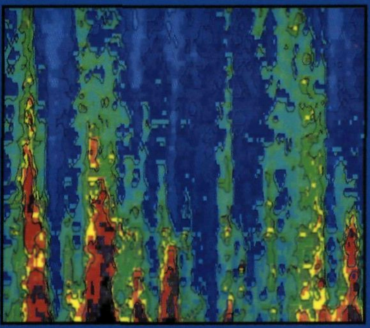

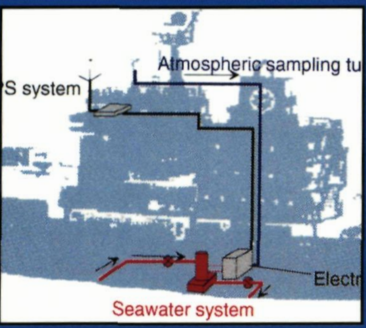


# Centre for Coastal & Marine Sciences

# Annual Report 1994 - 1995

Natural Environment Research Council

# Mission Statement

The Centre for Coastal and Marine Sciences (CCMS) will deliver the integrated coastal and marine science capability required by the Mission and Strategic Aims of the Natural Environment Research Council.

CCMS will enhance the capacity of its Laboratories to undertake cost-effective strategic and interdisciplinary research, survey, monitoring and data management in coastal and marine sciences.

CCMS will undertake an appropriate level of contract research and co-funding, consistent with the Laboratories' strategic priorities and with the needs of users.

CCMS will collaborate and encourage research partnerships with the wider national and international community of environmental scientists and institutions.

CCMS will initiate and participate in appropriate education and research training activities consistent with the education and training remit of the Natural Environment Research Council.

CCMS will promote the development of new tools and techniques appropriate to its research mission and sustain specialist facilities and services.

*The NERC Centre for Coastal and Marine Sciences was formed in December 1994 under the Directorship of Dr B L Bayne. Its components are the Plymouth Marine Laboratory, the Proudman Oceanographic Laboratory at Bidston, and the Dunstaffnage Marine Laboratory at Oban.*

**Front cover illustrations**

Main picture: *Intertidal fieldwork in the Humber estuary (photo: J. Davey)*

Inset illustrations, from top to bottom:

*Biodiversity studies near a North Sea oil rig (photo: A. Rowden)*

*Acoustic analysis of suspended sediment in a 1m layer above the sea floor*

*Instrument system for automated surveys of carbon dioxide in the surface ocean*

*Satellite image of the coccolith-forming phytoplankton* Emiliania huxleyi *north west of Scotland (CZCS/NCS)*

# Report of the Centre for Coastal and Marine Sciences 1994 - 1995

Natural Environment Research Council

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***The Centre for Coastal and Marine Sciences (CCMS) brings together the research strengths, expertise and facilities of the Plymouth Marine Laboratory, the Proudman Oceanographic Laboratory, and the Dunstaffnage Marine Laboratory. The formation of CCMS is an integral part of the refocussing of NERC research and training, to enhance scientific quality whilst also establishing more effective links with the beneficiaries of its work.***

# *Director's Introduction*

## What is CCMS?

How can three, widely separated marine laboratories constitute a Centre? The new grouping relates to their overall common purpose and coherence, not a physical coalescence. For a research community with strong worldwide links, routinely using modern communications to work with colleagues overseas, productive science partnerships are not site-dependent: shared objectives and complementarity of research skills are of much greater importance. Furthermore, a distributed geographic base is highly advantageous in relation to the Centre's wide fieldwork interests in UK coastal waters, European shelf seas and beyond.

The three Laboratories comprising CCMS have been instrumental in developing national excellence across a wide spectrum of marine science. Their research and training capabilities are particularly well-suited to tackling strategic research problems of an "expertise intensive" nature. Working within the CCMS framework, the main scientific thrusts of each Laboratory are determined by its own particular mix of specialist knowledge and facilities, evolving within the wider context of national and international advances in marine science.

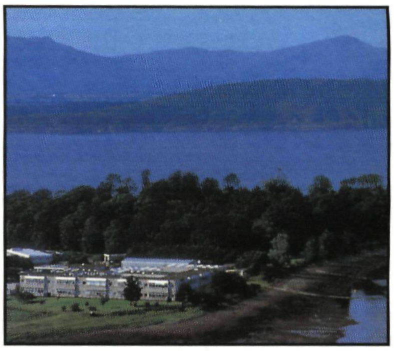
A key task for CCMS is to ensure that research of the highest scientific quality is carried out in its Laboratories, as formulated and implemented by well-equipped research teams. The Centre must also provide a positive and unified response to critical challenges in three main areas of endeavour.

*Brian Bayne.*

## The triple challenge

Firstly, progress in environmental sciences now requires increased integration of effort across traditional boundaries, whether of scientific discipline, or of space and time domains. This challenge is explicitly identified in NERC's new Charter,





*CCMS laboratories (from left to right): Plymouth Marine Laboratory, West Hoe site; Proudman Oceanographic Laboratory, Bidston Observatory, near Liverpool; and Dunstaffnage Marine Laboratory, near Oban.*

and matches other calls for the development of novel, integrative approaches; for example, in the 1993 White Paper on Science and Technology, *Realising our Potential.* Responding to this challenge presents no great difficulties for CCMS, since:

• Research on marine environmental problems is inherently collaborative and interdisciplinary. Thus CCMS scientists are very familiar with the interdependence of physical, chemical and biological processes within marine ecosystems, and also the importance of boundary interactions (occurring at shores and estuaries, and at air-sea and benthic interfaces) on the distribution of energy and materials.

• CCMS researchers work across the full continuum of spatial scales: for example, investigating pollution effects at the molecular, cellular and population levels; relating pigment biochemistry to satellite-based determinations of ocean productivity; and modelling the effects of fluid dynamics on zooplankton feeding, the dispersal of fish larvae, coastal erosion, and ocean circulation.

• A similarly wide appreciation exists of the close linkages across temporal scales, of both a regular (diurnal, tidal and seasonal cycles) and irregular nature (interannual variability and extremes). Such events are highly relevant to the decoding of past events (e.g. from sedimentary records), and to the design and interpretation of cost-effective marine monitoring (e.g. for regional Quality Status Reports).

The second main challenge for CCMS is to match its research as closely as possible to the needs of user communities. National goals in this context have been developed by the government's Technology Foresight exercise; NERC has also strengthened its links with research users in both the public and private sectors, and has identified six priority environmental issues. Here again, CCMS is able "to hit the ground running":

• More than 40% of CCMS income currently comes from external receipts, involving joint planning with customers of deliverables and timetables. The Centre can therefore build on considerable experience in carrying out research that meets user needs – and that also involves high scientific motivation and productivity.

• CCMS research products are very diverse, including sophisticated instrumentation for experiments, surveys and monitoring; data products and computer models; and new insights into key processes affecting our use of marine resources. Many aspects are pre-operational in character (e.g. water quality modelling, and the development of new techniques for detecting pollution impacts), creating the vital link between research at the cutting-edge and the wider application of that new knowledge.

• CCMS research is closely matched to the NERC environmental issues: all six priority issues are covered, and analysis of the Laboratories' ten strategic research projects (as defined in 1994/95) showed that most addressed at least three issues.

The third, and perhaps most testing, challenge relates to the changing financial support for environmental research, affecting not only the amount available, but also the ways by which resources are obtained. The need is to achieve ever-greater efficiency in advancing, and applying, our understanding of important issues (e.g. relating to waste disposal strategies, the sustainable use of natural resources, the maintenance of biodiversity, and the prediction of global change) under increasingly competitive conditions. The following aspects of CCMS' track record are noteworthy in this context:

• Marine scientists pioneered the concept of community research projects within NERC, directing the pooled expertise and resources of researchers in universities, NERC laboratories and other institutes at complex environmental problems. Highly successful examples include the North Sea Project (with atmospheric scientists); the Biogeochemical Ocean Flux Study (also involving polar and palaeo-researchers); and the current Land-Ocean Interaction Study (with hydrologists, Earth and atmospheric scientists). CCMS has been at the forefront of these initiatives, using partnerships to obtain maximum value from scarce resources.

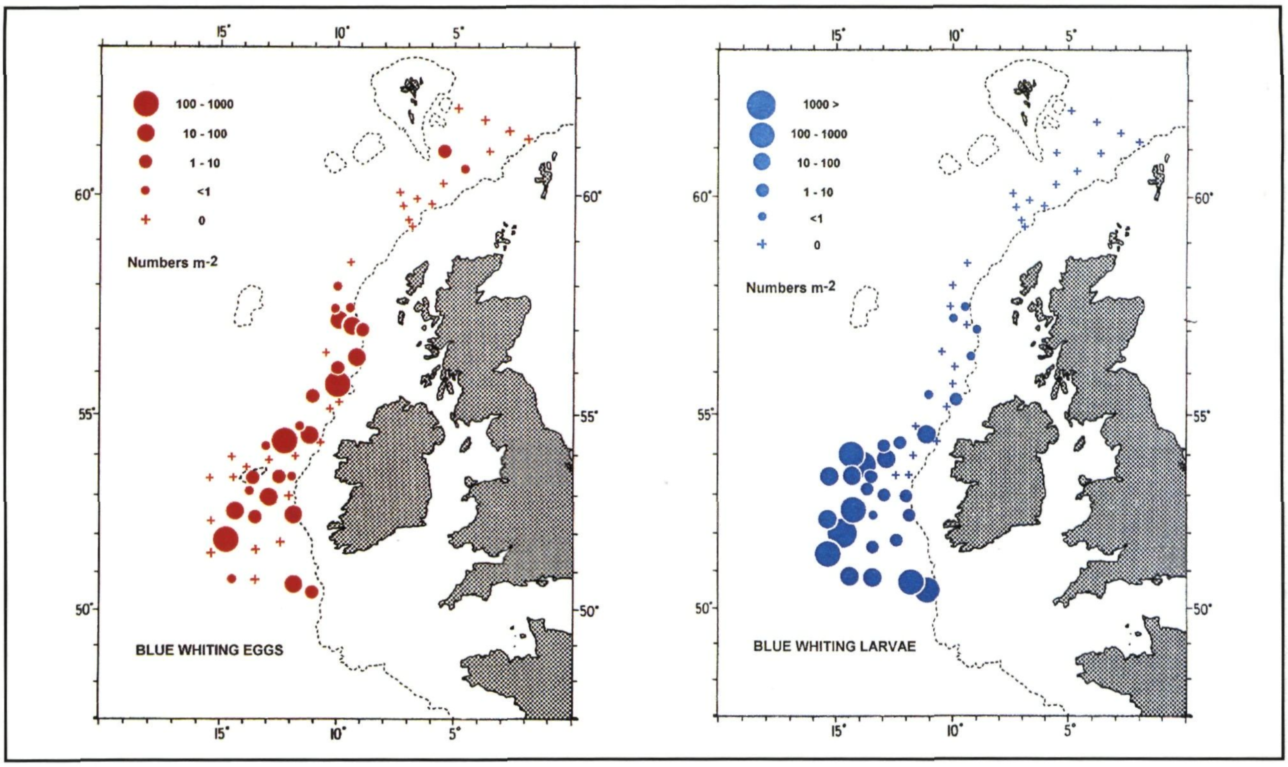
| | Environmental management | Biodiversity | Waste | Pollution | Hazards | Global change |
|---|---|---|---|---|---|---|
| *Pelagic Dynamics* | ✓ | ✓ | | | | ✓ |
| *Estuaries, Coasts and Shelf Seas* | ✓ | | | ✓ | | ✓ |
| *Health of the Sea* | ✓ | ✓ | ✓ | ✓ | | |
| *Biogeo-chemistry* | ✓ | | | ✓ | | ✓ |
| *Biodiversity* | ✓ | ✓ | | ✓ | | ✓ |
| *Coastal/Shelf Interactions* | ✓ | | ✓ | ✓ | ✓ | ✓ |
| *Ocean/Shelf Interactions* | ✓ | | | ✓ | ✓ | ✓ |
| *Sea Level Changes* | ✓ | | ✓ | | ✓ | ✓ |
| *Predator-Prey Interactions* | ✓ | ✓ | | | | |
| *Nutrient Fluxes* | ✓ | | ✓ | ✓ | | |

*The match between the six NERC environmental issues (from left to right) and the strategic research projects at CCMS laboratories (listed vertically, as structured in the NERC Strategy for Marine Science & Technology, 1994).*

• Similarly, the increasing importance of the European Commission as a funding agency for strategic research has led to significant realignment in many areas of marine science, with the development of new collaborations and networks designed to add value to on-going and new research programmes. CCMS scientists have been able to rapidly adapt to, and benefit from, the new funding and leadership opportunities at the European level.

