MARINE SCIENCE AND TECHNOLOGY

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EXECUTIVE SUMMARY

1998, the International Year of the Oceans helped to focus increasing attention on the importance of a very broad range of marine topics, such as trade, fisheries, flood protection and coastal defence, energy resources, transport, species and habitat conservation, and scientific research.

The economic value of the marine sector to the UK has been estimated to provide nearly 5% of the nation's wealth. While this large figure is derived from a very broad definition of 'marine', work by the Marine Foresight Panel, and its associated task forces has indicated that there is undoubtedly a large potential market for products and services in the marine sector. In particular, growth areas could include developments in:

- Shipping - such as integrated port operations and the all-electric ship.
- Offshore energy - both conventional and renewable.
- Marine environmental information services - such as operational ocean forecasting.

Marine Foresight has suggested how such markets could develop, underpinned by advances in marine science and technology (MS&T).

UK MS&T has a chequered history. The entire research area originated in the UK at the end of the last century, with the epic voyage of HMS Challenger. This established the foundations for modern scientific study of the oceans, with the UK building and maintaining a very strong reputation in this area since then. Nevertheless, the organisation of and strategy for UK MS&T has been subject to criticism for some years. The most notable Parliamentary interest was an inquiry by the House of Lords Select Committee on Science and Technology in 1985, which found that UK MS&T was underfunded and fragmented, and that the UK's reputation was in danger of being lost.

The Government's response was to set up the Coordinating Committee on Marine Science and Technology (CCMST) to develop a strategic framework for UK MS&T. This was published in 1990. The Committee's recommendations were not implemented fully and current arrangements appear to be a long way from those envisaged in 1990.

Added to this, questions have also been raised about current arrangements for MS&T research and development. In particular, issues arise over the level of funding, the balance between basic and applied research, the commercialisation of publicly-funded science and the ability to provide appropriately specialised graduates.

Finally, there is concern over the funding and mechanisms for Government support to the commercial marine sector, in particular, the future of Marine Foresight, with the Government due to make a decision in September 1999. Similarly, there are concerns over the role of the Department of Trade and Industry in promoting the UK's marine industries.

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WHAT IS MS&T?

Marine science and technology is a very broad term covering a wide range of scientific, engineering and technological disciplines applied in the maritime sector. **Appendix 1** provides an overview of the kinds of activities that have been grouped under this banner. Examples of marine **science** include marine biology, physical oceanography, marine chemistry and marine geology. Marine **technology** has two facets: providing technologies to support marine science (e.g. developing measuring or sampling equipment), or to support marine engineering (e.g. the development of vessels and structures placed in the marine environment, such as coastal defence works and oil rigs).

THE SECTOR'S IMPORTANCE

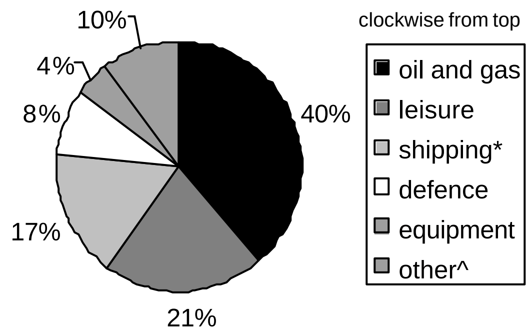
Economic Value of the Marine Sector

For centuries the UK has depended on the sea for food, trade and defence. In more recent times, offshore waters and the seabed have also provided minerals such as oil, natural gas, sand and gravel, as well as being used for the disposal of industrial wastes and sewage. The government's Inter-Agency Committee on Marine Science and Technology (IACMST) estimated that the marine sector generated close to £28 billion of value-added in 1994-95, some 4.8% of GDP. A separate report[1], commissioned by the Marine Foresight Panel reported a similar figure (4.7%). As **Figure 1** shows, much of this comes from offshore oil and gas activities, but significant contributions come from other activities such as leisure, shipping and defence. In the context of MS&T, however, a critical qualifier is what proportion of this value is underpinned by science and technology, and so could be related to expenditure on MS&T.

