office to manage the programme of research. The Committee used the funds provided by the whaling licences to purchase and refit Scott's *Discovery* at a total cost of £114 000 (about £3 million at present day prices), had the *William Scoresby* built for £33 000, and set up the scientific laboratory at Grytviken for just under £10 000.

Eventually, the whole programme became known as *'Discovery* Investigations' and the Committee became the *Discovery* Committee. It appointed Dr Stanley Kemp to be 'Director of Research' and Leader of the *Discovery* Expedition (or 'Commission'). Kemp had spent over ten years with the Zoological Survey of India and had gained experience of fisheries research off Ireland. He was a charismatic leader, "a man of great physical stature, modest, beloved of his staff, whom he was able to inspire (and sometimes exasperate) through his devotion to the task, in often trying conditions on board the ever rolling ship". However, as Ann Savours writes in her recent book, *The Voyages of the Discovery*, "one reason for the *Discovery* Investigations being comparatively little known was that its leader (and the [Executive] Committee) shunned publicity". Perhaps another reason was that all the results were published in the house journal, *Discovery Reports*, which had a limited circulation and is now almost totally overlooked in Antarctic oceanographic literature.



The original* Discovery *in the Solent in 1924
(From a photograph taken by J. Russell and Sons, Southsea)

Another inspired appointment was that of Alister Hardy as chief zoologist. Although Hardy was appointed to the Chair in Zoology at Hull at the end of the first research 'Commission', he continued to take an active and influential interest in the *Discovery* Investigations until the early 1960s. His book, *Great Waters*, published in 1967, is a very readable source of information, not only about the first Commission, but also on biological oceanography and the theories prevailing in the late sixties. The other zoologist appointees were N.A. Mackintosh, J.E. Hamilton, J.G.F. Wheeler, L. Harrison Matthews, E. Rolfe Gunther (all in 1924), soon followed by David Dilwyn John (1925), F.C. Fraser (1927), James Marr, G.W. Rayner, Professor F. John Hart, F.D. Ommaney and A.H. Laurie (1929). The first hydrologists (as they were known) were Henry Herdman and A.J. Clowes, with George Deacon joining in 1927. Many of these scientists eventually became Fellows of the Royal Society.

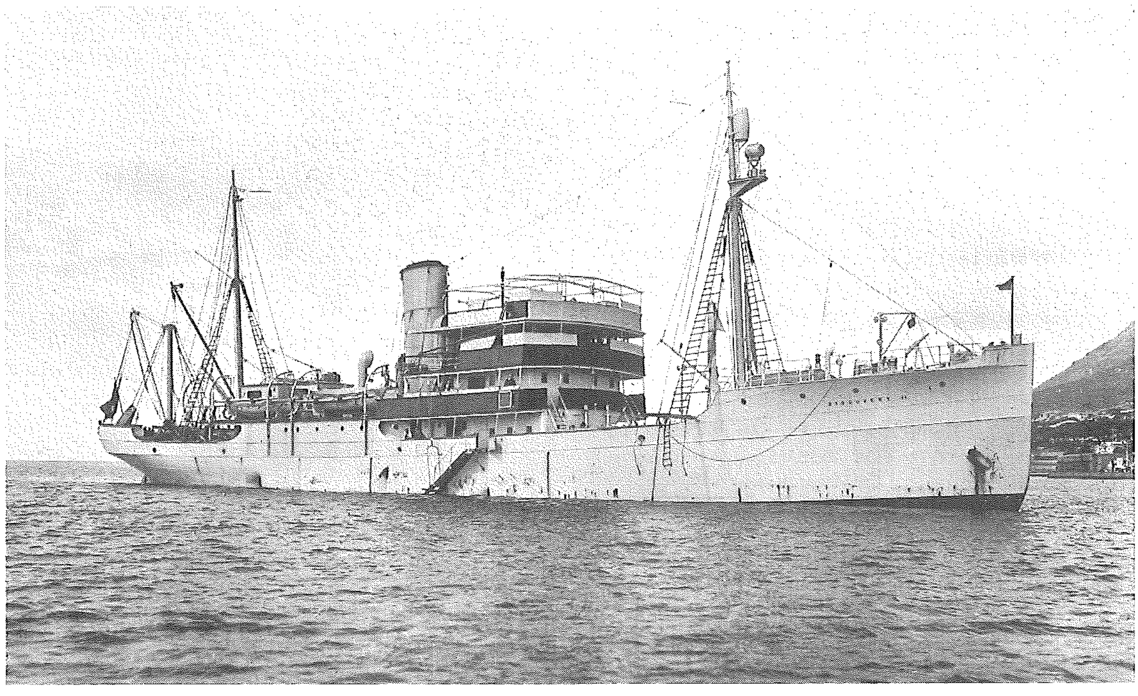
After the first Commission, it was apparent that Scott's ship was not an ideal platform for open-ocean work, and was replaced by a custom-built vessel *Discovery II*, which was to end its days in the breaker's yard in 1962.

It was Kemp and Hardy who, in Volume 1 of *Discovery Reports,* set out the objectives of the Investigations, described the ships and their equipment, and established the methods which were to be used in biological research until well after the Second World War. The attention to detail was exemplary. All the nets were carefully specified, from the 'N50' with its 200 meshes to the inch, to the 'N450', an immense ring net 4.5 m in diameter with mesh grading from 0.5 in to 4 mm. Fixation methods were described (a 10% solution of formalin, neutralised with 5 g of borax per litre, and 75% ethyl alcohol, was most often used); many specimens were initially anaesthetised with either menthol crystals or chloral hydrate. Specimens which required individual preservation were placed in tubes plugged with cotton-wool wrapped in tissue paper (better than using corks or plain cotton wool). Ten sizes of label were prescribed, made of "heavy paper of the best quality Antique parchment cream wove, supplied by Messrs Waterlow & Sons Ltd". The station number, date of sample, gear code and depth of sample were written on the label, and "All entries were made in soft B or BB [pencil] and the labels curled around inside the tube or bottle with the written side against the glass." Seven sizes of standard fruit-preserving jar were used, but with the lacquered tin lids replaced with copper. The bottles were then kept in felt-lined boxes. Information about each haul was entered into a General Scientific Log, which was used to generate the station lists which were published at regular intervals. The material collected during the first Commission was initially referred to as originating from the '*Discovery* Expedition'. That name evolved into *Discovery* Investigations and then into *Discovery* Collections, which has been retained ever since.

Apart from some changes to the nets, and a disastrous change to the preservation methods (described later), the same protocols were still in use when Peter Herring and I participated in the International Indian Ocean Expedition in 1963.