## Providing added value

As indicated above, staff at CCMS Laboratories have a proven ability to respond positively to (and frequently anticipate) current trends in the management of the civic sciences. New, closer links within the Centre will enable standards to be raised even higher, particularly in reaction to the increased emphasis now given to scientific synthesis, user needs and value for money.




*CCMS has been highly successful in obtaining European Commission support, and provides a leading role for many projects. Research on the distribution of fish eggs and larvae (sardine, mackerel, hake, blue whiting and herring) is a key component of the Shelf-edge Fisheries and Oceanography Study (SEFOS).*

Actions are now underway to achieve further interdisciplinary integration in CCMS, not only across the component Laboratories, but also with the wider marine science community and with other parts of NERC. The pooling of basic, strategic and applied expertise within the Centre will improve our dialogue with users, introduce new contacts and give a better appreciation of their needs. The collective ability of CCMS to add value (both intellectual and economic) within the fundamental framework of marine processes and systems benefits UK marine science and technology as a whole; it also provides the necessary scientific underpinning for policy making, at both the national and international levels.

What, then, exactly is CCMS? The short answer is that it is a collection of researchers, from many different backgrounds, dedicated to understanding the natural (marine) world. By combining their vision, experience and effort, CCMS scientists accelerate their own progress in tackling the complex environmental issues that we face today – and in the future.

The longer answer lies in the quality and the relevance of CCMS research. The next section of this Report gives examples of what is being achieved, identifying a few of the Centre's many science highlights in 1994-95. The new research structure of CCMS is summarised in Appendix 1, and fuller accounts of recent progress and current effort can be found in the separate Annual Reports of the Plymouth Marine Laboratory, the Proudman Oceanographic Laboratory and the Dunstaffnage Marine Laboratory.

Brian L Bayne

***The dynamic behaviour of the semi-enclosed seas around Britain has both scientific and economic importance. Water movements affect coastal erosion and flooding, the dispersal of pollutants (mostly entering via rivers), offshore oil and gas extraction, shipping, and the distribution and abundance of wildlife, including many commercially-important fisheries. An overall research goal for CCMS is to develop models that integrate our understanding of these interactive processes.***

# *Models and Measurements of Shelf Sea Processes*

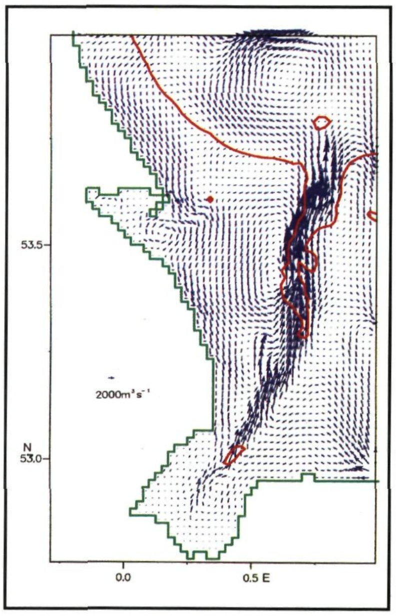
### Coastal connections

Water quality models are needed to maximise the beneficial use of marine resources, whilst minimising environmental damage. Their greatest value is in connecting different areas of knowledge. For example, answering such questions as: how much of material X entering the system at point Y accumulates in sediments or in food chains, or reaches the open ocean? are events such as the collapse of fisheries, or an increasing frequency of toxic algal blooms in coastal waters, due mostly to human impacts, or is natural variability of greater importance?

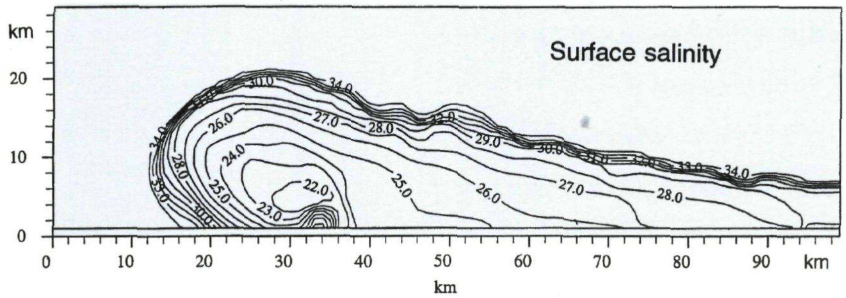
These are complex problems – and many uncertainties remain. Nevertheless, CCMS researchers have gained sufficient understanding of many of the physical, chemical and biological processes occurring in marine systems, that they can now begin their wider integration. The coupled models that are being developed provide an important management tool, not only helping to interpret observations, but also for exploring scenarios relating to different policy options.

The NERC North Sea Project (1987-1992) provided the basic interdisciplinary data set for building models of transport and transformation processes. Emphasis was then given to quantifying the seasonal cycle of water mixing (driven by tides, winds, freshwater inflows and open ocean exchanges), nutrient changes and plankton productivity in the southern sector of the North Sea.

The NERC thematic programme Land-Ocean Interactions Study (LOIS), hosted by CCMS, is extending this work, with particular attention given to key processes occurring at the ocean and land boundaries of the shelf sea system. Thus LOIS includes studies at the edge of the open Atlantic, west of the Hebrides; also models and




*Water transport model for the Humber plume zone, showing residual (non-tidal) effects of a moderate east wind. The 20 m depth contour is shown in red.*

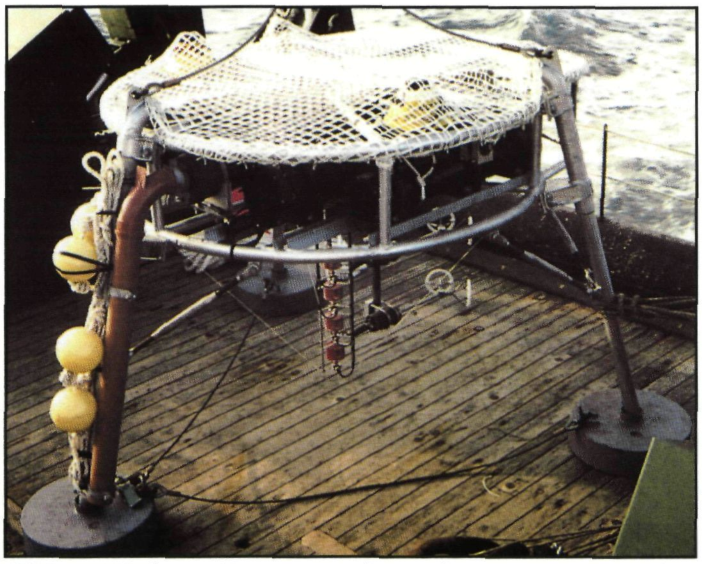



*Large coastal plumes show strong salinity gradients. These can directly affect biological and chemical processes, as well as having a major influence on stratification and water mixing.*

measurements of river deliveries of freshwater, nutrients, sediment and other materials – with effort focussed on catchments and coastal fluxes between Northumberland and Norfolk.

## Plumes and pulses

Realistic models of mixing at the river-sea boundary are critical for LOIS. Estuaries and coastal plumes are sites of high physical energy, of high chemical activity (with many salinity-driven transformations of natural and industrially-derived products) and, frequently, of enhanced biological production. Models simulating the seaward advection of river outflows must allow for two effects of tidal pulsing: not only does diurnal and lunar variability in sea level directly affect freshwater flow rates, but tidal forcing can also drive strong, and rapidly changing, coastal currents.



*STABLE II (Sediment Transport and Boundary Layer Equipment) has provided unique time series data on near-bed turbulence and erosion processes off Holderness.*

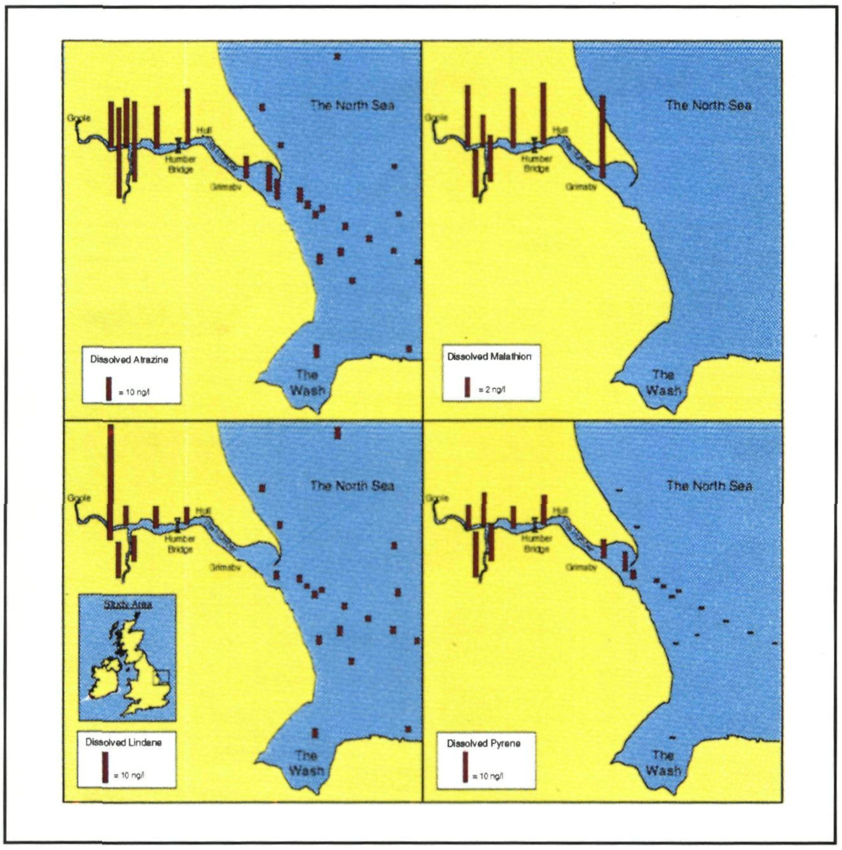
3D models of tidal effects on coastal plume mixing are being developed at the Proudman Oceanographic Laboratory, in collaboration with Belgian and other European research groups. Recent results include simulations of the Rhine plume in the Southern Bight, as an example of a large river outflow entering a relatively shallow, unstratified coastal sea.

The model shows stratification within the plume (due to the buoyancy of the freshwater) and "tidal straining", with onshore and offshore tidal currents generated in the stratified areas. At high water there is maximum offshore displacement of the plume at the surface; there is also a sharp front at the plume edge, and maximum separation of salt and freshwater within the plume. Results from this model show that wind effects have a considerable influence on mixing within a large plume. Thus strong winds can produce more stirring than tidal turbulence alone: stratification is most reduced by a "downwelling" wind direction, that drives buoyant (low salinity) surface water towards the coast.

## Tracking the fate of micropollutants

The Humber estuary and nearby coastal waters have been chosen as the main field site for land-sea exchange studies within LOIS. The Humber provides high nutrient and suspended sediment loads; in addition, its catchments are highly populated (supporting around 20% of the UK population), cover many agricultural and industrial land-uses, and the adjacent coastline is subject to considerable physical change.

Flux studies in the Humber region include work by Plymouth Marine Laboratory on the transport and fate of micropollutants. These are synthetic, organic compounds that are present in low concentrations, yet can have important ecological effects. Surveys were carried out in the Humber estuary and plume (up to 40km offshore) in October 1994 and January 1995. Micropollutants measured in the water column included several herbicides and insecticides, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and phthalate ester plasticisers. These groups were found to have different distributions, that could be related to their sources (e.g. agricultural for the herbicides, industrial for the PAHs and PCBs) and their physico-chemical behaviours.