Hazards from the Sea

As well as providing a source of income, the sea also presents hazards. Protecting the lives of people at sea against accidents and bad weather has always been of concern. Similarly, powerful dynamic forces from currents, waves and tides cause coastal erosion and flooding, and a battle has been waged for hundreds of years to protect life and property along the coast. Relevant issues include the extent to which 'hard' coastal defence structures should be deployed rather than allowing a more 'natural' balance to be attained through 'managed realignment' of the coastline (see **Box 1**).

FIGURE 1 THE UK MARINE SECTOR, 1994-5 (% OF GDP)



* shipping trade, invisibles and shipbuilding.
^ (in decreasing order): fisheries, environment, ports, construction, research, telecommunications, safety, bridges and tunnels, aggregates and education
Source: IACMST

Physical and Ecological Value

The marine environment is also an important physical and ecological system. The coast, shallow seas and the deeper oceans harbour a diverse range of animals and plants, many of which are of great scientific interest and conservation value. Also, there is now a greater understanding of the workings of the oceans and how they interact with the atmosphere and the polar ice caps in a single 'Earth system'. One of the most important outcomes has been to enable scientists to begin to monitor the state of the global environment and to predict how it might alter in the face of world-wide phenomena such as possible climate change, and more regional or local phenomena such as over-fishing and pollution.

A Growing Concern

Over the last 40 years, there has been increased international attention on the seas and oceans. Regional and global arrangements (such as the United Nations Convention on the Law of the Sea, UNCLOS) have been established to protect the marine environment, to safeguard shipping and to control the exploitation of marine resources. As a symbol of this growing interest, the UN declared 1998 to be UN International Year of the Oceans (IYO).

The UK marine science and technology research community has been among the leading world players for many years (see Appendix 1). For example the Southampton Oceanography Centre (SOC) is one of the leading centres for deep ocean research in the world - ranking alongside the Scripps and Woods Hole institutes in the USA.

1 This study shared a number of assumptions with the IACMST study, but others were unique. In both, much use was made of 'guesstimates'.

However, the organisation and direction of UK MS&T has been subject to criticism over the years. In the early 1960s, the Natural Environment Research Council (NERC) was established, its remit including marine subjects. Later, in 1969, a further review indicated that the original intentions of setting up NERC had not been fulfilled (in particular in relation to nature conservation, and fisheries). In 1985, the House of Lords Science and Technology Committee critically reviewed UK MS&T, and in response, the government acted to improve its co-ordination and strategy. A brief history of UK MS&T, and a chronology since the Lords' 1985 report is provided in **Appendix 2.**

More recently, in 1995, a dedicated Marine Panel was created during the first round of the Foresight process[2] to help develop links between academic MS&T and business (although the original plan for Foresight had not included a Marine Panel). In 1997, the Marine Panel reported that there are great opportunities for developing new markets for MS&T, both domestically and abroad, particularly in the areas of energy from the sea, marine information, shipping and ports, leisure and aquaculture. Nevertheless, there are concerns that this market potential has not been sufficiently recognised, and that little is being done to realise the gains across the marine sector as a whole (see later). It is not planned to continue the Marine Panel into the new round of Foresight (Foresight 2000), but ministers will take a decision on its future in September 1999 (see later).

MS&T has enabled the understanding and management of activities taking place in the seas, oceans and along the coast to increase –to enhance wealth creation, improve the sustainable use of the oceans, and understand the role of the oceans in global environmental change.

Four strands have come together to highlight how the UK might develop its MS&T potential:

- Increased appreciation of the marine sector's role in wealth creation, safety, quality of life and research.
- The UK's historical high standing in MS&T – recently reconfirmed by a study discussed in the issues section below.
- MS&T's chequered history of fragmentation, underfunding and lack of an overall strategy.
- The marine sector's contribution to the UK economy and its potential for growth.