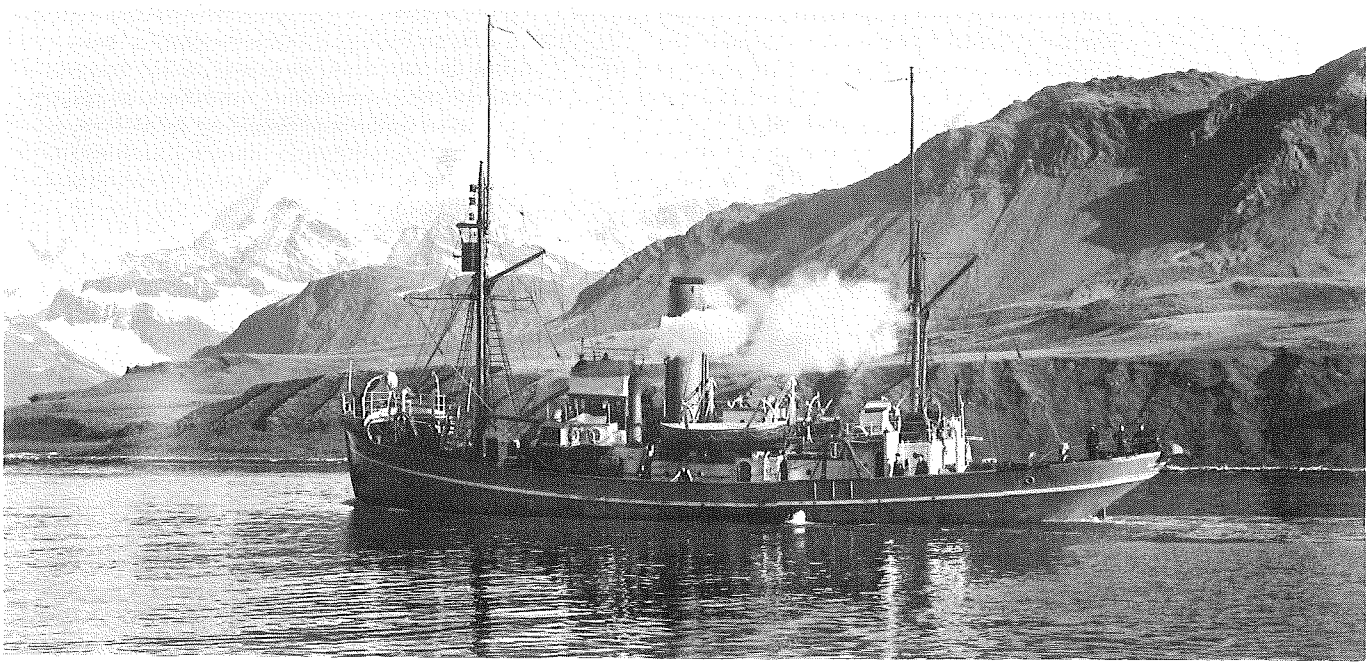
In the First Report of the *Discovery* Investigations, published in 1926, it was stated that: "In order to deal with the collections of scientific specimens gathered by the Expedition, an additional scientific officer has been appointed to take charge of, and to sort and arrange the material pending the return of officers who would work on it in this country. Through the good offices of the Trustees, the material has been housed, and laboratory accommodation has been provided, at the British Museum (Natural History), South Kensington." Dr Helene (Binkie) Bargmann took up her appointment as Curator in 1928, to be followed by a Mrs White in 1929. Helene Bargmann eventually became a Principal Scientific Officer; the status of the Curator has declined as the recognition of the value of the collection has declined, so that our last two Curators, Kate Chidgey and Ben Boorman, are three grades lower. All the early correspondence about the collections was signed by Kemp, and loans had to be approved by the Committee. The correspondence we have shows that material was sent to almost every marine taxonomist in the world, and that many of them wrote memoirs for *Discovery Reports.*

By 1930, the whaling industry had become almost totally pelagic. The shore stations went into decline, although Grytviken continued to function for many years. Although the income from the licensing levy declined rapidly, the Government continued to pay for the research.



***Discovery II*, off Simonstown in 1930**

(Courtesy of the Institute of Oceanographic Sciences)



The* William Scoresby *leaving Grytviken, South Georgia

(Courtesy of the Institute of Oceanographic Sciences)

In 1936, Kemp resigned as Director to become Director of the Plymouth Laboratory. Alister Hardy wrote that "in the aerial bombardment of Plymouth Dr Kemp suffered severe strain in saving the laboratory from destruction by fire while incendiaries destroyed his own house with all his precious personal belongings, including his as yet unpublished research material; few can doubt that this was largely responsible for bringing on the illness from which he died in 1945". Dr Neil Mackintosh succeeded Kemp as Director of the *Discovery* Investigations.

Discovery II had continued to collect material from the Southern Ocean; the detailed survey carried out around South Georgia on the First Commission was repeated on the Second. In early May 1931 she worked a line of closely spaced stations from 57° S to 14° N along 30° W. Arthur Baker and Kate Chidgey (1986) summarised the rest of the pre-World War I sampling as follows:

> In their subsequent 18 month to 2 year commissions, which continued until 1939 with only short breaks between each one, *Discovery II* and *William Scoresby* extended the coverage of the Southern Ocean. The Southwest Atlantic continued to receive a good deal of attention because of the high concentrations of krill in that area. In addition *Discovery II* also undertook two circumpolar cruises, the first from March to October 1932 and the second from November 1937 to April 1938. These cruises took the form of star-shaped lines of stations running from the region of the Antarctic Convergence to the ice-edge and they provided a great deal of data on latitudinal changes, where physical and biological gradients were likely to be most marked, and also data on longitudinal differences. As well as the repeated work at South Georgia, two other repeated surveys were made to study seasonal changes. One was in the Bellingshausen Sea along 80° W, where the same line of stations was worked between December 1933 and November 1934. In the other a track was made westwards from Cape Town to the Greenwich meridian, down this to the ice-edge, eastwards along the ice-edge and back up 20° E to Cape Town. This was started in May 1936 and was repeated ten times either wholly or in part by March 1939. At the same time *William Scoresby* continued work mainly in the Scotia Sea but also carried out a survey of the Peru Current and another trawling survey of the Patagonian shelf.

Both *Discovery II* and *William Scoresby* were chartered to the Ministry of Transport during World War II, and were recommissioned for research in 1950. The former undertook another circumpolar cruise, and the latter undertook two surveys of the Benguela Current and attempted some work in the western Indian Ocean. The *Discovery* Committee was wound up in April 1949, and replaced by the formation of the National Institute of Oceanography, which was located at Wormley. George Deacon was appointed Director and Neil Mackintosh Deputy Director. Not all the ex-*Discovery* Investigations staff welcomed this change; Mackintosh in particular felt that the whale research should be continued at the Natural History Museum, and he stayed in London in charge of the whale research group, which eventually formed part of the Sea Mammal Research Unit. Consequently, only some of the collections were moved to Wormley between 1953 and 1960, and there was a sharp reduction in marine taxonomists seeking to work on the material. The Institute's research became focussed on the north-eastern Atlantic.

continued ➢➢

The prospect of the International Indian Ocean Expedition provided the means of persuading Government to fund a new vessel. *Discovery II* was broken up and the new *Discovery* launched at the end of 1962. The consecutive numbering of the stations was maintained (and continues to be maintained even after the ship's latest refit in Portugal). The first three cruises of the new ship were in the Indian Ocean; station 5000 was worked in the Red Sea on the way out in 1963. Station 10 000 was worked in the Southern Ocean in 1979 on cruise 100. This was also a notable cruise in several other ways: it was Sir George Deacon's last, at the age of 73 (a privilege which will be denied to his successors, thanks to Health and Safety regulations); and the line along 20° E was again repeated, but this time using oblique tows with rectangular mid-water trawls.

However, it was during the post-World War II period that the first disastrous change to the protocols laid down by Kemp and Hardy was introduced. The borax used to neutralise the formalin was replaced by hexamine, as advocated by J.L.B. Smith (the South African chemist turned biologist who described living coelacanths). It was possibly the greatest disservice to biological oceanography ever made by one man, because during long-term storage the preservative acidified, decalcifying the samples and resulting in disintegration of the specimens. Hence much of the material collected in the years immediately post-War, including that from the Indian Ocean, became useless and had to be discarded; on the other hand, all the original material collected in the Southern Ocean is still in superb condition.