*Levels of dissolved organic micropollutants in the Trent, Ouse and Humber rivers and in coastal waters.*

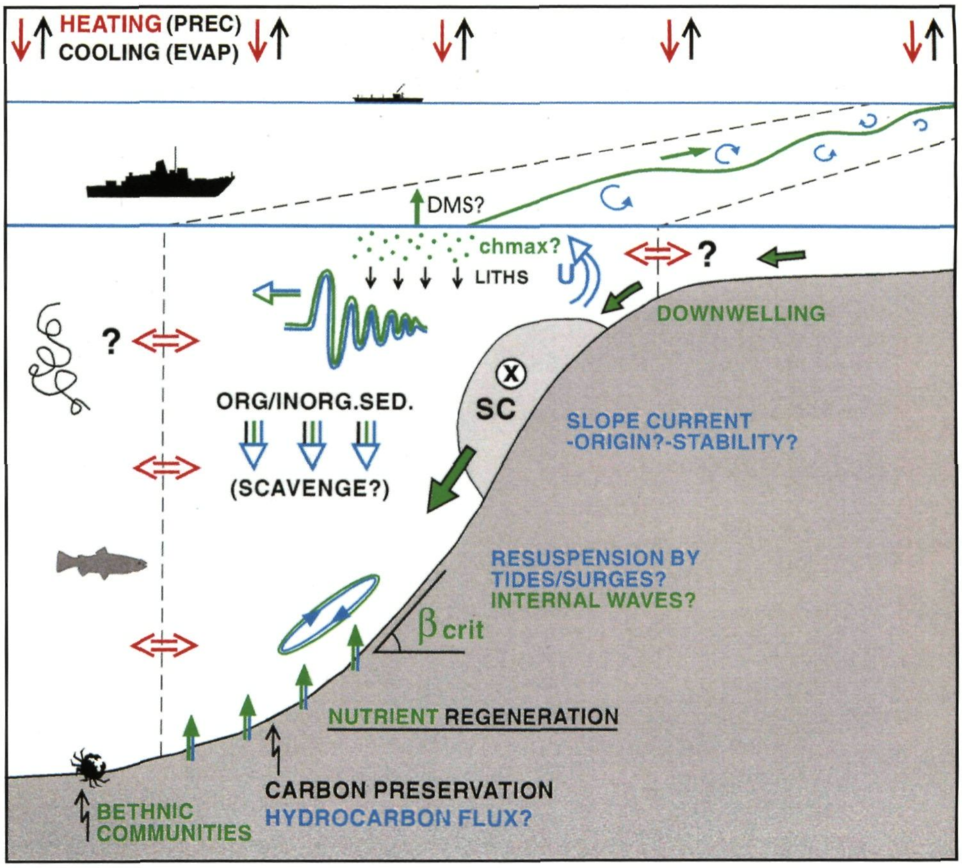
Current work in this project is extending the database of seasonal changes, with detailed mapping of distributions in suspended and deposited sediments. The overall goal is to relate transport and transformation processes to the physical models that are being developed for the Humber region.

### Mixing at the edge

The coastal ocean meets the deep sea at the edge of the continental shelf. Environmental conditions at this highly dynamic boundary are complex, with exchange processes showing considerable variability.

Better knowledge of the causes and consequences of that variability is urgently needed, in order to gain a predictive understanding of open ocean forcing of shelf sea conditions – and vice-versa. For example, changes in inflow and outflow rates for shelf seas affect their stratification (with many knock-on effects); the overwintering success of important zooplankton species depends on physico-chemical conditions at the shelf edge (hence influencing the food supply for young fish, and their year-class strength); and freshwater inputs to the North Atlantic are now recognised as critical drivers of global ocean circulation patterns and climate change.

A wide range of circulation processes control the large scale movement (and irreversible, small scale mixing) of water and its constituents at the shelf edge. These physical processes include along-slope currents, fronts, meanders and eddies, upwelling and downwelling, and internal tides, waves and surges. Researchers at the Proudman Oceanographic Laboratory have successfully developed a 3D hydrodynamic model for the shelf edge region west of Scotland. This model has been used within LOIS to




*Interactive processes at the shelf edge.*

study the spatial variability of tides and wind-driven circulation.

The grid size of the model is around 5 km x 10 km, with coordinate transformation to enhance the vertical resolution for the near-surface and near-bed boundary layers. Vertical mixing is modelled using various closure methods, including prognostic equations for turbulence energy and mixing length. The model successfully reproduces areas of locally-intensified tidal currents near the shelf edge. In addition, modelled flow fields under typical wind conditions for the region are in good agreement with observational data; for example, the flow fields derived from radioactive tracer studies.

The POL 3D model has also been used in the form of a cross-shelf section, with locally enhanced lateral resolution (to c 1 km), to examine the generation of internal tides, associated turbulent mixing and other fine-scale, baroclinic effects. Results show that the intensity and spatial variability of internal tides are sensitive to the (seasonally varying) density field, and to the shelf-slope depth profile. At the sea surface above the shelf break, internal tidal shear enhances mixing: this may cool sea surface temperatures, whilst increasing the upward supply of nutrients.

Downwelling and upwelling events, related to the formation of frontal systems, can also be simulated by the enhanced resolution model. These results have helped in the design of mooring arrays and sampling strategies for the field component of the LOIS shelf edge study. For example, areas of high bed stress have been identified, where greater abundance of suspended particulate matter can be expected.

***Marine ecosystems are forever changing. The continued survival of plants, animals and microbes depends on their adaptive responses – as individuals, species and communities – to less than fully-favourable conditions. The severity of some human impacts lies outside the normal range of natural environmental stresses, potentially resulting in species extinction; however, in most cases anthropogenic perturbations induce responses that either match or mimic natural events.***

# *Responses to Environmental Stress*

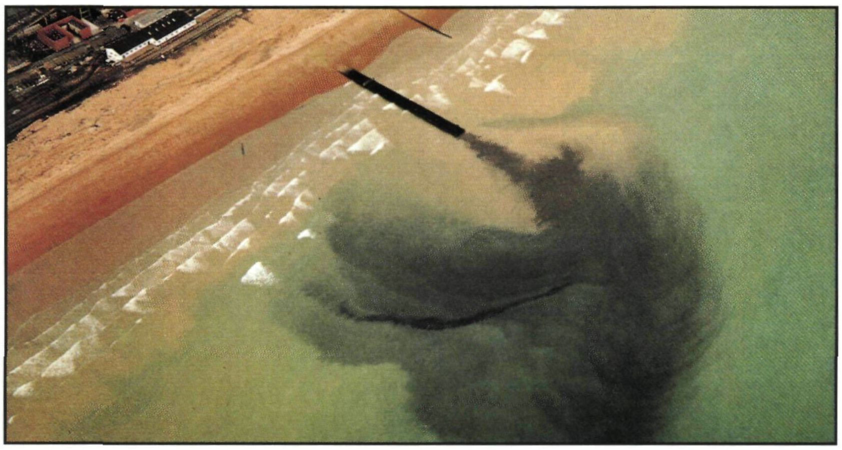
## Pinpointing pollution

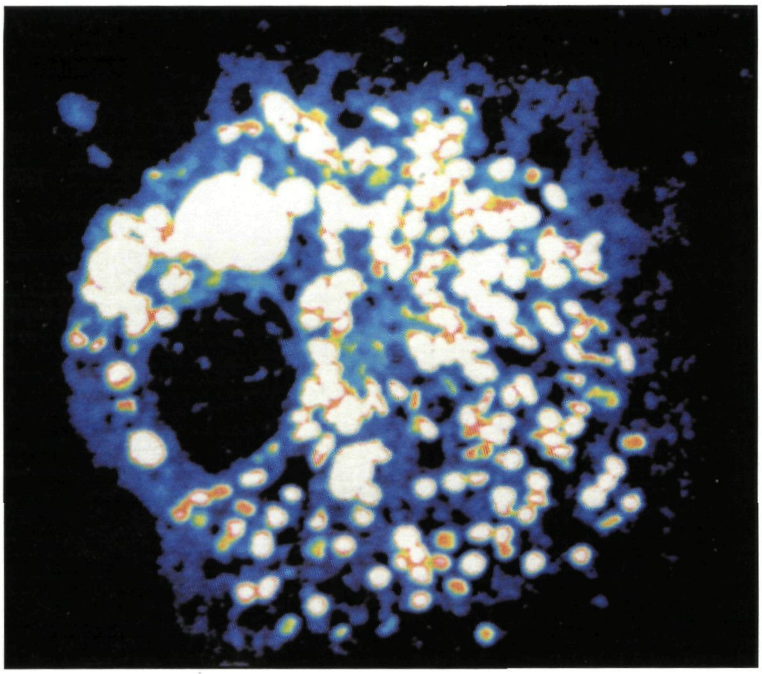
Heavy metals and hydrocarbons are near-ubiquitous marine contaminants, released into the environment by a wide variety of human activities. However, both these groups of substances occur naturally, and marine organisms have developed some protective mechanisms to limit their damage. An organism's defence reactions may also be induced by synthetic organic compounds, not previously encountered.

Cellular reactions to environmental stress are particularly useful if they can be detected at an early stage, as precursors to injurious, pathological effects. These reactions can then provide an early warning signal of distress – measurable before significant whole-organism damage occurs (that may, in turn, cause population and ecosystem changes). Such analyses are much easier to carry out than direct measurement of the very wide range of chemicals that may be potential pollutants, at very low levels: there are now over five million synthetic chemicals, some of which are toxic at levels of parts per billion or per trillion.

Relatively simple diagnostic biomarker tests are being developed at Plymouth Marine Laboratory, based on the detection of defence responses. Two cellular response mechanisms have been found to occur in almost all animal groups: the lysosomal-endocytic system, and the multi-drug resistance system.

*Can dilution be a solution to pollution? How widespread are deleterious effects? Novel and cost-effective monitoring methods are being developed to address these issues.*





*A mussel blood cell showing fluorescence (white) of a chemical pollutant accumulating in intracellular vacuoles known as lysosomes.*

The lysosomal-endocytic system involves body fluid cells similar to human white blood cells. These contain lysosomes that defend against infections and remove unwanted body tissue, via the processes of cellular ingestion (phagocytosis) and protein breakdown. The effects of toxic chemicals on this system are currently being studied in mussels, crabs, starfish and lugworms.

Some toxins, such as polycyclic aromatic hydrocarbons (PAHs) and chlorinated heterocyclics (e.g. chlorpromazine) not only inhibit the phagocytic uptake process, but also directly affect the lysosomes, causing an over-production of reactive free radicals. This may lead to the excessive breakdown of the cell's own proteins (autophagy or self-digestion). A standard test has been developed to study these processes, using laserscan microscopy to follow the transfer of flourescently-labelled intracellular proteins into the lysosomes.

The multi-drug resistance system is a protective mechanism for lysosomes, pumping toxic chemicals out of the cell. In mussel blood cells, this defensive response can be induced both by complex environmental pollutants (e.g. diesel oil) and by substances with anti-cancer properties (e.g. vincristine), thereby identifying the mechanism for the latter's protective action.

Many similarities have been found in these pathways and processes for other marine animals (studies at PML have used flatfish, such as turbot); also for earthworms, rats and humans (as investigated elsewhere). Thus the diagnostic kits that are being developed have considerable potential as a general tool for detecting chronic (low level) pollution stress in free-living organisms. They can also be used to predict the environmental risks of novel chemicals, avoiding many of the disadvantages of traditional animal testing methods.

### Different levels of diversity: why some species are more equal than others

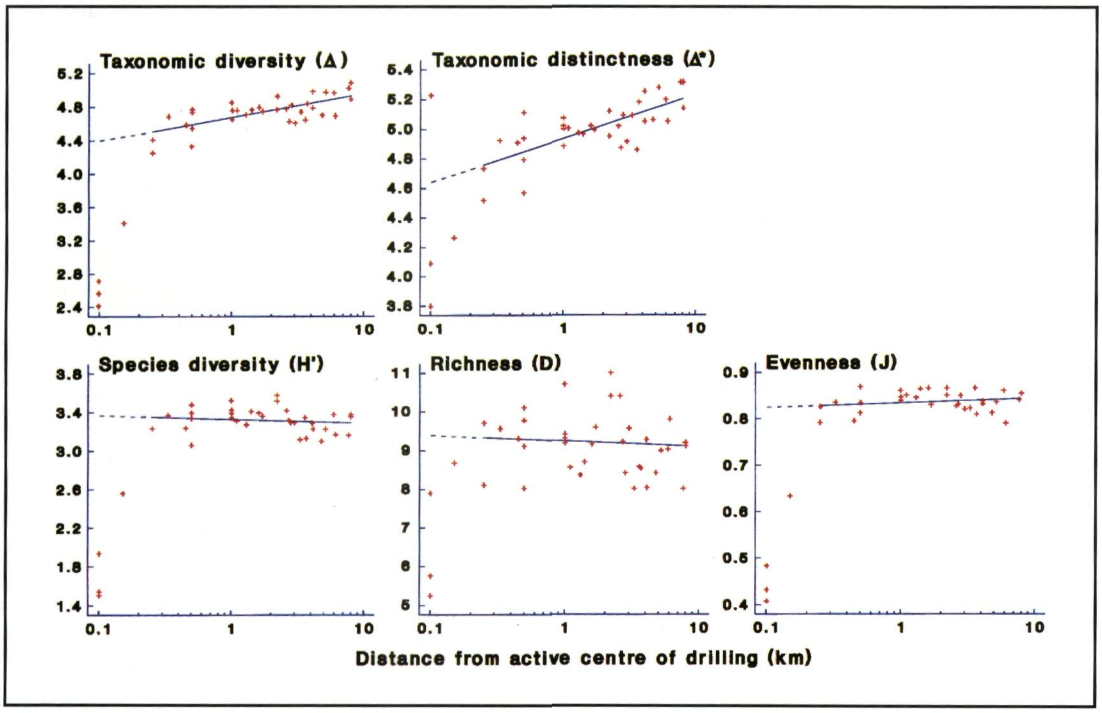
Biological diversity – or biodiversity – is usually considered in terms of the number of species living in a particular habitat or geographic region. But are all species equal? Species richness in a rain forest (with butterflies, birds, trees and mammals) is popularly regarded as being somewhat different from species richness in ocean mud (with nematodes, protozoa and microbes). Some aspects of these "quality" differences are aesthetic; nevertheless, there are important limitations in describing biodiversity only in terms of heterogeneity at a single grouping level – the species.