APPLICATIONS OF MS&T

MS&T underpins the UK's ability to:

- **Transport** goods and people mainly on (but sometimes under) the surface of the sea.
- Carry out **military** activities on, over and under the sea
- **Improve safety** at sea – e.g. by designing safe vessels and structures, and helping to predict the location of a vessel, crew or cargo after an accident.
- Find, extract and manage both **living and non-living resources** e.g. fish, oil, natural gas and aggregates and other minerals.
- **Protect property and life** e.g. by predicting storms and protecting coastlines against erosion.
- **Safeguard the environment** e.g. by monitoring of water quality, protecting areas and species of marine conservation importance and understanding global environmental variability and changes.
- Recognise, enhance and conserve **marine-based cultural heritage** (e.g. coastlines, historical wrecks, war graves and marine archaeology).

Supporting and enabling all human uses of the sea is the need to understand the powerful, changing and often hostile marine environment. The marine environment can be classified as three interacting parts of a single system. Nearest the land – is the **continental shelf** (with water depths to 200m); further out is the **continental slope** which reaches down to the **deep ocean** at depths of ~4000m. Interactions between these zones are particularly important: they should not be envisaged as distinct.

Operating in the sea is fundamentally different from working on land. The setting for operations is constantly moving in poorly understood and complex ways; salt water is corrosive and can damage equipment quickly; difficult access is required across large distances, often in dangerous conditions; workers are cut-off for long periods of time; and safety issues become paramount.

Under such difficult conditions, therefore, MS&T is necessary to enable the UK's effective use and management of the marine environment – to enhance wealth creation, to improve the quality of life and to help protect the environment. An overview of the types of applications of MS&T are given in **Box 1**.

[2] This initiative aims to identify opportunities in markets and technologies likely to emerge during the next 10-20 years.

BOX 1 EXAMPLES OF APPLICATIONS OF MS&T

Transport
In its 1997 report, the Foresight Marine Panel stated that 95% of EU trade across seas is carried by ships (rather than by air or via the Channel Tunnel), and that one-third of freight enters and leaves Europe by sea. Here, science and technology play an important part in the design of vessels, on-board equipment and systems for handling cargoes (e.g. changing from one form of transport to another – intermodal shift). With vessel design, it is necessary to understand the dynamics of winds, waves, currents and tides to predict the behaviour of a ship under different conditions (sea-states). Similarly, specialised marine equipment (such as ships' propulsion and electrical systems) is required to take account of particular conditions found only at sea. Clearly, increased vessel speeds, and more efficient port operations, could improve the efficiency of maritime freight transport movements around the UK coast.

Defence and Security
As an island state, the UK has operated both a navy and a coastguard service for many years. Examples of MS&T include:

- An underwater acoustics facility at Loch Goil in Scotland, operated by the Defence Evaluation Research Association (DERA).
- DERA's scale-replica of a Trafalgar class nuclear submarine used for investigating submarine manouevering and control.
- DERA's development of a prototype three-hulled warship (a trimaran, *RV Triton*) to be faster, more stable and more adaptable than a conventional single-hulled vessel for a range of defence roles. DERA plans to launch the *RV Triton* next year.

Environmental Management
Perhaps one of the most promising applications of MS&T is the development of mathematical models of the oceans as part of the international effort to predict the effects of climate change. Ocean currents are now understood to be a key element in the movement of heat around the Earth. In this context, there have been a number of large-scale international research programmes and experiments to improve data collection and modelling. One is WOCE (the World Ocean Circulation Experiment). Also, it is necessary to predict the fate of pollutants entering the marine environment – e.g. by monitoring and modelling the dispersion of oil spills and sewage discharges. A key element is a series of Quality Status Reports (QSRs) produced for the countries bordering the North Sea. The last QSR was produced in 1995 and the next is due in 2000. These provide extensive data on the chemical and biological quality of the coastal and offshore waters in the North Sea and adjacent waters. Another important application is in identifying and safeguarding marine species and habitats of conservation interest.