Since that time, procedures have radically altered, with the development of new samplers controlled acoustically, both for pelagic and benthic sampling. The emphasis of the scientific questions has shifted away from descriptive biology and more towards process studies. Even so, the material collected has been managed with much the same objectives. All material that is retained is properly logged, but nowadays into a computer database. Whereas the old *Discovery* investigators kept all their records in notebooks, we now have a pelagic biological database (managed by Phil Pugh) in which we bank top quality data so that they remain fully

Just a very small part of the* Discovery *Collections

(Courtesy of the Institute of Oceanographic Sciences)

accessible for further analyses. Although we have been unable to enter any of the data acquired prior to 1965, the database already includes data on over 4.5 million identifications, including 81 500 records of 13 taxonomic groups (Table 1). Recently, it has proved to be invaluable in examining patterns of oceanic diversity. The aim is to be able to reconstruct the contents of all standard samples. Information technology and the advances made in statistical analyses have increased the speed with which data can be interpreted, but unfortunately not the speed at which sampled material can be turned into data. Over the last decade, the time that IOS Deacon Laboratory biologists have been able to devote to identification and taxonomic studies has declined from 75 per cent to less than 10 per cent.

Table 1 *Taxonomic data in the IOS pelagic biology database*

Taxon	No. of records entered	No. of specimens identified
Amphipoda	771	6 455
Chaetognatha	1 245	218 552
Copepoda	3 285	708 226
Ctenophora	102	1 139
Decapoda	7 126	91 820
Euphausiacea	11 646	593 123
Fish	19 259	246 690
Heteropoda	249	1 738
Medusae	861	30 672
Mysidacea	2 422	93 496
Ostracoda	10 849	1 144 213
Pteropoda	373	1 809
Siphonophora	23 335	1 500 000

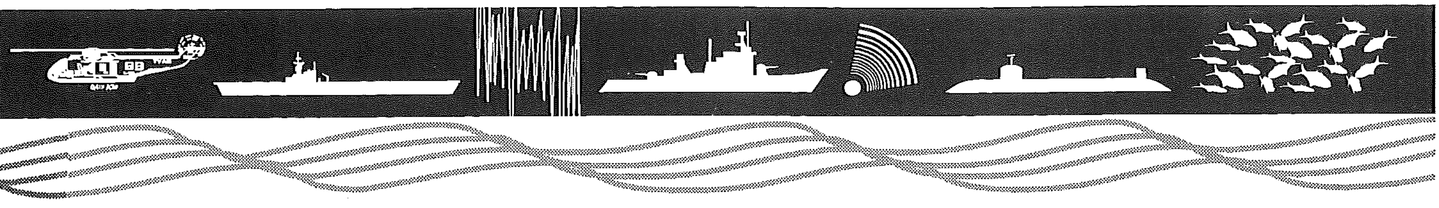
The value of the routine analyses begun by the *Discovery* Investigations is re-emerging, partly through the emphasis now being placed on the importance of understanding biodiversity, but also because of the need to develop methods of reducing the complexity of biological oceanographic processes without losing too much precision. Physical oceanographers have only a few parameters they can work with, but biologists have many hundreds; these may lack precision, but they carry a record of the history of the water over a range of time-scales from days to years. Moreover, the Collections now offer a uniquely long (albeit interrupted) time-series, whereby decadal-scale changes in Southern Ocean communities can be assessed. It covers the period of a major (if unintended) ecological experiment: the wide-scale removal of the top predators, the large whales. Julian Priddle of the British Antarctic Survey has identified changes in the specific composition of large diatoms off South Georgia, and we have a collaborative study with Finnish biologists looking to see if there have been changes in the size spectra of the planktonic communities.

The series of *Discovery Reports* ended with Volume 37 in 1980, providing – as Sir Alister Hardy observed – a fitting memorial to the vision of Stanley Kemp. The reports provide a massive (albeit rather indigestible) compendium of information about the ecology of the Southern Ocean, and include the original descriptions of around 800 new species. Type specimens are still deposited at the Natural History Museum, and our close relationship with the Museum continues to flourish, mainly at present through our benthic studies.

What of the future? There is considerable uncertainty as to whether the integrity of the Collections can be maintained for much longer. For the last ten years we have been unable to invest in adequate curatorial effort. While there is no imminent danger of serious deterioration, another decade would see the onset of problems. Demands for 'prime space' at the main site at Wormley have resulted in the dispersal of the samples between four locations. Now, with the move to the Southampton dockside, the space allocation is shrinking still further, to only a third of that available at IOS. While some material can probably be culled without too much loss, such culling will involve a substantial amount of unprofitable time and effort. Moreover, the cost of disposal of formalin-preserved material is far from negligible.

Like vintage port, the older the material gets the more valuable it becomes in providing source material for inferring past conditions. It is also a resource that can be exploited to test new hypotheses without the additional expense of going to sea. The ship-time involved in collecting the material held in the Collections since I joined in 1965 is around £20 million (*without* taking inflation into account). If lost, the Collections can never be replaced; the policy at most institutions is to discard all material within a few years, so it becomes impossible to revisit material in the light of new theories and information. While recognising that it is a resource that is presently under-utilized, to discard even some of the material would, in my opinion, be an act of vandalism.

Martin Angel was head of the Biology Department at the Institute of Oceanographic Sciences Deacon Laboratory from 1982 to 1994. He believes passionately that oceanographic and climatic studies must be underpinned by sound taxonomic understanding.



Bioacoustics and bioluminescence: living clues for the naval strategist

Howard Roe, Gwyn Griffiths and Peter Herring

Most sound-scattering within the oceans, and all of the bioluminescence, is due to the biota. Populations and communities are not distributed uniformly but are patchy on a wide variety of spatial and temporal scales. This patchiness results from interactions between physical and biological factors with the dominant forcing function changing with scale: gyral circulation dominates large basin-scale variability and sets the overall context within which biological distributions are correlated with water masses; at the mesoscale (scales of 10s–100s km), variability is dominated by eddies and frontal systems; and at scales below this, variability becomes a function of biological behaviour, e.g. movement, predation, reproduction, interaction with physical turbulence and mixing processes. The relationships between patches of plankton, between biological and hydrographic features, and hence between nutrients and production, are key elements in understanding the dynamics of ocean ecosystems and, for example, the role of biology in modifying climate.

This biological variability is important in a naval context because it produces variability in acoustic backscatter – or 'volume reverberation' – which is a critical parameter in the sonar equation for active sonars.

In an era when improved sonar hardware performance is becoming increasingly costly and fraught with technical difficulties, it is vitally important to make best use of knowledge of the acoustic environment. It is not uncommon for the biota to be responsible for spatial and temporal variability in acoustic backscatter of 30 dB (i.e. over three orders of magnitude). This variability has implications for both surface and sub-surface naval operations, for vessels and for weapon systems. Much of the biological variability (i.e. backscatter) is concentrated around fronts and eddies which may have strategic significance owing to their physical characteristics. Similarly, variability in bioluminescent activity is a measure of environmental variability, and bioluminescence is of considerable additional interest because of its potential use in non-acoustic detection of submarines.

Acoustic and bioluminescent techniques for studying biology are non-intrusive and can provide a variety of high-resolution quantitative and qualitative data in near real time, and over a variety of time- and space-scales. They can also be used concurrently with other underway sampling devices, for example along with *SeaSoar*, an undulating hydrographic sensor package developed at IOS Deacon Laboratory. It is therefore possible routinely to obtain a suite of biological data simultaneously with, and on the same time- and space-scales as, physical and chemical data.