Thus within a single species, there can be a considerable range of genetic (molecular) diversity, whilst a multi-species assemblage can also be characterised in terms of functional diversity (are all the species doing the same things?) and its overall taxonomic diversity (how closely are the species related to each other, in evolutionary terms?).

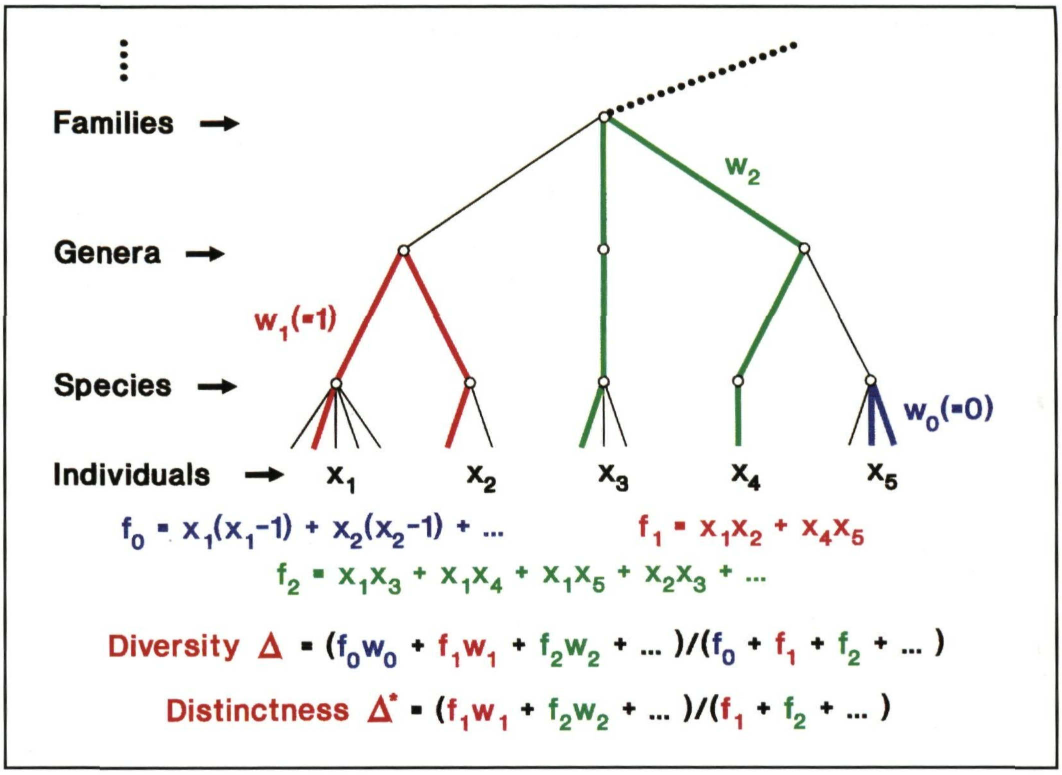
Marine communities typically show greatly-reduced species diversity under conditions of gross disturbance or pollution stress: whilst a few species survive (and may flourish), many others disappear. Less severe perturbations are harder to detect, since species diversity can then be as high as for undisturbed communities. However, work by Plymouth Marine Laboratory has shown that low levels of environmental stress can bring about other changes in ecosystem structure.

Two new indices were used to analyse wider aspects of diversity for macrobenthos communities near to an oil-drilling platform in the North Sea: a taxonomic diversity index (taking account of higher phylogenetic groupings, as well as species), and a taxonomic distinctiveness index (with the contribution from species diversity removed). Both these indices show a clear effect of distance up to 10km from the pollution source, correlating with the abundance of contaminants derived from drilling muds (barium and petroleum hydrocarbons). However, similar plots for the three most-used traditional measures of biodiversity – Shannon's species diversity index (H'), Margalef's species richness index (D), and Pielou's evenness index (J) – are all insensitive to these effects at distances greater than 150m from the rig.

*Collection of benthic samples in the North Sea (photo: A. Rowden).*




*New techniques for assessing taxonomic diversity show that low-level pollution can change community structure in ways that would remain undetected using standard indices for species diversity, richness and evenness.*




*Taxonomic diversity and distinctness expressed in terms of the mean path length within a hierarchical taxonomic tree.*

Genetic diversity, within a single species, seems to respond differently. Evidence to date indicates that species are genetically *more* heterogenous in stressed environments than under more stable, unpolluted conditions. Considering that effect and the new results together, it is possible that the total genetic diversity at a locality may be relatively unaffected by environmental stress. Instead, the net result of such disturbance is to partition diversity differently among the hierarchy of taxonomic units.

***Many important marine properties and processes operate on the global scale – such as sea level change, ocean circulation patterns, and the biogeochemical cycles that transfer materials between ocean and atmosphere. CCMS research effort is directed at these problems through extensive, as well as intensive, investigations. Relevant technological developments include automated* in situ *instruments, satellite remote sensing and communication, and sophisticated data management systems.***

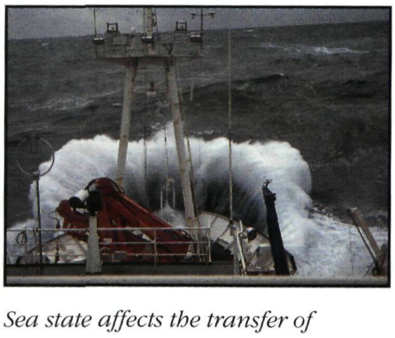
# Global Data Gathering

## Balancing the carbon budget

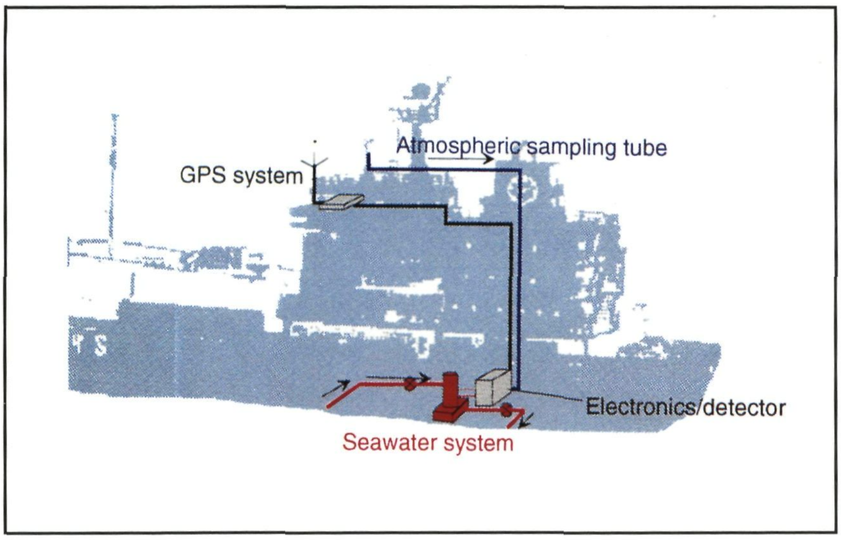
If all the carbon dioxide produced by human activities remained in the atmosphere, the threat of climatic disruption would be much more serious. Fortunately, nearly half of the carbon dioxide released by burning fossil fuels, other industrial processes, and deforestation is currently removed from the air by natural uptake mechanisms, on land and at sea. We need to know where and how this is occurring, in order to predict how atmospheric composition will change in future – and all the climatic implications that follow.

Researchers at Plymouth Marine Laboratory have developed a new, fully-automated analytical system for direct measurement of the variable uptake (and release) of carbon dioxide across the ocean surface. The equipment is sufficiently robust for use in commercial vessels, with computer-controlled sampling and logging. Data collection is started when the ship leaves port, using satellite signals to give global positioning information. In 1994, such instruments were installed on the container vessel *MV Prince of Seas*, travelling between the UK and the Caribbean, and on *RMS St. Helena*, travelling between the UK and South Africa. Development and trials were funded by DoE and MAFF, and the equipment is now being manufactured and marketed under licence.

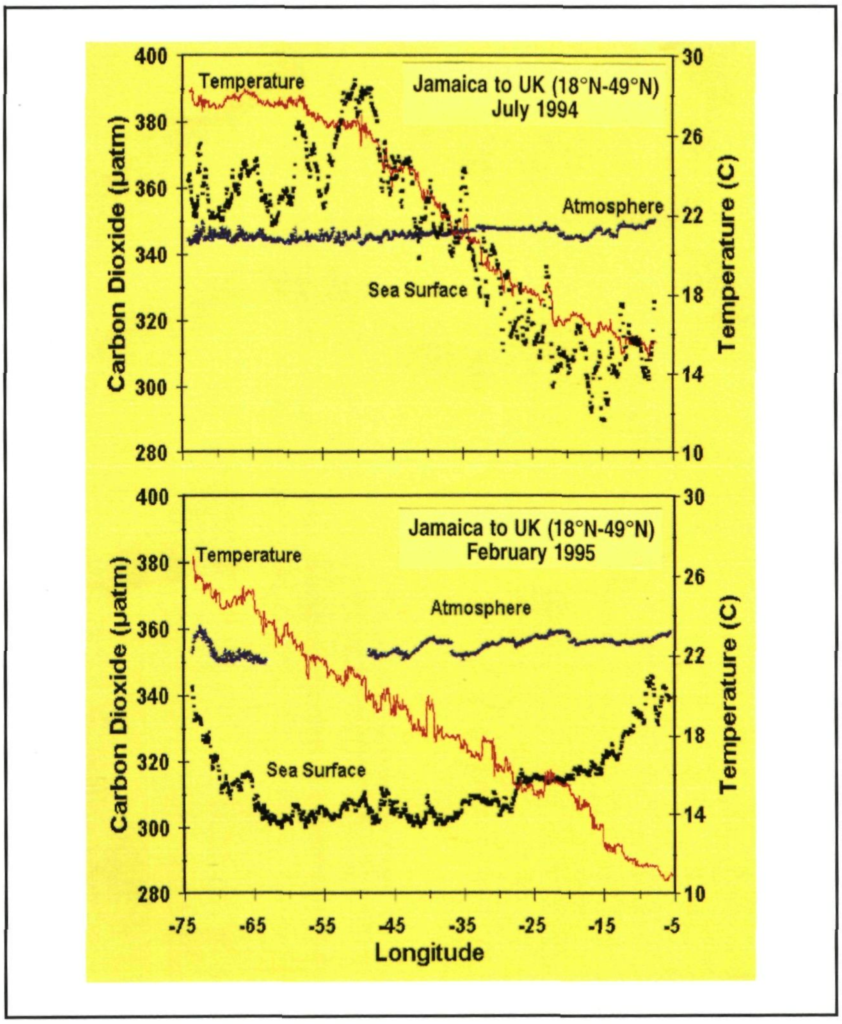
The continuous operation of these automated systems has provided comprehensive seasonal and spatial coverage – and has already doubled the number of carbon dioxide measurements for the surface waters of the North Atlantic. Data from the UK-Jamaica transect have confirmed that net carbon uptake occurs throughout the year in waters to the north east of the Azores. However, in summer, there is carbon dioxide out-gassing between the Azores and the Caribbean, with considerable



*Sea state affects the transfer of carbon dioxide into and out of the oceans. Winter measurements and those under rough conditions are needed for global modelling (photo: W. Broadgate).*




*An automated system has been developed for underway measurements of carbon dioxide in the atmosphere and in the surface ocean.*




*Summer and winter transects of the North Atlantic showing water temperature (red) and changes in the exchangeable carbon dioxide in the sea surface (black) relative to levels in the atmosphere (blue).*

variability, due to biological activity, imposed on the overall pattern.