Protecting Life and Property
Natural and human-induced changes to the UK's coastline have the potential to cause widespread damage and loss of life through erosion and flooding. As a safeguard, it is necessary to understand the processes of current movements, tides, waves, and their interaction with the weather. For example, when atmospheric pressure is low over the southern North Sea, and the wind is blowing strongly from the east, the water level along the east coast of England rises. This 'storm surge' can cause severe coastal flooding. Prediction of such events is therefore vital if loss of life and property is to be minimised. Consequently, significant effort (the Ministry of Agriculture, Fisheries and Food, MAFF and the Department of the Environment, Transport and the Regions, DETR each spend around £1.5 billion per year) is made to protect coasts from flooding and erosion. Responses range from hard engineering solutions such as the Thames Barrier, sea walls and rock armour, to more 'natural' methods such as artificial offshore reefs and 'managed realignment' – the latter being where hard defences are removed, or not maintained, so that the coastline and its vegetation are allowed to adapt to changing sea levels; providing defence by absorbing wave energy and fixing sediments.

Using Natural Resources
Food has been derived from the sea for thousands of years, but more recently, many **fisheries** have declined from over-fishing, and fishing for inappropriate species. Science and technology are now increasingly deployed to find, measure, monitor and predict fish stock levels, and to set maximum allowable catches, aimed at conserving remaining stocks and creating sustainable fisheries. Similarly, **sand and gravel** have been extracted from the sea-bed for centuries, with the UK offshore aggregates industry now the largest and most technically advanced in the world. Again, scientific methods (such as computer modelling of the dispersion of fine sediments discarded during aggregate dredging) and technologies (such as satellite-based geographical positioning systems) are being used increasingly to manage the process of aggregate extraction. **Hydrocarbon fuels** (oil and natural gas) have been found and developed on the back of offshore engineering developments from the 1950s and 1960s. Since then, the North Sea fields have matured and new techniques are being developed to increase sub-sea processing and to enhance oil recovery. Similarly, new activities are beginning in the Atlantic Ocean to the west of the Shetland Islands, where depth, currents and poor weather provide greater engineering challenges than have been faced before. The UK is also 'blessed' with **renewable energy** resources offshore – it has the best wave 'climate' in the world and the best wind resource in Europe. Thus, interest is now being turned to marine-based renewable energy e.g. from waves, tides and currents, with much interest in offshore wind energy (e.g. a recently commissioned project at Blyth Harbour in the north east of England).

Cultural Amenity and Heritage
People enjoy both living near to and visiting the coast, and this supports a significant industry, which accounted for over £8 billion in 1994-95 (Figure 1). Maritime heritage (e.g. historic ships, wrecks and archaeology) introduces a cultural value. Science and technology are applied widely in these areas (e.g. innovations in ship and boat design and the design of harbours and marinas are based on understanding the dynamics of the sea and advanced engineering principles). Similarly, marine archaeology uses a number of sophisticated scientific tools to find, extract and conserve artefacts, such as the sixteenth century warship, the *Mary Rose*. As with the need to protect life and property from erosion and flooding, there is also a need to protect many beautiful coastal landscapes and habitats from the same forces, and so a similar level of understanding of coastal processes is necessary to underpin conservation.

ORGANISATION OF UK MS&T

Historical Coordination

UK MS&T is conducted by and used in three main areas:

- **Academia** – funding through the Research Councils and universities.
- **Government** – the use of MS&T in support of policy or statutory obligations.
- **Business** – the provision of marine services and the use of MS&T to support business operations (e.g. offshore oil and gas exploration and production).

It was against this backdrop that the House of Lords inquiry found UK MS&T to be fragmented and underfunded, despite being technically excellent, and that there was no overall strategy for research. The Committee recommended some form of coordinating body and the main outcome was the setting up of the Coordinating Committee on Marine Science and Technology (CCMST), which (in 1990) established for the first time a strategy for MS&T in the UK. This identified 6 main objectives:

- **Environmental protection** – to protect against pollution; to monitor and improve biological productivity; to conserve natural resources; and to promote economic viability.
- **Exploitation of resources** – to maintain and enhance commercial and safe exploitation of energy resources, minerals, fisheries and the use of the sea.
- **National defence** – to improve the performance of naval vessels and understand the effects of the marine environment on ships and submarines.
- **Prediction of climate change and its effects** – to reduce uncertainties by improving observations and understanding of ocean-atmosphere interactions.
- **Marine technology** – to develop and maintain a strong, innovative industrial effort able to compete in world-wide markets.
- **Statutory and regulatory obligations** – to provide for and coordinate marine research necessary for official bodies to fulfill their duties.