Acoustics

Acoustics have been used in fisheries research since the 1930s, and sophisticated techniques now exist for routine estimates ranging from stock size and abundance to individual numbers and sizes, along with information about behaviour and identification of fish species. However, much of the oceanic biota is considerably smaller than commercial fish (centimetre-sized or less), and techniques appropriate for fisheries are not suitable for detecting these much smaller animals. The ability to detect objects with sound in the absence of gas bubbles (which themselves reflect sound strongly) depends mainly on the frequency of sound used, and the size and orientation of the object. The wavelength of the sound used should be of the same order as, or less than, the size of the object; essentially, to detect zooplankton and micronekton we need to use frequencies >100s kHz to MHz – much higher than those used in normal fisheries sonar.

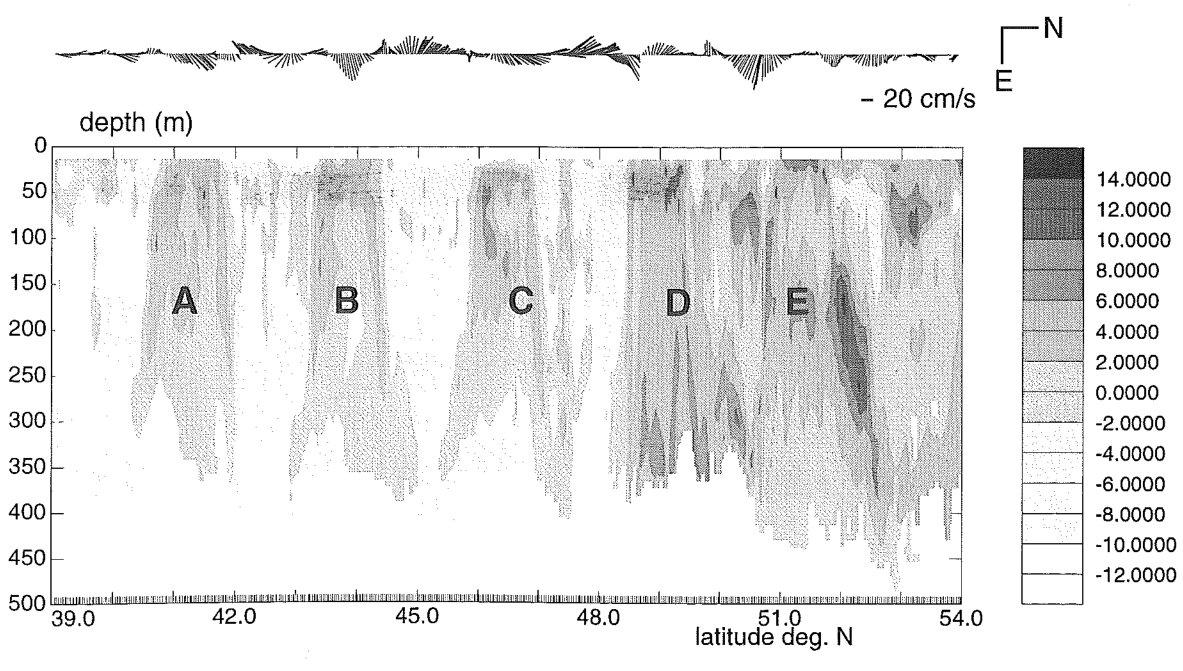
Novel acoustic systems have been developed and applied to zooplankton in the past two decades, and it is now possible to obtain quantitative data on biomass, size and numbers of plankton and micronekton, in addition to information on distribution and behaviour. These new developments are, however, extremely specialized and not in general use. In contrast, acoustic Doppler current profilers have, since the mid 1980s, become routine instruments for the measurement of ocean currents. ADCPs measure current velocities over a depth range of 10–600 m depending on frequency; they rely upon acoustic backscatter from particles which are assumed to be drifting passively in the water. In the open ocean these particles will be mainly zooplankton, and it follows that ADCPs should therefore be capable of providing biological data in addition to current profiles. This possibility has been recognized and it is now clear that ADCPs can provide quantitative and qualitative biological data on biomass, rates of movement and distribution. Significantly, many of these data can be obtained and displayed routinely in real time from hull-mounted instruments operated continuously underway. Very large amounts of data can be collected in this way – e.g. the 1991 Vivaldi cruise of RRS *Discovery* surveyed ~13 000 km of the north-east Atlantic with continuous ADCP coverage. ADCPs are therefore an invaluable mapping tool which can be used to identify areas of interest in real time and thereby to identify target areas for more conventional sampling programmes.

Various types of information can be obtained from ADCPs. Figure 1 shows a continuous section taken over 5½ days and nights between 39° N and 54° N in the north-east Atlantic at a longitude of ~35° W during May 1991. The section is some 1 500 km long and shows relative acoustic backscatter (dark areas = high backscatter) measured from a hull-mounted ADCP whilst RRS *Charles Darwin* was underway at a speed of ~8 knots.

The intensity of backscatter is a measure of biomass, and the section shows variability (patchiness) in backscatter (biomass) in both time and space. Between ~39° N and ~48° N there are three distinct 'zones' of high biomass (A, B and C). These 'zones' all occur at night between sunset and dawn and result from the diel migrations of animals from deep day-time depths into the upper 300 m at night. Smaller scale patchiness in the day *between* these intense zones reflect spatial variability. In addition, the section shows the gross effects on biomass of a major physical feature – in this case the polar front at 51° N. Backscatter intensity increased markedly as the front was approached and crossed – masking the day/night differences around zones D and E. The physical signature of the front is shown by the current vectors from the ADCP as a current jet moving to the east at a speed of over 0.5 m s^{-1}. For clarity only the currents at 101 m are shown although the ADCP measures currents every 8 m throughout the depth range of the section. The current vectors also show the presence of mesoscale eddies at 42° N, 44.25° N and 47.5° N – in this section the effects of these eddies on biomass are masked by the strong diel migration.