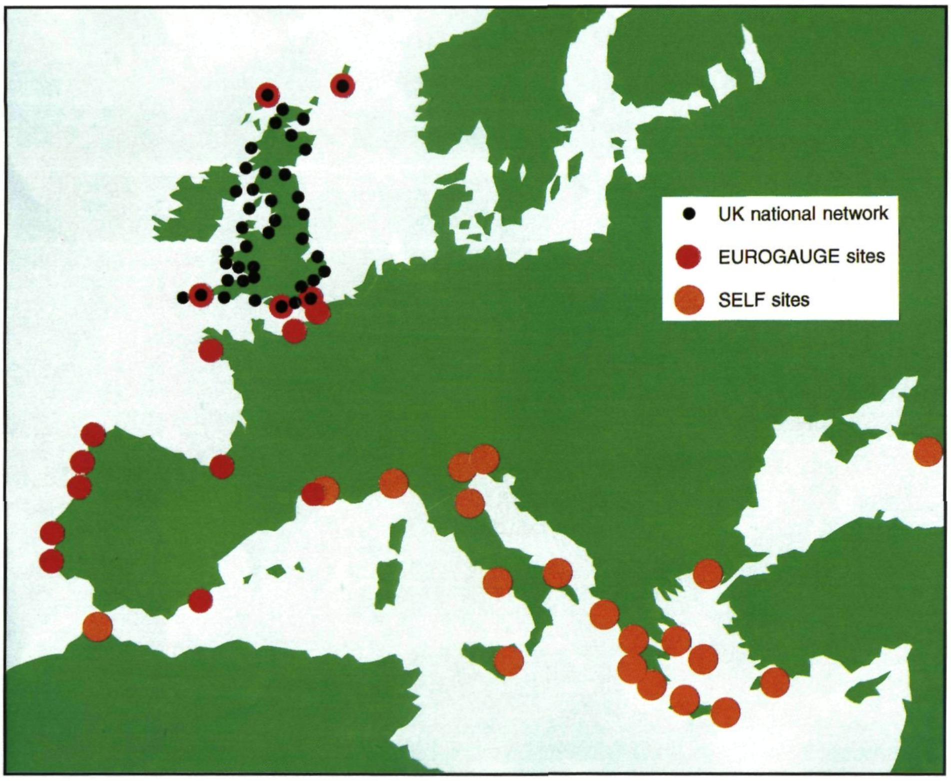
The occurrence of a strong mid-latitude wintertime sink for carbon dioxide in the North Atlantic is an important finding. Whilst its presence was suspected, as a consequence of lower surface temperatures in that season, the magnitude of the effect was previously unknown. Few research cruises take place in winter months, and sea conditions then can often make it difficult to carry out scientific studies.

Results from this work are now being combined with those obtained by other international groups through the Joint Global Ocean Flux Study (JGOFS). The global data set will then be used to improve models of the ocean carbon cycle, hence balancing the budget for current anthropogenic emissions of carbon dioxide and predicting their future fate. This work is also helping to develop effective monitoring protocols for worldwide application, as part of the planned Global Ocean Observing System (GOOS).

### A satellite fix for sea level changes

On a worldwide basis, sea level is rising and is likely to continue to do so: current climate models predict an increase of around 50 cm during next century. But the risk of coastal flooding is determined by *relative* sea level change, taking account of regional and local land movements – with rates of sinking or uplifting that can be as great as the current rates of absolute sea level change.

Global positioning satellites now make it possible to obtain accurate measurements of local land level variability, and its own longterm trends. Using techniques initially developed for earthquake studies, daily changes of around 10 cm in




*UK tide gauges and European networks involved in Global Positioning System (GPS) studies of sea level change.*

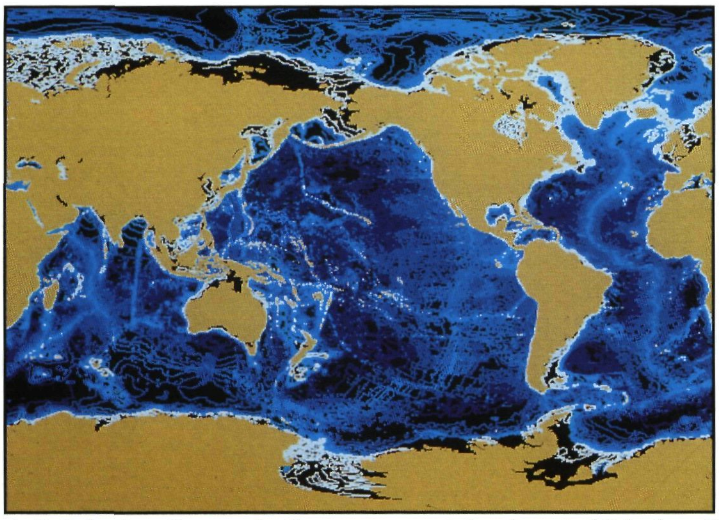
land surface height have been detected at coastal sites in Southern England. These crustal deformations are due to tidal movements, and can be corrected for.

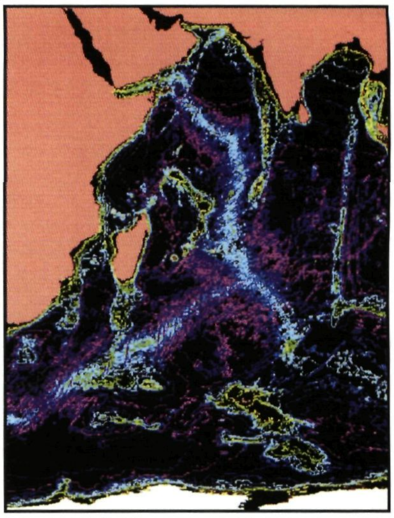
The satellite measurements are made relative to the centre of the Earth, with current accuracy of around 15 mm (over a total distance of 6400 km). Comparative studies to improve the reliability of the technique were carried out in 1993-94, using data from 16 tide gauge stations along the Atlantic coast of Europe, between the Shetlands and south Portugal. This EC-funded project (EUROGAUGE) involved collaboration between the Proudman Oceanographic Laboratory, UK university groups and research partners in France, Spain and Portugal.

Attention is now directed at the Mediterranean Basin, through the SELF project (Sea Level Fluctuations: geophysical interpretation and environmental impact) that includes new partners in Italy, Switzerland, Greece and Germany. Results to date show that changes in atmospheric circulation – affecting air pressure and wind fields – are responsible for the major seasonal and interannual variability in sea level, as recorded at the tide gauge sites. There are two main implications: first, by modelling this "noise", the longterm trends can be better defined; second, that there may be additional effects on relative sea level arising from regional shifts in weather patterns, as a component of future climate change.

### Safeguarding and supplying marine data

The British Oceanographic Data Centre (BODC) at POL has responsibility for the remote collection of sea level data from the 42 UK coastal sites that make up the National Tide Gauge Network. Records are taken every 15 min, and downloaded weekly. BODC also





*A digital atlas of ocean depth measurements has been published on CD-ROM by the British Oceanographic Data Centre. Left, global overview; right, revised bathymetry of the Indian Ocean.*

collects and curates sea level data from the ACCLAIM network in the South Atlantic (Antarctic Circumpolar Current Levels from Altimetry and Island Measurements), receiving twice-daily satellite transmissions from tide gauges at Ascencion, St Helena, Tristan da Cunha, Port Stanley, and the BAS bases at Signy and Faraday.

Access to marine environmental data is as important as its archiving and stewardship. Such information is expensive to collect and mostly irreplaceable: its use should therefore be maximised, not only by researchers but also (with appropriate charges and safeguards) for commercial purposes. BODC has been vested data management responsibilities for the integrated datasets from over a 100 research cruises since 1989. For half of these, the final output has now been published on CD-ROM, including datasets from the North Sea Project and the Biogeochemical Ocean Flux Study (BOFS). CD-ROMs for the Land-Ocean Interaction Study (LOIS), the World Ocean Circulation Experiment (WOCE) and the Ocean Margin Experiment (OMEX) are currently being compiled.


*The CD-ROM atlas includes information on survey tracks used to compile the contours.*

The diversity of these studies has necessitated the use of flexible and innovative procedures for data handling and data product development – frequently with a fully global approach. BODC capabilities at this scale are exemplified by the preparation and release, on CD-ROM, of the first digital bathymetric contour chart of the worlds' oceans, under the auspices of Intergovernmental Oceanographic Commission (IOC) and the International Hydrographic Organization (IHO). The publication of this General Bathymetric Chart of the Oceans (GEBCO) in 1994 stimulated interest in its further upgrading. Working with the Scripps Institution of Oceanography, recent attention has been given to the Indian Ocean, with the digitisation of 134 bathymetric contour charts and their associated tracklines.

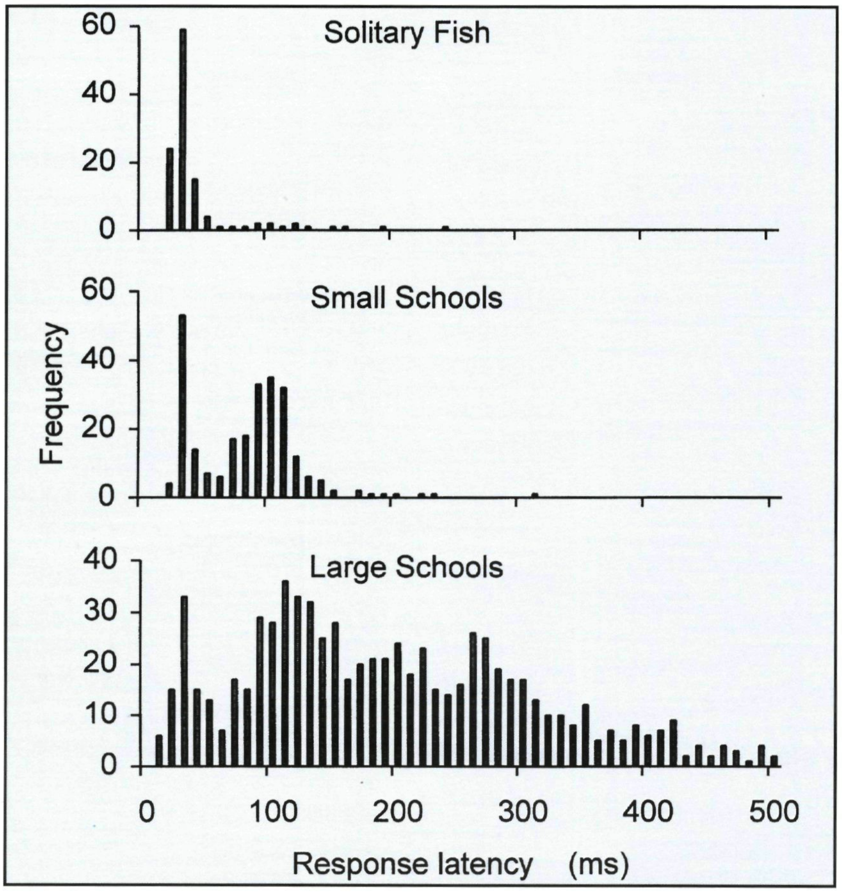
***Knowledge of how fish develop and behave is needed to avoid their over-exploitation. Their relationships with other organisms, and responses to environmental change, also have profound significance for the overall structure and functioning of marine ecosystems. Work on these topics at Dunstaffnage Marine Laboratory has focussed on feeding, predation and the effects of temperature, with close links to university research groups and marine aquaculture initiatives.***