CCMST proposed setting up a coordinating body comprising representatives from these areas "*to make sure that the proposals work in practice*." However, it was not the intention of CCMST to give the coordinating body direct managerial control over the various bodies concerned. Rather, it envisaged the body being responsible for "*coordinating, monitoring, advising, supporting and promoting MS&T*". Line management would have rested with the usual government departments and the other public bodies responsible.

BOX 2 THE ROLE AND WORK OF IACMST

Policy for marine management and legislation is decided within the separate Government Departments and other bodies, officials from which are members of IACMST: i.e. MAFF, Ministry of Defence (MoD), Meteorological Office, DETR, Department for International Development (DFID), Department of Trade and Industry (DTI), the Office of Science and Technology (OST), Engineering and Physical Sciences Research Council (EPSRC), Natural Environment Research Council (NERC), Environment Agency, Northern Ireland Office, Scottish Office and the Health and Safety Commission and Executive. Advisers are from the Foreign and Commonwealth Office (FCO) and the Department for Education and Employment (DfEE), and there are also three independent advisers (one of whom is from industry). The IACMST maintains an overview of marine activities across Government. It encourages links between Government and the national marine community, the wider application of marine science and technology, optimum use of major UK marine facilities, training and education and international links. Its terms of reference are:

1 To maintain an overview of national and international activities in MS&T.

2 To ensure that there are satisfactory arrangements for:

a) The co-ordination of national and international MS&T activities;

and to encourage:

b) Making optimum use of major UK facilities for MS&T;

c) Enhancing wealth creation and the quality of life through targeted interaction between science and industrial and other user interests in MS&T;

d) Training and education in MS&T.

3 To report on its activities and the broad scope of all Departmental MS&T activities, to the Chief Scientific Adviser annually, and to other member agencies as and when appropriate.

Its work includes holding plenary meetings; maintaining an overview of UK Government policy as represented to various intergovernmental marine-related agencies (although it does not formulate policy); maintaining the marine environmental data coordinator at the NERC British Oceanographic Data Centre; operating a marketing liaison function to assist in the commercial development of government marine data and forecasting services; organising an annual open forum on a special theme; holding special technical meetings on current issues and trends; maintaining a UK input to international collaborations.

Current Arrangements

CCMST was wound up in 1991, and the IACMST[3] was founded in its place. In practice, IACMST does not fulfill all the roles envisaged by CCMST but acts more as a 'forum' for discussion and information exchange between **public bodies** with an interest in the marine environment (**Box 2**). For example, IACMST has produced a number of publications analysing aspects of MS&T, such as the market, education and training needs and international arrangements for MS&T. It convenes meetings, and has put in place a marine environmental data coordinator based at the British Oceanographic Data Centre at Bidston on Merseyside.

[3] **IACMST's web site is at www.marine.gov.uk**

BOX 3 MS&T IN GOVERNMENT DEPARTMENTS

The **Ministry of Defence** is responsible for research, development, production and procurement of weapons systems and platforms and receives assistance from **DERA** in this. The **Meteorological Office** provides marine weather and ocean forecasts. The **Hydrographic Office** provides hydrographic and oceanographic information and charts.

The **Department of the Environment, Transport and the Regions** is responsible for environmental protection (e.g. climate change, coastal and marine wildlife, marine environmental policy). It also responsible for general shipping policy, marine safety and marine pollution, ports' regulation, marine accidents, the Maritime and Coastguard Agency, offshore aggregates, planning and regulation and construction best practice and the Health and Safety Commission and Executive.

The **Joint Nature Conservation Committee** is the forum through which the three country nature conservation agencies deliver their responsibilities for Britain as a whole.

The **Environment Agency** is the statutory regulator for industrial discharges, water resources and water quality, and some fisheries. It is also responsible for forming an opinion on the general state of the environment of England and Wales.