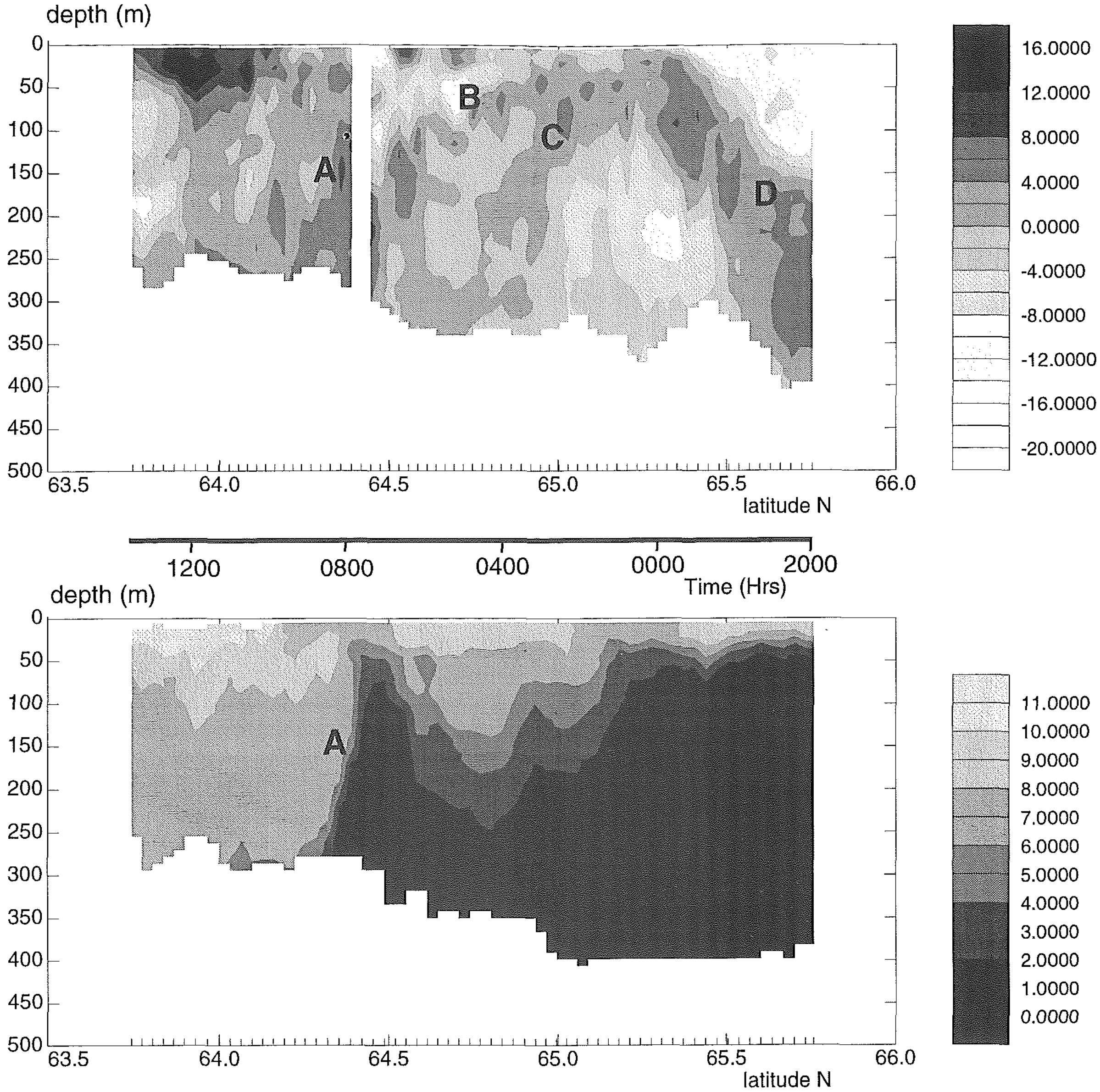
Figure 1 *Relative acoustic backscatter (dB) along a section at 35° W in the north-east Atlantic. Increased backscatter reflects diel migrations (A,B,C) and the presence of the polar front (D,E). Above are current vectors at a depth of 101 m, showing mesoscale eddies and a frontal jet. The scale shown on both upper and lower axes is the latitude in °N, and the small ticks on the lower axis indicate the positions of data points.*

Calibrating the acoustic backscatter from an ADCP is not straightforward, as the instrument was not designed with this application in mind. Backscatter plots such as those in Figures 1–3, are obtained by subtracting the long-term mean backscatter within a depth interval ($\bar{\sigma}$) from each observation within the interval (σ), so giving relative highs and lows. We use a scale in decibels, so relative acoustic backscatter = 10 $\log_{10}(\sigma/\bar{\sigma})$.



The effect on acoustic backscatter of nightly vertical migrations of zooplankton, and of a major front

Dynamic features and biological activity in the vicinity of the Iceland–Faroes Front, revealed by acoustic backscatter



(a)

(b)

Figure 2 *Records from the Iceland–Faroes Front: **(a)** acoustic backscatter (dB) showing enhancement at a subsurface eddy (A) and diel migration (B,C,D); **(b)** temperature (°C) from a concurrent* SeaSoar *tow showing the eddy (A) as a dome of cold water.*

Figure 2(a) shows backscatter intensity over a 18-hour period as *Charles Darwin* crossed the Iceland–Faroes Front. Again, spatial and temporal variability can be seen, with the effect of diel migration at B, C and D. Figures 2(a) and (b) also show a correlation between a subsurface eddy – identified as an upward dome in the temperature trace of the concurrent *SeaSoar* tow – and biomass (A in both figures). Here biomass is enhanced in the southern side of the cyclonic eddy – presumably due to localized upwelling bringing nutrient-rich waters towards the surface.

Figures 1 and 2 show synoptic coverage of relatively large areas of ocean taken at speeds of c. 8 knots, but at slower speeds finer scale resolution is possible. Figure 3 (*opposite*) plots relative backscatter over a period of 80 minutes at a ship speed of ~ 4 knots. The plot shows that animals characteristically migrate in layers which separate and rejoin, and that smaller scale patches exist within these layers. The effects of the thermocline are also seen – animals concentrating just below this during the day but tending to concentrate within and above it during the night.

Bioluminescence

Bioluminescence provides another marker of the biological contents of the ocean and consequently conveys information about its physical structure. In strategic terms it has both benefits and dangers, depending on the use to which the information is put, and by whom. There are three main reasons why naval strategists are interested in the bioluminescence patterns of the ocean. The first is to identify physical features (such as fronts) which may have acoustic consequences, the second is to follow the movements of submerged or surface vehicles, and the third is to establish the background 'noise' which could interfere with optical communication under water.

Very many marine organisms, from the surface to the greatest depths, are bioluminescent. That is to say, they are able to produce light. This results from a special

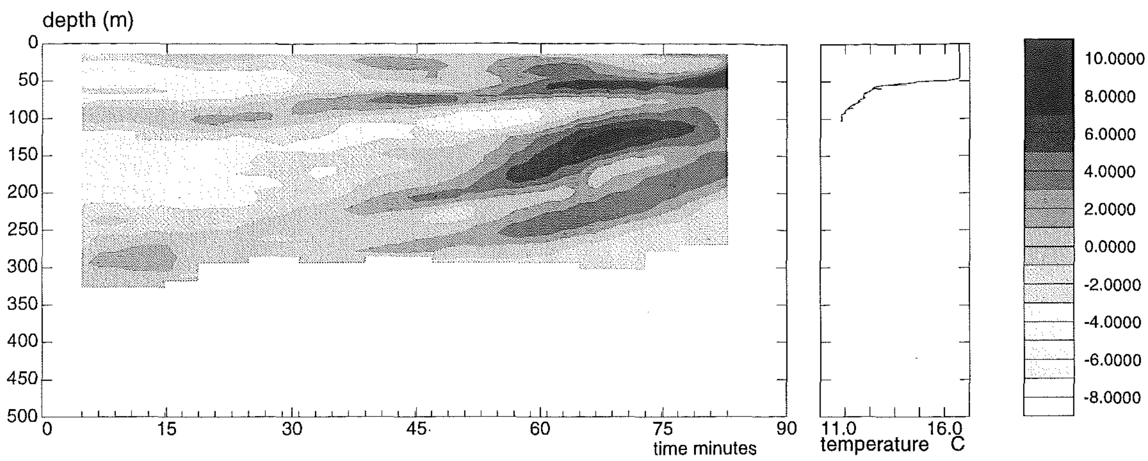


Figure 3 *Relative acoustic backscatter (dB) showing layers of diel migration and the effects of the thermocline, which can be seen in the temperature profile (right) as a marked temperature discontinuity of ~4 °C at a depth of ~50 m. (This section was taken in the Bay of Biscay.)*