# *Behavioural Ecology of Fish*

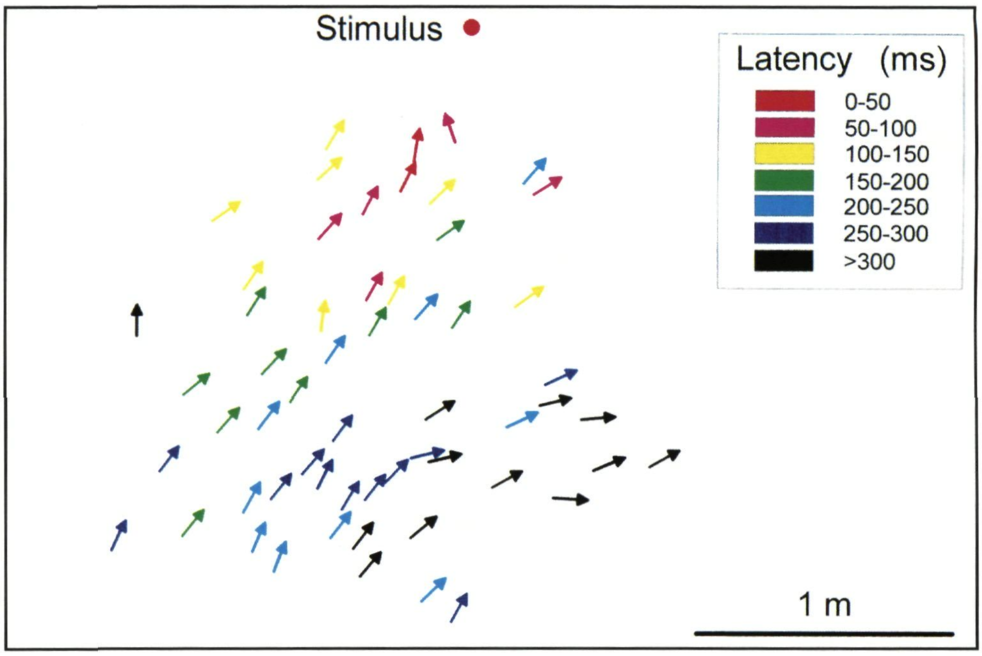
### The benefits of schooling

The herring *Clupea harengus* lives in schools throughout its life. Several fitness benefits may result from this behaviour – relating to feeding, reproduction, hydrodynamic efficiency, and predation avoidance. The last of these is the most uncertain: with regard to human predation (by trawlnets) schooling is clearly disadvantageous for the herring. But does being sociable reduce or increase the risk of being caught by natural predators?

DML researchers used a large tank (10 m long by 5 m wide) to investigate the escape reactions of solitary herring, and those in schools of 10-15 fish and up to 80 fish. Previously other workers had simulated a predatory attack using a mild electric shock, and found that schooled fish responded more rapidly than solitary ones. However, at DML a more natural, acoustic stimulus was used to initiate the escape reaction, with the pattern of




*Solitary herring show a more rapid escape reaction than when they are in a school. Under group conditions, alarm responses are reinforced and passed on between adjacent individuals.*




*Plan view of schooling herring, based on high-speed video. The arrows indicate the location and swimming direction of the fish when the sound stimulus was presented; the colours show the temporal progression of the response reaction.*

that behaviour recorded on high speed video. Under such conditions, around 90% of the solitary herring initiated an escape response (a rapid C-shaped bending of the body, then swimming away at speed) within 50 ms. In small schools, some of the fish showed a similarly fast response, but the majority reacted more slowly, with a second peak in the latency frequency around 100 ms. In the large schools there was a very much greater temporal spread in the escape reactions, with latencies up to 500 ms or longer.

Spatial features of the escape response were also studied using the video footage. In the large schools, more fish took "appropriate" directional action (swimming away from the noise source) than they did when solitary. As might be expected, the response latency was closely related to the distance from the stimulus – indicating that the slower reactions at greater distances were not directly elicited by the original sound, but by visual or sound stimuli produced by responding neighbours.

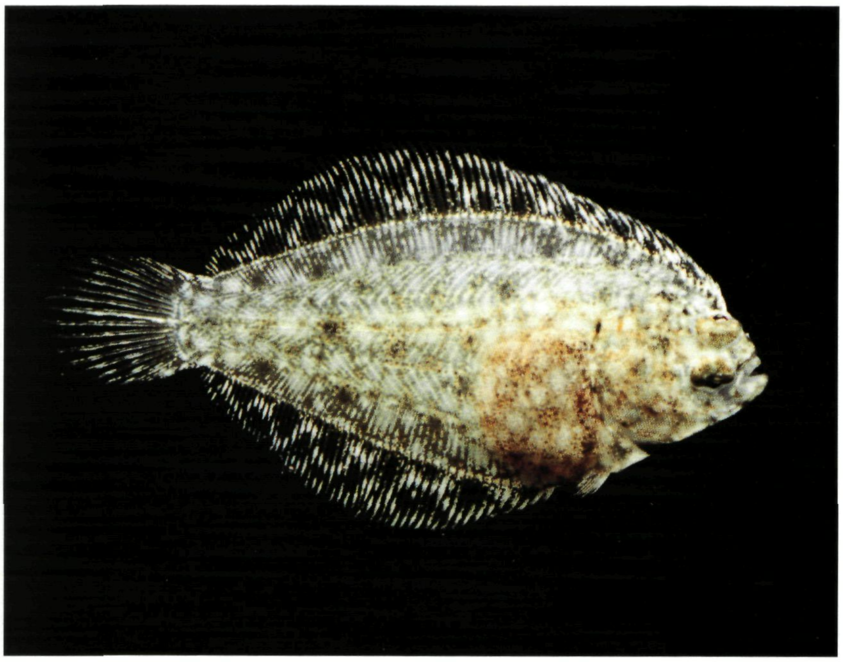
Hydrophones were used to detect pulses of sound emitted by the herring during their escape responses. These sounds were produced immediately before movement of the fish was observed, but followed muscle stimulation. There is evidence that this noise is produced by the contracting body muscle itself, rather than by the swimbladder (that can be used for sound-signalling in other species).

### Feeding strategies in young plaice

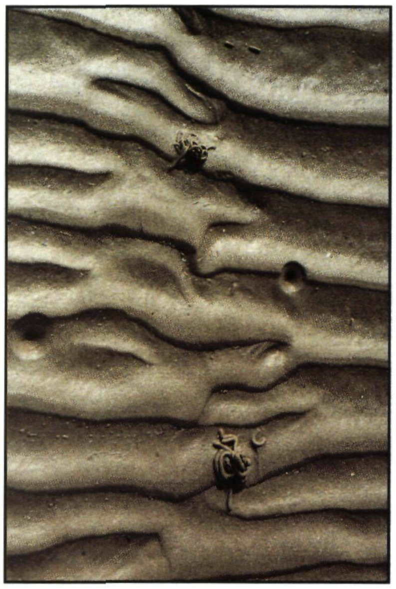
Juvenile plaice *Pleuronectes platessa* live in the shallow waters of sandy bays for at least the first six months of their lives. During this time they mostly feed on sessile prey, such as burrowing polychaetes (lugworms) and the bivalve *Donax vittatus*. The rate at which they find such food is influenced both by their search behaviour and the distribution of their prey. DML studies have investigated these relationships in the field (to determine natural diets), in the laboratory (to quantify foraging strategies), and through models (to generalise the rules for searching behaviour and predator-prey interactions).

The laboratory work has shown that juvenile plaice search for food by a series of short swims, interrupted by pauses when the animal is stationary. Most visual searching occurs during the pauses. If a prey item that usually has an aggregated distribution, such as *Donax vittatus*, is encountered, search behaviour changes from an extensive to an "area-restricted" search mode: the length of the pause increases whilst less distance is travelled in each swim. As a result, the search effort of the predator is concentrated in areas where it has the highest chance of success, close to the site of a recent encounter. However, an "area-avoidance" search strategy can also be shown by young plaice – when the dominant prey type occurs as isolated individuals in the environment.

Quantitative models are being developed to predict different foraging strategies in relation to prey distribution patterns. On the scale of individual prey encounters, statistical descriptions of spatial patterns of prey are used to recreate similar patterns in computer simulations. This enables prediction of optimal searching strategies for fish feeding on prey distributed in different spatial arrangements. On a larger scale, prey may be distributed along environmental gradients. Models of migration and behaviour have been made to predict whether predators maximise their food intake when exploiting their prey or not. Predictions from these models are currently being tested by observation of fish behaviour in tanks with gradients of depth, light and prey intensity.



*A juvenile plaice (photo: R. S. Batty).*



*Lugworm casts at low tide. These worms are a major part of the diet of young plaice (photo: A. D. Ansell).*

# Core Strategic Research

NERC's new funding model, developed in 1995, defines core strategic research in Centre/Surveys (such as CCMS) in terms of underpinning the NERC mission. In particular, through: longterm studies that have been identified as necessary to maintain UK capabilities; databases and the provision of information to government, the public, industry and commerce; monitoring and survey work; and technology development.

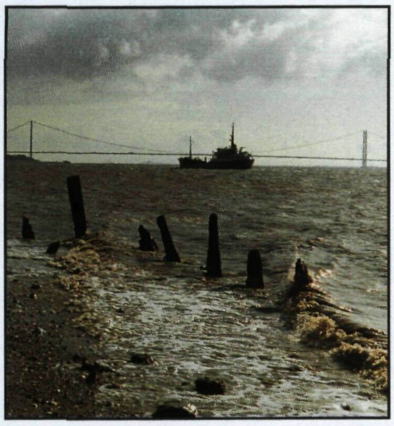
The main characteristics of core strategic research (in addition to scientific excellence) are that it involves a longterm commitment, requiring specialist skills and facilities, and other dedicated resources, brought together in integrated teams of critical mass.

Within CCMS, five core strategic programmes have been defined:

- Estuarine, coastal and shelf seas interactions
- Ocean processes and ocean-shelf interactions
- Global ocean processes
- Animal-environment interactions
- British Oceanographic Data Centre and Marine Biology Library.

These programmes comprise complementary projects carried out within the CCMS Laboratories (Plymouth Marine Laboratory, PML; Proudman Oceanographic Laboratory, POL; and Dunstaffnage Marine Laboratory, DML). The main components of the CCMS core strategic programmes are summarised below, and key features identified in the Table that follows.

| ***CCMS Core Strategic Programme:*** | ***Component Laboratory projects:*** | | |
|---|---|---|---|
| | *at PML* | *at POL* | *at DML* |
| *Estuarine, coastal & shelf seas interactions* | Estuarine, coastal and shelf seas | Coastal & shelf seas interactions<br>Technology development | Technology development |
| *Ocean processes & ocean-shelf interactions* | Pelagic ecosystem dynamics | Ocean-shelf interactions | LOIS shelf-edge study and related activities |
| *Global ocean processes* | Biogeochemical cycling tracers and global change | Global sea level change | |
| *Animal-environment interactions* | Marine biodiversity<br>Stress effects and health in the oceans | | Predator-prey interactions |
| *BODC & Marine Biology Library* | National Marine Biology Library | British Oceanographic Data Centre (BODC) | |



*The Humber estuary (photo: J. Davey).*

## 1. Estuarine, Coastal and Shelf Seas Interactions

### Estuarine, Coastal and Shelf Seas (PML)

| | |
|---|---|
| Core science | • Linked physical, chemical and biological processes<br>• Nutrient cycling and productivity<br>• Impact of biota on coastal dynamics (feedback in natural systems)<br>• Exchange gradients and biogeochemical fluxes at the sediment-water interface. |
| Technology | • Intelligent (event-triggered) automated data acquisition<br>• Algorithms for remote sensing (aircraft and satellite)<br>• Ships of opportunity and data buoys as platforms for sensor deployment. |
| Modelling | • Interdisciplinary modelling of processes in estuaries, estuarine plumes and the coastal strip<br>• Water quality modelling<br>• Coupled ecological and economic models. |
| Survey and monitoring | • CPR Survey (SAHFOS)<br>• Data buoy surveys. |
| Users | MAFF, DoE, NRA, SOAEFD, Water Companies, English Nature, chemical and other industries. |