The **Ministry of Agriculture, Fisheries and Food** is responsible for policy on fisheries in England and Wales, for the protection and enhancement of the marine environment and for flood defence. It is assisted by the Sea Fisheries Inspectorate, and the Centre for Environmental, Fisheries and Aquaculture Science (CEFAS).

The **Scottish Office Agriculture, Environment and Fisheries Department** is responsible for the conservation of fish stocks and the management of sea fisheries around Scotland. It conducts research on marine fisheries and conservation, environmental pollution, fishing gears, and fish and shellfish cultivation.

The **Northern Ireland Office,** Department of Agriculture for Northern Ireland (DANI) is responsible for managing and conducting scientific studies on fisheries, conservation and the environment.

The **Department for International Development** is responsible for managing development assistance to poorer countries on the environment, trade investment and agricultural policies (including fisheries, aquaculture and coastal management. It is also responsible for policy and coordination with UN agencies e.g. FAO and UNESCO (see Box 6)

The **Department of Trade and Industry** aims to help business to compete successfully at home, in the rest of Europe and throughout the world. Its role includes industrial sponsorship, export promotion through **British Trade International**, science and technology, and support for small firms. Marine aspects include: supporting UK offshore oil and gas companies; satellite earth observation), shipbuilding, regulation of oil and gas developments and BREEZE –(British Exclusive Economic Zone Exports), which helps British companies sell expertise and equipment to overseas governments. The DTI also houses the **Office of Science and Technology** which is responsible for the science and engineering base, the science budget and the **Research Council** system. It also oversees the UK Foresight Programme, including the work of the **Marine Foresight Panel**.

So, rather than IACMST acting as the 'hub' of activity in UK MS&T, it provides a networking service to the government departments and agencies with an interest in marine matters. Information on the government departments involved is given in **Box 3** while **Box 4** outlines the role of the Research Councils.

In general, most of the day-to-day coordination occurs through a series of bilateral or multiparty arrangements between these organisations. Examples of arrangements with NERC include concordats with MAFF and DETR, and a closer collaboration with MoD (under the CAROS initiative). Another example is the DETR Marine Division's Research Requirements Committee, which includes MAFF, the Welsh and Scottish Offices, the Environment Agency and IACMST (informally), but NERC is not a member[4].

Data from IACMST show that, in 1994-95, the UK spent £561 million on marine-related research and development (R&D). Of this, £264 million (47%) was spent in government laboratories, £200 million (36%) in the commercial sector, and £97 million (17%) in university departments. Within government departments more specifically, 64% (£168 million) was spent by DERA, and 20% (£52.2 million) by NERC. All other government marine R&D accounted for 16% of total government expenditure in this area, and 7.5% of the total UK spend.

It can be seen, therefore, that public expenditure on MS&T is dominated by military applications. Box 1 highlights a few examples of the applications currently being developed. Much of DERA's work is geared towards development (rather than research) - this requires sizeable expenditure on large-scale projects such as the trimaran *RV Triton*.

The Research Councils' Role

In the civil sector, the government finances the **Research Councils** to provide basic and strategic research (**Box 4**). Most civil MS&T research is funded by NERC, although the Engineering and Physical Sciences Research Council (EPSRC) has some involvement (e.g. in coastal and offshore engineering and marine renewable energy).

Within NERC and EPSRC, recent policies have shifted to place more emphasis on providing funding to tackle 'themes' rather than to support research in particular academic disciplines

[4] **This is due to a potential conflict of interest arising because NERC is a major contractor to DETR.**

BOX 4 MS&T IN THE RESEARCH COUNCILS

Engineering & Physical Sciences Research Council (EPSRC)
The EPSRC runs research programmes dealing with offshore and coastal engineering. The recent evaluation of EPSRC's *Engineering for Infrastructure, the Environment and Healthcare* and *General Engineering* programmes identified offshore engineering as a particular strength. Consequently EPSRC asked the Centre for Marine and Petroleum Technology (CMPT - a body set up by the oil and gas operating companies) to scope a programme of managed research into oil and gas. Following this, EPSRC launched a *New Programme in Oil and Gas Recovery* that was informed by the *Energy from the Sea* Task Force under the Marine Foresight Panel. EPSRC has also launched a new programme in renewable energy, which will include offshore sources, such as wind, wave, and currents.