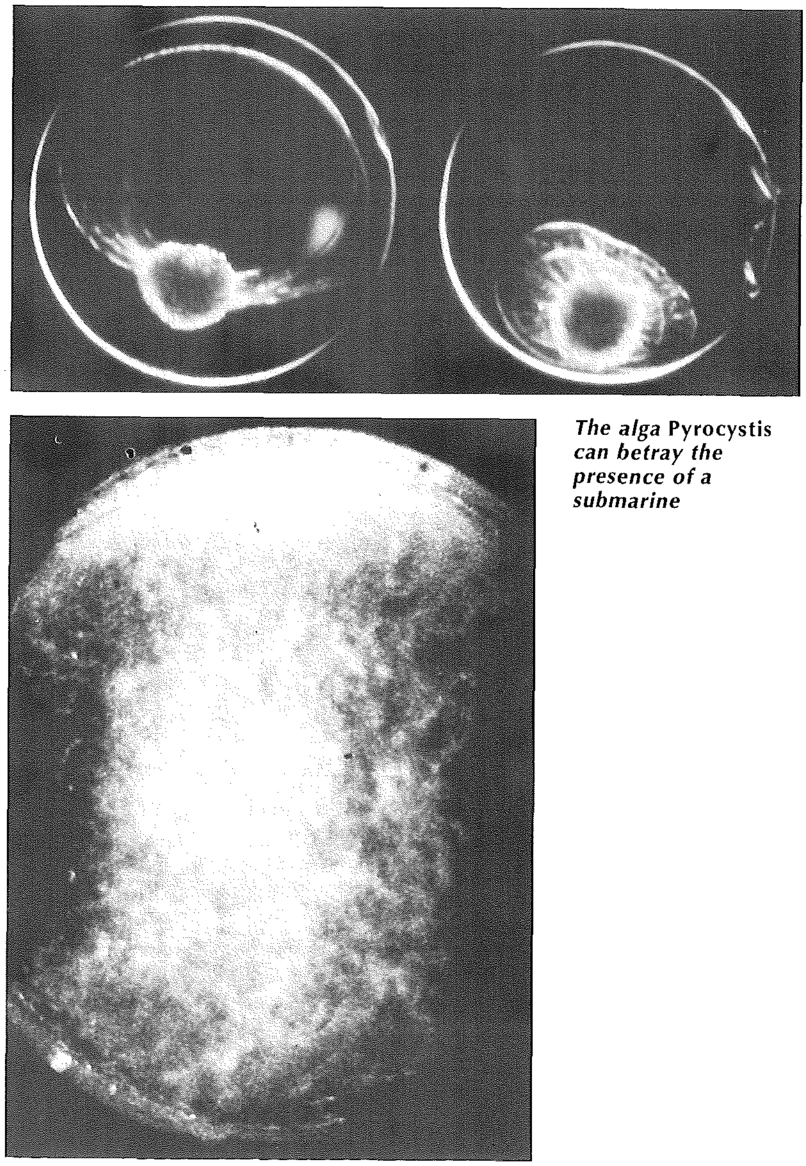
Acoustic backscatter shows how vertical migration can occur in layers

energy-producing chemical reaction which takes place inside particular cells, and which is under the organism's control. Most energy-producing reactions result in heat; bioluminescent ones emit light instead.*

The fact that the bioluminescence is under the organism's control makes it impossible to interpret bioluminescence data without some understanding of the biology. Not all marine organisms are bioluminescent; not all bioluminescent species respond to the same stimuli; not all individuals of a bioluminescent species will give the same response to a given stimulus, nor will they necessarily give similar responses at different times of a 24-hour cycle. The basic correlation between stimulus and response is filtered through the organism's physiology.

To measure bioluminescence in a given volume of water a mechanical stimulus is most frequently used, usually presented in the form of rather ill-defined turbulence (cf. Figure 4. The assumption is made that this produces the maximum bioluminescent response of which the organisms in the water are capable. The sensor (photo-multiplier or photodiode) can be mounted in a towed instrument, where it will detect the luminescence in the water flowing past it; alternatively it can be in a static instrument package which incorporates a pump and turbulence-generating chamber and which can be hung on a vertical wire. A towed vehicle allows large-scale horizontal mapping, with a vertical component if the vehicle has an undulating pathway (as in the case of *SeaSoar*, for example). A more detailed vertical profile requires use of the static package lowered on a vertical wire. Hull-mounted instruments in surface vessels are limited to surface data.

*See Peter Herring's article, 'Biological light in the sea', *Ocean Challenge*, Vol. 1, Autumn/Winter 1990.



The alga* Pyrocystis *can betray the presence of a submarine

Figure 4 ***Upper*** *Two specimens of the luminous oceanic dinoflagellate* Pyrocystis noctiluca. *This photosynthetic single-celled organism is often the cause of bioluminescence in the bow wave and wake of ships at sea. (Photo: Image Quest 3-D)*

Lower *The bioluminescence of a dish of seawater containing* Pyrocystis *and stimulated by stirring. The turbulence in a bow wave, or round a submarine, would produce a similar, though more dramatic, effect.*

Groups of the brightly luminescent copepod Metridia *can reveal the presence of fish or dolphins, or of a submarine*

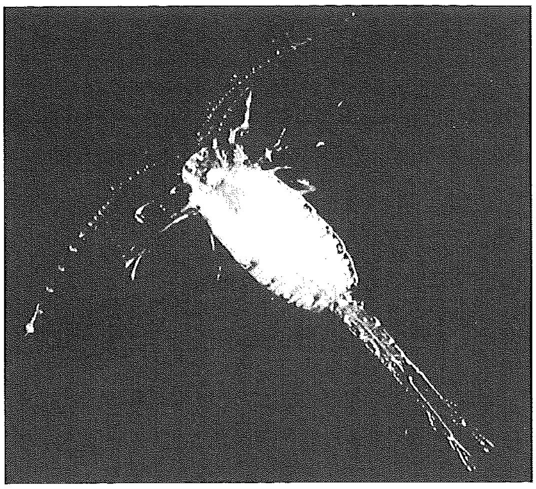


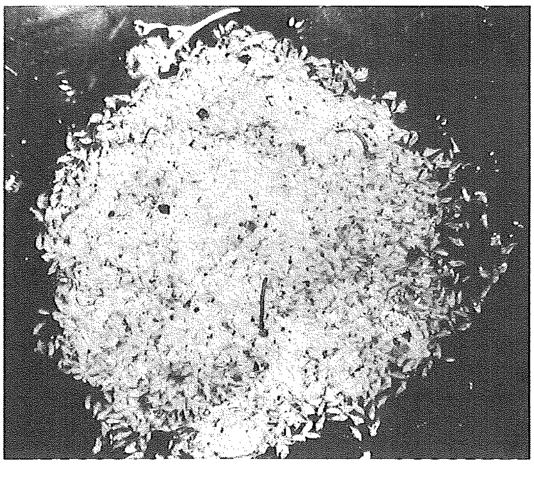
Figure 5 *The copepod crustacean* Metridia *is a brightly bioluminescent animal. It sometimes occurs in large enough numbers to provide visible bioluminescence in the turbulent crests of breaking waves, to illuminate the bow-wave and wake of surface vessels and to outline fish, dolphins or submarines.*

With instruments such as these, large areas of ocean can be surveyed, and attempts made to map the distribution of bioluminescence. Large variations occur: particularly intense signals are obtained from some tropical coastal and slope regions, for example the Arabian Sea and Persian Gulf waters. Most of the global information about bioluminescence has been derived from the anecdotal descriptive reports of bow wave and wake luminescence, sent with the meteorological reports by merchant vessels. These reports have clearly identified the seasonal fluctuations in surface bioluminescence in particular regions. The distribution of observations has inevitably been biassed by the general emphasis on commercial shipping routes, which do not necessarily accord with areas of strategic interest. Detailed three-dimensional information on a smaller scale had to wait for the development of appropriate instruments and their deployment on oceanographic cruises. This work has been led by Russian and American scientists responding to the strategic pressures of perceived military threats, particularly those of missile-carrying submarines.

Enhanced productivity of surface waters is often associated with mixing at a front. The phytoplankton population responds rapidly to this process and often includes numbers of bioluminescent dinoflagellates. Thus as a front is approached it may be recognised by an increased bioluminescence signal. As a front has important effects on sound propagation, advance (and silent) warning of its presence is therefore particularly valuable to a submarine commander.