### Coastal and Shelf Seas Interactions (POL)

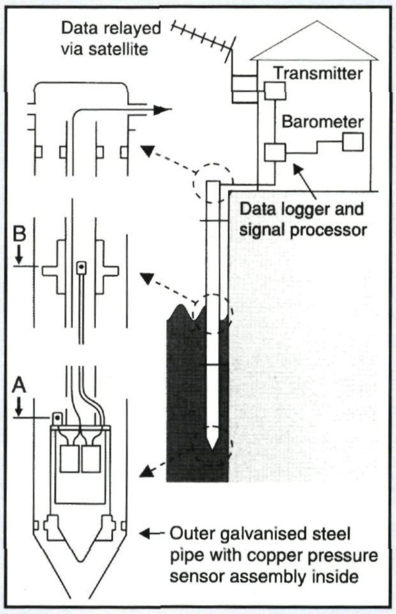
| | |
|---|---|
| Core science | • Interactive dynamics of physical processes (waves, surges, tides, turbulence, density and currents)<br>• Erosion, transport and deposition of sediments<br>• Algorithms for coupled modelling of passive constituents from coast to shelf edge.<br>• Application to biogeochemically active constituents. |
| Technology | • *In situ* instrumentation, automated data acquisition and multisensor platforms<br>• Remote sensing from coast, air and space, with algorithm development<br>• Supercomputers: multi-processor code development<br>• Sampling designs leading to coherent data sets. |
| Modelling | • Interactive prognostic and pre-operational models<br>• Development of transportable models<br>• Model assimilation with remote sensing<br>• Transfer of models to operational agencies. |
| Survey and monitoring | • New coastal/shelf surveys<br>• Analysis of UK monitoring data. |
| Users | MAFF, NRA, DoE, MoD, DRA, port authorities. |

### Technology Development (POL)

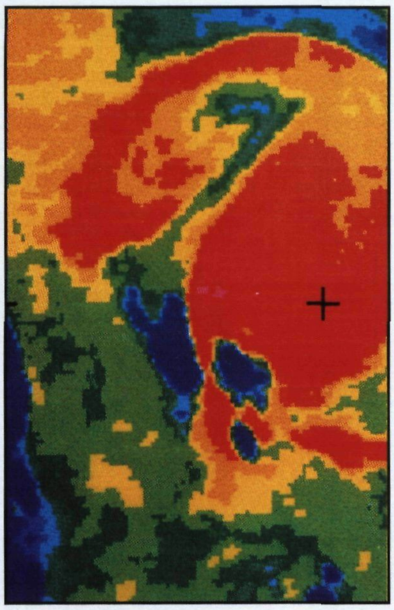
| | |
|---|---|
| Core research | • General sensor and systems development<br>• 3D acoustic imaging<br>• Satellite-controlled, autonomous, Lagrangian undulating profiler<br>• Sea level measurements near and under polar ice. |
| Methodology | • Assess commercial products against requirements<br>• Purchase, operate and evolve *or* invent, design and develop in-house<br>• Maintain expertise in underwater acoustics and engineering<br>• Build prototype in-house; contract-out production quantities<br>• Licence manufacture and sale to third parties. |
| Facilities | • Electronics labs; computer aided mechanical and electronic designs<br>• Acoustic tanks and flow chambers<br>• Sediments laboratory; calibration laboratory. |
| Fieldwork | • Instrument support of seagoing science<br>• Field trials of new instruments<br>• Diving team for field deployments. |
| Users | mostly within CCMS. |

### Technology Development (DML)

| | |
|---|---|
| Core research | • Satellite position-finding and communications for instrument packages and vehicles at sea surface<br>• Artificial intelligence and adaptive sampling for data acquisition and transmission<br>• Data telemetry and control for long-term instrumented buoy deployments<br>• Graphical user interface techniques for laboratory data acquisition and control<br>• Acoustics for biomass and internal wave determinations. |
| Methodology | • Evaluate available products; modify if appropriate<br>• If necessary, develop new techniques and/or equipment in house<br>• Develop technology links within CCMS<br>• Maintain in-house test and trial facilities and expertise. |
| Facilities | • Ships and diving support for local field testing<br>• Seawater exposure tanks<br>• CAD; circuit production and testing<br>• Mechanical workshop and assembly areas. |
| Fieldwork | • Sea trials for Autosub hull and associated instrumentation.<br>• Seagoing support of CCMS/NERC cruises. |
| Users | DRA, DoE; also CCMS/NERC. |




*Sea level station assembly, developed for use on oceanic islands.*



*Infrared satellite image of eddies in the Bay of Biscay.*

## 2. Ocean Processes and Ocean-Shelf Interactions

### Ocean-Shelf Interactions (POL)

| | |
|---|---|
| Core science | • Transfer of matter and energy across the ocean-shelf boundary<br>• Incorporate into generic 3D models<br>• Processes of vertical exchange (especially in stratified seas)<br>• Fluxes of dissolved, suspended and sedimenting constituents<br>• Mutually consistent boundary conditions for shelf and ocean models. |
| Technology | • *In situ* instrumentation, automation and multisensor platforms<br>• Natural and man-made tracers<br>• Remote sensing from air and space<br>• Supercomputers; multi-processor code development<br>• Sampling designs for coherent data sets. |
| Modelling | • Interactive prognostic and pre-operational models of physics, primary production and nutrients<br>• Methods of initialisation and data assimilation<br>• Transportable 3D models<br>• Models coupling ocean and shelf seas<br>• Transfer models to operational agencies. |
| Survey and monitoring | • Assimilation of relevant datasets |
| Users | MAFF, MoD, DRA, DoE. |

### Pelagic Ecosystem Dynamics (PML)

| | |
|---|---|
| Core science | • Primary (new) production; phytoplankton community structure and function<br>• Microzooplankton and bacterial community structure and function<br>• Macrozooplankton and fish larval ecology<br>• Interactions between physical processes and pelagic ecosystems. |
| Technology | • Ocean colour algorithms for remote sensing<br>• Sensor technology<br>• Molecular biomarkers<br>• Pattern recognition and automated biological data analysis. |
| Modelling | • Interactions between physical processes and pelagic systems. |
| Survey and monitoring | • Western Approaches (L4) time series<br>• CPR Survey (SAHFOS). |
| Users | MAFF, DoE, DRA, SOAEFD, NRA, industry, IGBP, ICES |

*Calanoid copepod.*

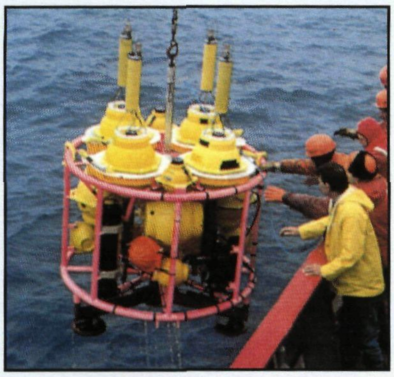
**LOIS Shelf Edge Study and related activities (DML)**

| | |
|---|---|
| Core science | • Dynamics of biological processes transferring carbon and nutrients across the ocean/shelf boundary<br>• Production and degradation processes in water column and sediment; water column and benthic coupling<br>• Carbon consumption and utilisation in sediments<br>• Algorithm development relating optics of surface waters with biological and chemical constituents. |
| Technology | • *In situ* sensors; instrumented buoys<br>• Undisturbed sediment coring<br>• Instrumented benthic landers and sediment probes. |
| Modelling | • Flow network modelling of carbon utilisation<br>• Parameterization of microbial processes<br>• Provide data sets for Shelf Edge Study (SES) models. |
| Survey and monitoring | • Contribute to SES surveys. |
| Users | MAFF, SOAEFD, DoE, EU, LOIS/SES community. |

## 3. Global Ocean Processes

**Biogeochemical cycling, tracers and global change (PML)**

| | |
|---|---|
| Core science | • Natural cycles of trace gases and trace organic compounds, their impact on global change and their use as biomarkers<br>• Carbon cycle dynamics in the global ocean<br>• Tracer studies and longterm (decadal) investigation of mixing and water movement<br>• Manipulative experiments in the open ocean, coastal and shelf seas. |
| Technology | • Intelligent (event-triggered) automated data acquisition<br>• Underway measurements from ships of opportunity<br>• Sensor technology<br>• Coupled biomarkers and ocean colour algorithms. |
| Modelling | • Modelling natural feedback links between biological and geochemical cycles |
| Survey and monitoring | • Global ocean carbon dioxide. |
| Users | DoE, MoD, NRA, MAFF, SOAEFD, WOCE, IGBP, industry. |



*Deployment of deep sea pressure recorder with releasable data capsules.*

**Global Sea Level Change**

| | |
|---|---|
| Core science | • The spatio-temporal spectrum of sea level as it relates to climate change<br>• The forcing functions for sea level change<br>• Estimate future changes<br>• Fluctuations and forcings of sea level change related to "choke" points. |
| Technology | • *In situ* sensors for sea level<br>• Remote sensing from space; algorithm development<br>• Earth tides, GPS geodesy and absolute gravimetry. |
| Modelling | • High resolution global and regional ocean tide models<br>• Global model of interannual sea level change<br>• Earth tide models<br>• Non-tidal surge models run for decades. |
| Survey and monitoring | • Office for Permanent Service for Mean Sea Level<br>• UK WOCE Sea Level Centre<br>• Class A Tide Gauge data<br>• Altimetry, including calibrations. |
| Users | MAFF, MoD, DRA, Met O, DoE, IOC, FAGS/ICSU, EC. |

4. ANIMAL-ENVIRONMENT INTERACTIONS

**Marine Biodiversity (PML)**

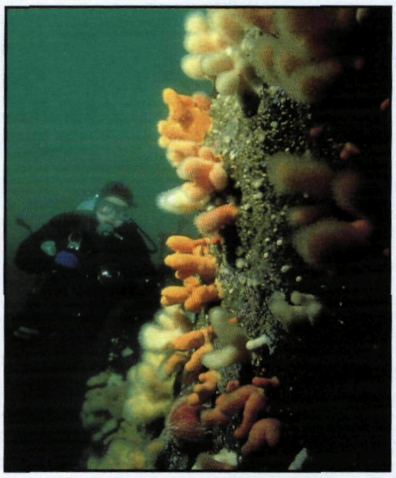
| | |
|---|---|
| Core science | • Mechanisms controlling diversity<br>• Impact of changes (natural and man-made) on diversity<br>• Relationships between biodiversity and ecosystem function<br>• Taxonomic underpinning for biodiversity studies, including genetic studies. |
| Technology | • Molecular biomarkers<br>• Pattern recognition and automated biological data analysis. |
| Modelling | • Statistical analysis of patterns of variability. |
| Survey and monitoring | • Long-term studies of changes in pattern in time and space. |
| Users | MAFF, SOAEFD, DoE, NRA, chemical and other industries, IOC, UNEP, WWF, ODA, JNCC. |

**Stress effects and health in the oceans (PML)**

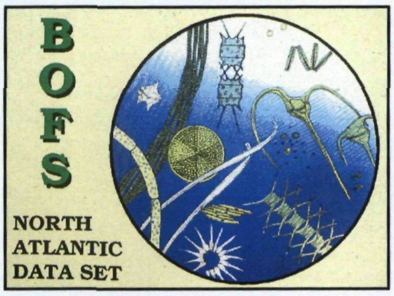
| | |
|---|---|
| Core science | • Cycling and fate of organic micropollutants<br>• Environmental persistence and chronic effects of pollutants<br>• Pollutant uptake, metabolism and pathology<br>• Impact of pollution on population dynamics<br>• Mechanisms controlling patterns of benthic communities. |
| Technology | • Biomarkers and indicator species as diagnostic and prognostic tools<br>• Molecular sensors<br>• Pattern recognition and data analysis. |
| Modelling | • Models of pollutant speciation, uptake, metabolism and effects. |
| Survey and monitoring | • Mussel watch<br>• Biomarkers in pollution monitoring. |
| Users | MAFF, DoE, NRA, chemical and other industries, WRc, ICES, EU, IOC, UNEP, EERO, EPA (USA), environmental consultancies. |

**Predator-Prey Interactions (DML)**

| | |
|---|---|
| Core science | • Feeding and predator avoidance in coastal marine animals<br>• Temporal and spatial organisation of behaviour in relation to predators and prey; consequences for habitat selection<br>• Effects of processes at level of individuals (growth and behaviour) on higher levels of organisation (populations and communities). |
| Technology | • Sampling of animals in shallow coastal habitats<br>• Underwater television observations<br>• Visual recording using time-lapse and high-speed video<br>• Analysis of video recordings with computer-based event recording and tracking programmes. |
| Modelling | • Individual-based models of behaviour, based on optimisation techniques<br>• Models of community development using stochastic realisations of behavioural interactions. |
| Survey and monitoring | • Ecological surveys of shallow water systems. |
| Users | MAFF, DoE, Scottish Salmon Growers Association, Highland & Islands Enterprise, Crown Estate. |



*Diving study of fish behaviour using underwater video.*




*Dataset publication on CD-ROM.*

## 5. British Oceanographic Data Centre (BODC) and National Marine Biology Library

### British Oceanographic Data Centre (POL)

Core mission

- Data management support for UK marine science
- Maintain and develop UK oceanographic database
- Supply high quality data to UK scientists, commerce and government
- Develop innovative data products
- UK focus for international exchange and management of data
- Marine hub in NERC network of Data Centres.