Perhaps the most crucial part played by bioluminescence in the decision-making of naval strategists is its potential for betraying the presence of a vessel at night (Figures 4 to 6). Luminous bow waves and wakes are a source of concern to those in blacked-out surface vessels during time of war. Similarly the potential luminous trail left by a nuclear submarine below the surface cannot be eliminated artificially, and if it can be detected from an aircraft or satellite provides potential enemies with a means of remote surveillance of the nocturnal movements of such vessels. The attraction of such non-acoustic methods of detection is that the vessel is unaware of the surveillance. An advance knowledge of the depth distribution and abundance of bioluminescent organisms, and their sensitivity to disturbance, enables the strategists to limit the danger of detection by optimal routeing of the vessels. One optimist has even taken out a patent aimed at the prevention of bioluminescence. This involves leaking detergent from the bows of a vessel, on the assumption that this will effectively reduce the turbulence generated by its passage through the water! To our knowledge this has never been tested at sea; we are confident that it would not work!

Pleuromamma *is another luminous copepod that could betray the presence of a vessel at night*



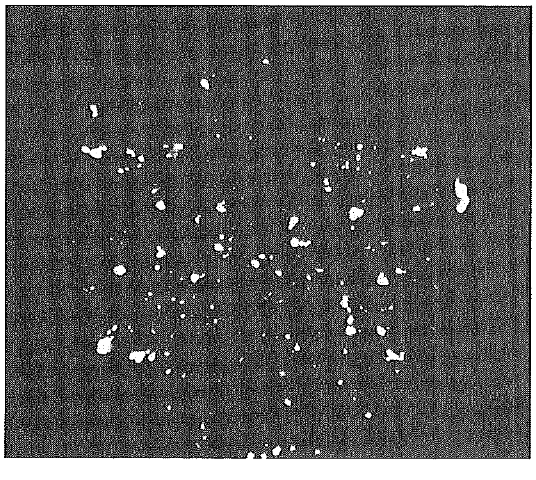


Figure 6 ***(Left)*** *A small sample of a net catch of the luminous copepod* Pleuromamma *(each individual is some 2 mm long).*
(Right) *The same sample photographed by its own luminescence; individuals flash randomly as they begin to dry out.*

Optical communication between submerged vessels, or between surface vessels and satellites, is potentially practicable using lasers. In order to achieve maximum range under water the light would have to be blue–green, to which oceanic water is maximally transparent. For precisely the same reason, marine organisms communicating by means of bioluminescence usually use blue–green light. The background bioluminescence therefore contributes to the optical noise in the frequency range of most use. The problem may be compounded by the organisms responding to the laser, so that the signal stimulates *additional* noise. Many organisms (e.g. the copepod *Metridia*, shown in Figure 5) produce bioluminescence not only in response to mechanical stimulation but also in response to light, and even to sound.

One example of the potential nuisance of background bioluminescence was identified in the DUMAND (Deep Underwater Muon and Neutrino Detector) experiment in the Pacific. A three-dimensional array of sensitive photomultiplier tubes was to be moored on the sea bed to detect neutrinos by the (blue) Cerenkov radiation they produce along their track in the water. These instruments were just as sensitive to the background bioluminescence of organisms within the array, and elaborate processing was necessary to filter out this biological 'noise'.

For all these applications a knowledge of the oceanic distribution of bioluminescence and its seasonal changes is clearly vital. One of the problems has been that different pumping systems and towed instruments have different aperture sizes and different turbulence-generating characteristics. Quantitative data from each of them are therefore not truly comparable and the datasets cannot simply be combined. Small-aperture pump systems do not catch actively mobile animals effectively. Where such animals (e.g. small crustaceans) are important components of the potential bioluminescence of the area, the instrument will give misleadingly low results. Similar underestimates may arise from a limited degree of turbulence in the optical chamber, by 'pre-stimulation' of the organism before it reaches the chamber, or by water flow so fast that the sensor only 'sees' part of the organism's response.

In order to address some of these difficulties two different strategies have been followed by Navy-supported researchers in the US. One is to redesign pump sampling systems, the other to make *in situ* video-recordings of the bioluminescence from submersibles.

A new bathyphotometer system (HIDEX: High Input Defined EXcitation) combines a defined turbulent excitation with a very large volume flow (up to 40 litres a second), and can measure both the absolute intensity along the flow path and the spectral characteristics of the bioluminescence. The alternative *in situ* video system uses an ISIT videocamera (the greatest sensitivity available) mounted in a manned submersible. The camera is focussed on a coarse mesh screen outside the submersible and records the luminescence induced by the impact of organisms on the screen as the submersible moves through the water. The results can then be quantified by image analysis.

The huge flow rate of HIDEX allows vertical profiles to be recorded very rapidly and the instrument can also be used in towed mode or attached to a mooring for longer-term deployment. The video method gives much more realistic indications of the natural responses of organisms in a particular community. This is particularly valuable for those (such as the fragile gelatinous fauna) that cannot be sampled in any other way. The video studies have shown, to the surprise of most oceanographers, that there is little or no continuous background bioluminescence in the ocean. The bioluminescent 'minefield' present in the midwater environment is revealed only by the movements and interactions of the inhabitants. Unfortunately, both methods are very expensive and are unlikely to generate a database that will allow us with confidence to predict the absolute level of bioluminescence at any point in the world ocean. Meanwhile, comparative measurements will continue to be valuable, from whatever source.

Conclusions

Bioluminescent sensing is not as 'remote' as that of acoustic techniques in that the potential range is considerably less. Nevertheless, datasets from both approaches give real-time biological information on the same time- and space-scales as hydrographic information. The data suites comprise invaluable scientific information and can provide critical input to strategic decision-making.

Gwyn Griffiths is head of the Ocean Technology Division at the Southampton Oceanography Centre. His interests include viewing the ocean with sound, and extending the capacity and utility of *in situ* instruments.

Peter Herring is a biologial oceanographer specialising in bioluminescence and the role of ambient and biologically generated light in the ecology of the deep ocean.

Howard Roe is head of the George Deacon Division for Ocean Processes at the Southampton Oceanography Centre. His interests include the linking of biology and physics at the same time- and space-scales, using acousics coupled with concurrent net and *SeaSoar* sampling.

All three authors are supported by contracts with the Defence Research Agency to investigate acoustic and bioluminescent variability in the ocean.

IGCP Project 367: Late Quaternary Coastal Records of Rapid Change

This new Project was adopted by the IGCP Board in January 1994 and the first International Meeting took place in Scotland, 13–20 September 1994. On my return from that meeting I received a letter informing me that the Royal Society's Earth Resources Committee has decided that it would be appropriate for the UK to participate. I have accepted their invitation to become UK National Correspondent for Project 367 and organise a UK Working Group.

Please find below a description of the Project and the workplan outlined at the International Meeting. The first meeting of the UK Working Group was held in March at BGS, Keyworth, and attended by over 30 scientists. This group endorsed the 6 topics outlined as providing the framework for the UK contribution. The following UK meetings are planned – September 1996, South-West England; September 1997, Norfolk; May 1998 Islay and Jura.

I invite you to participate in the project. If you wish to do so please complete both forms (photocopy the following pages as necessary) and return them to me, and also send a photocopy of the Membership Form for Directory to David Scott.

In order to reduce circulation costs I will be distributing future information by Email whenever possible. Please enclose your Email address if you have one. A new Email listserv system has been set up for the International Project. If you wish to register with it send the message:

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I look forward to receiving your membership forms and hope to see you at one of our meetings.

Best wishes,

Ian Shennan

UK National Correspondent for IGCP Project 367

Email: ian.shennan@durham.ac.uk

Summary of IGCP 367

Short title: Late Quaternary Coastal Records of Rapid Change

Full title: Late Quaternary Coastal Records of Rapid Change: application to present and future conditions

Outline and main objectives:

1. To document and explain rapid changes (events that occur on the scale of seconds to 1000s of years) in the late Quaternary coastal zone. High resolution studies will be used to assess the impact of short-term events on global and regional coastal change. These data will be used to suggest scenarios for future coastal changes and help in planning for possible coastline problems.

2. To provide, in final volumes and national reports, a set of reference material that do cuments regional and global short-term coastal events, and explains how these events relate to present and possible events in the near future.

3. To develop and prepare, through international meetings, newsletters, common data-banks, etc., a common approach to these studies that allows comparison of data on a worldwide basis.

Project leader: David B. Scott, Centre for Marine Geology, Dalhousie University, Halifax, Nova Scotia B3H 3J5, Canada

Duration: Five years, from 1994

First workplan: To address some of the items in the proposal, developed at the meeting in Scotland.

1. Seismic events and tsunamis
2. Tidal amplitude changes
3. Storm surge history and change
4. Rapid sea-level change and response
5. Changes in sedimentation rate and response
6. New high resolution geochronological techniques

IGCP PROJECT 367
MEMBERSHIP FORM FOR DIRECTORY

NAME: ....

ADDRESS: ....

....

....

....

PHONE: ....

FAX: ....

E-MAIL: ....

TELEX: ....

<u>SPECIAL INTERESTS</u>:

<u>GEOGRAPHIC LOCATIONS OF WORK</u>:

IGCP PROJECT 367 – UK WORKING GROUP

I wish to participate in the IGCP UK Working Group **YES/NO**

Please send me further details of the 2nd International Meeting (Antofagasta, Chile, 19–26 November 1995) available now **YES/NO**

Please send me details of the other meetings planned, when they become available **YES/NO**

COMMENTS on possible workplan of the UK Working Group

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Signature ....

Date ..../............../ 1995

OCEAN Challenge

The Magazine of the Challenger Society for Marine Science

SOME INFORMATION ABOUT THE CHALLENGER SOCIETY

The Society's objectives are:

To advance the study of Marine Science through research and education.

To disseminate knowledge of Marine Science with a view to encouraging a wider interest in the study of the seas and an awareness of the need for their proper management.

To contribute to public debate on the development of Marine Science.

The Society aims to achieve these objectives through a range of activities:

Holding regular scientific meetings covering all aspects of Marine Science.

Supporting specialist groups to provide a forum for discussion.

Publication of a range of documents dealing with aspects of Marine Science and the programme of meetings of the Society.

Membership provides the following benefits:

An opportunity to attend, at reduced rates, the biennial four-day UK Oceanography Conference and a range of other scientific meetings supported by the Society.

Regular bulletins providing details of Society activities, news of conferences, meetings and seminars (in addition to those in *Ocean Challenge* itself).

A list of names and addresses of all members of the Society.

MEMBERSHIP SUBSCRIPTIONS

The subscription for 1996 will cost £25.00 (£12.00 for students in the UK only). If you would like to join the Society or obtain further information, contact The Membership Secretary, Challenger Society for Marine Science, c/o Southampton Oceanography Centre, European Way, Southampton SO14 3ZH, UK.

The Challenger Society for Marine Science

ADVICE TO AUTHORS

Articles for *Ocean Challenge* can be on any aspect of oceanography. They should be written in an accessible style with a minimum of jargon and avoiding the use of references. If at all possible, they should be well illustrated (please supply clear artwork roughs or good-contrast black and white glossy prints). Manuscripts should be double-spaced and in a clear typeface.

For further information, please contact the Editor: Angela Colling, Department of Earth Sciences, The Open University, Walton Hall, Milton Keynes, Bucks MK7 6AA, UK. Tel: 01908-653647; Fax: 01908-655151.

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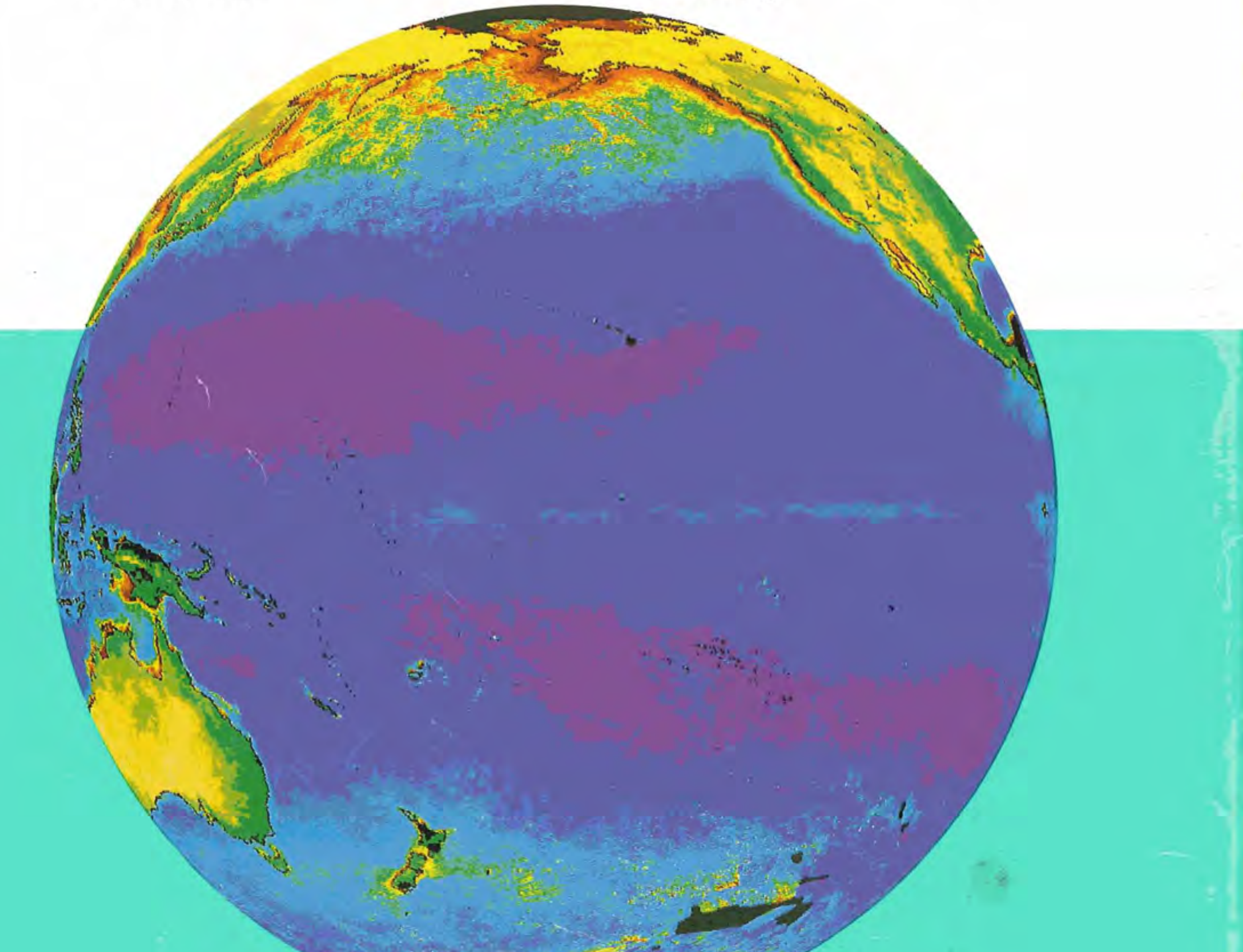

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