Methodology

- Early involvement in data acquisition; process for quality and consistency; store; on-line access; product design
- Use relational databases to optimise storage and archiving
- Research efficient quality assurance procedures
- Publish on disks, CD-ROMs, FTP and by Internet
- Respond to *ad hoc* requests for data
- Pro-active searches for data outwith NERC.

Facilities

- Computers, workstations, mass store, GIS.

Fieldwork

- Early involvement in data acquisition planning

Users

NERC, MAST, MAFF, NRA, MoD, DoE, EN, ICES, IHO, WOCE, JGOFS.

### National Marine Biology Library (PML)

Core mission

- Maintaining and developing a world-class library for the marine life sciences
- Maintaining and developing a world-class Marine Pollution Information Centre
- Providing information, literature and data extraction services for the UK and overseas
- Acting as a key partner in international data networks and abstracting.

Methodology

- Publication of bibliographies
- Preparation of current awareness literature and computer-based abstracts
- Provision of on-line bibliographic services
- Development of Internet contact networks.

Facilities

- One of the world's most comprehensive archives of literature on marine sciences and marine pollution
- Networked computer systems and other communication systems
- Highly developed interactive data base.

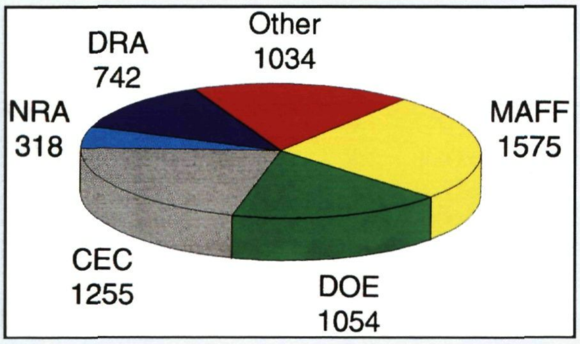
Users

NERC, universities, UNESCO, UNEP, FAO, IOC, NRA, water industry, environmental consultancies.

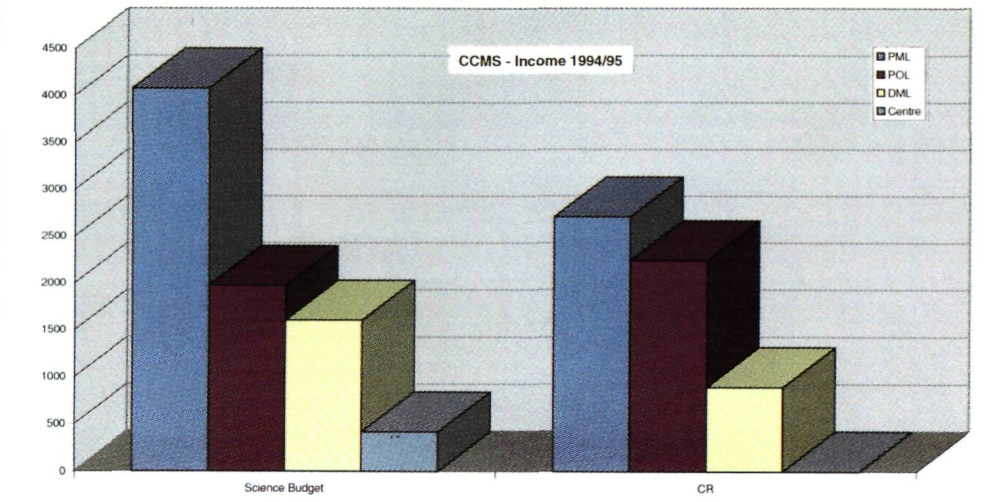
# CCMS Statistics

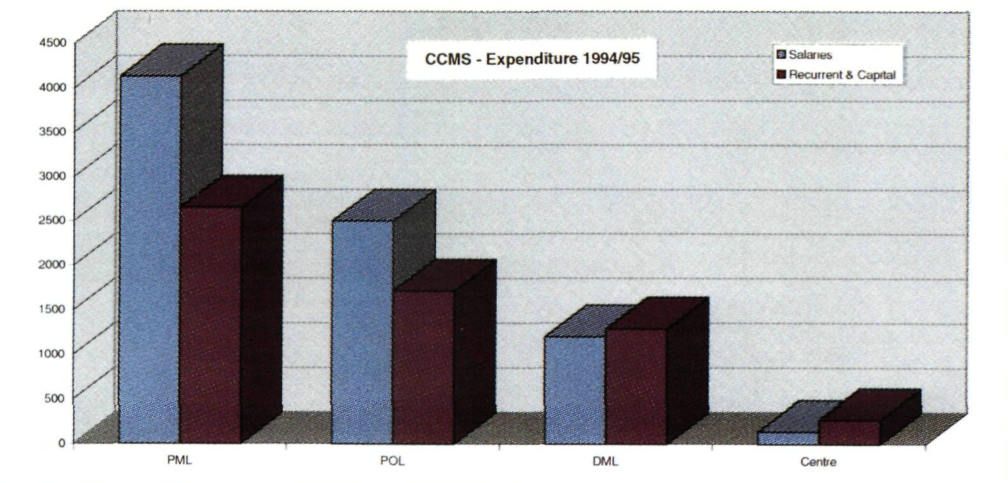
### Finances

The total receipts (and expenditure) of CCMS in 1994-95 was £13,754k, comprising a Science Budget income and external receipts of £7,656k (55.7%) and £6,098k (44.3%) respectively. The charts given here quantify the Centre's main sources of non-SB support, and show budget breakdowns between PML, POL, DML and the Centre Office, and between salary and non-salary (recurrent and capital) costs.

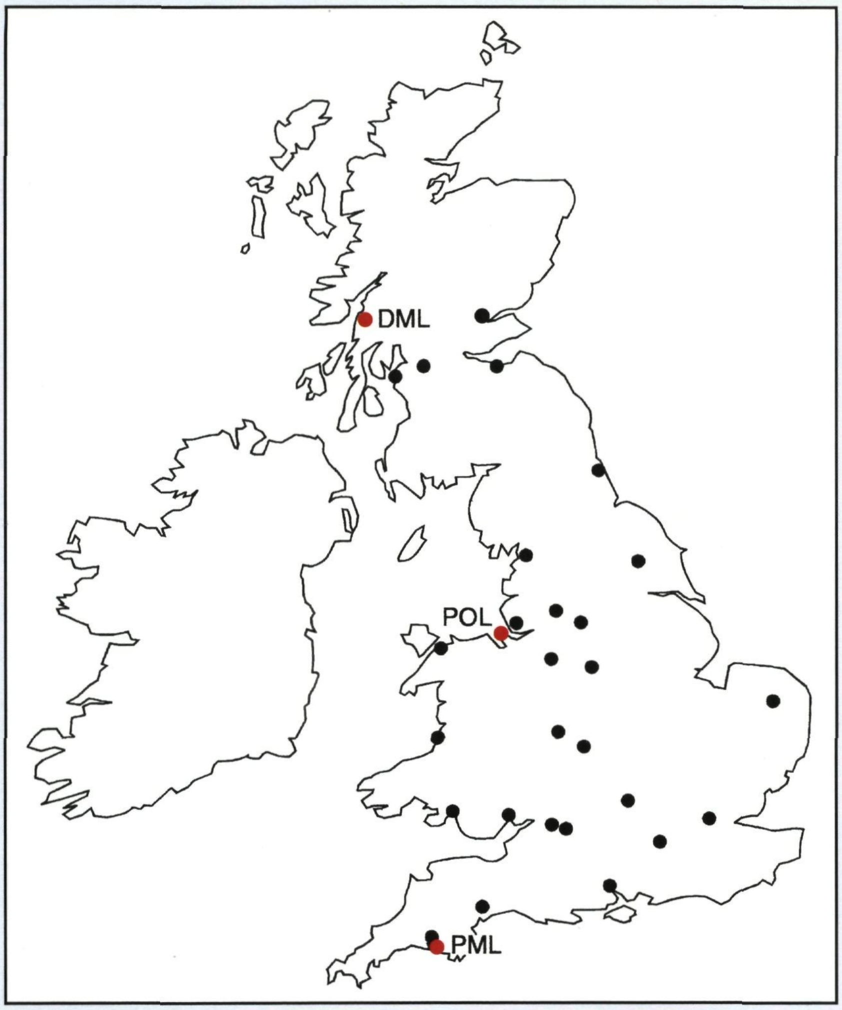



*Above, customer support (£k) for CCMS research in 1994-95; below, breakdown of Science Budget and commissioned research income, and of salary and non-salary expenditure, between Laboratories.*



# APPENDIX 2




*Locations of the 31 UK universities involved in training collaborations with CCMS during 1994-95 (Aberystwyth, Bangor, Bath, Birmingham, Bristol, Cardiff, Dundee, East Anglia, Exeter, Glasgow, Lancaster, Liverpool, Liverpool John Moores, Napier, Nottingham, Paisley, Plymouth, Reading, Salford, Sheffield, Sunderland, Surrey, Southampton, Staffordshire, Strathclyde, Swansea, University College London, University of London: Marine Biological Station Millport, Warwick, Westminster and York).*

## Staff

A total of 316 staff (including 76 fixed term appointments) were in post within CCMS on 31 March 1995. The total figure comprised 232 scientific posts, 35 administrative, 23 professional and technical, and 26 industrial and other grades. There was an overall reduction in staff numbers, by 15 posts, during 1994-95.

## Training

In addition to field courses, workshops, open seminars and short-term working visits, 73 students received training at CCMS Laboratories for periods of six months or more during 1994-95. This total comprised 45 CASE students, 23 industrial training students, and 5 other postgraduate students and doctoral fellows. Thirty-one universities were involved, widely distributed throughout the UK.

## Publications

CCMS staff published 145 papers in refereed journals and 25 book chapters in 1994-95; 54% of these publications were co-authored with external colleagues. Full publication lists for 1994-95 are given in the separate Annual Reports for the three CCMS Laboratories, together with other background information.

Since the above data relate to the year of CCMS' establishment, it is not yet possible to quantify trends or developments relating to the Centre as a whole.

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## Acronyms and Abbreviations

*Excluding those given in full on each occasion of use.*

| | |
|---|---|
| BODC | British Oceanographic Data Centre |
| CAD | Computer aided design |
| CCMS | Centre for Coastal and Marine Sciences |
| CD-ROM | Compact disk - read only memory |
| CPR | Continuous Plankton Recorder |
| CZCS | Coastal Zone Color Scanner |
| DML | Dunstaffnage Marine Laboratory |
| DoE | Department of the Environment |
| DRA | Defence Research Agency |
| EC | European Commission |
| EERO | European Environmental Research Organisation |
| EN | English Nature |
| EPA | Environmental Protection Agency |
| EU | European Union |
| FAGS | Federation of Astronomical and Geophysical Data Analysis Services |
| FAO | Food and Agriculture Organisation |
| FTP | File transfer protocol |
| GIS | Geographical information system |
| GPS | Global positioning system |
| ICES | International Council for the Exploration of the Sea |
| IGBP | International Geosphere-Biosphere Programme |
| IHO | International Hydrographic Organisation |
| IOC | Intergovernmental Oceanographic Commission |
| JGOFS | Joint Global Ocean Flux Study |
| JNCC | Joint Nature Conservancy Council |
| LOIS | Land-Ocean Interaction Study |
| MAFF | Ministry of Agriculture, Fisheries and Food |
| MAST | Marine Science and Technology programme (EC) |
| MetO | Meteorological Office |
| MoD | Ministry of Defence |
| NERC | Natural Environment Research Council |
| NCS | NERC Computer Services |
| NRA | National Rivers Authority |
| ODA | Overseas Development Administration |
| PML | Plymouth Marine Laboratory |
| POL | Proudman Oceanographic Laboratory |
| SAHFOS | Sir Alister Hardy Foundation for Ocean Science |
| SB | Science Budget |
| SES | Shelf edge study |
| SOAEFD | Scottish Office Agriculture, Environment and Fisheries Department |
| UNEP | United Nations Environment Programme |
| WOCE | World Ocean Circulation Experiment |
| WRc | Water Research Centre |
| WWF | Worldwide Fund for Nature |