EPSRC has designated world-class Marine Technology Centres at 8 UK universities: Glasgow, Cranfield, Heriot Watt, Newcastle, Southampton, Strathclyde, London and Marintech Research (a consortium of Liverpool, Salford, Manchester and UMIST universities). Examples of research covered include: offshore structures, biofouling resistant surfaces, remotely operated underwater vehicles, robotics and computational fluid dynamics.

Natural Environment Research Council (NERC)
The NERC sponsors basic and strategic research into the physical and biological sciences relating to the natural environment and its resources. Its marine science is conducted mainly in two Centres:

- **Centre for Coastal and Marine Sciences (CCMS)** is an amalgamation of three previously separate laboratories – the Plymouth Marine Laboratory (PML), Dunstaffnage Marine Laboratory (DML) and the Proudman Oceanographic Laboratory (POL). Most CCMS work is focused on marine environmental science related to coastal and shallow (shelf) seas.
- **Southampton Oceanography Centre (SOC)** is a joint venture set up in 1995 between NERC and Southampton University. SOC's main expertise lies in the deep ocean such as global-scale ocean circulation, deep-sea ecology, and ocean-floor formation processes. However, it has capabilities in shelf-sea science, teaching and technology development.

The NERC also supports marine sciences within the **British Antarctic Survey** (e.g. the biology and ecology of Antarctic marine species, and processes at the interface of ice and water).and the **British Geological Survey** (e.g. surveying and mapping the sea-bed and the structures underneath the sea-bed). It also has links with the Sea Mammal Research Unit, the Marine Biological Association and the Scottish Association for Marine Sciences. Finally, the NERC also supports MS&T in universities.

The NERC's current priorities for marine science are:

- Sustainable Use of Marine Resources
- Climate Change
- Marine Biodiversity

TABLE 1 KEY ISSUES AT NERC AND THE ROLE OF MS&T

Theme	Example of MS&T input
Biodiversity	Marine biodiversity and genetics
Environmental Risks and Hazards	Earth observation; prediction of floods and storm surges
Global Change	ocean-atmosphere interactions in the climate system
Natural Resource Management	Geological processes beneath ocean margins; EEZ [5] resources.
Pollution and Waste	Integrated water quality models for fresh and marine waters.

Source: NERC

Thus, EPSRC deals with *Engineering for Infrastructure, the Environment and Healthcare; General Engineering* and *Engineering for Manufacturing* – each of which has some marine content. NERC's 1998 strategy for science *Looking Forward* identified five themes on which it wished its four Science and Technology Boards[6] to concentrate their funding. **Table 1** illustrates where MS&T features in the themes, but is not a complete map of its marine science programmes.

Following the 1998 Comprehensive Spending Review, NERC's funding via the science budget was increased by 3% in real terms to 2003/04. NERC 'rebalanced' its priorities in the light of this new money, and one outcome is that **funding for marine sciences will fall in real terms between 1997/98 and 2003/04**. Further, as described in Box 4, the emphasis in marine science research is more focused on biological issues than on the physical sciences (see later).

Moreover, in *Looking Forward* NERC states that it will increase the proportion of its funding for curiosity-driven 'basic' science, and thus away from 'strategic' and 'applied' science. This refocusing and rebalancing has caused some concerns in the MS&T community about the level and direction of the underpinning research necessary for the further development of MS&T industry. This is discussed later.

The Business Interest

The last element of MS&T in the UK is the role played by the business sector. As pointed out earlier, IACMST estimated that in 1994/95 (the latest year for which figures are available) the marine sector generated £28 billion of value-added, which contributed 4.8% to the UK's GDP. The exact figure for the economic value of the marine sector is uncertain, as it was based on a wide range of data sources and assumptions of varying

[5] **Exclusive Economic Zone**
[6] **Atmospheric, Earth, Marine, and Terrestrial & Freshwater. Cross-cutting priorities exist on polar science and earth observation.**

quality and reliability. For example, the estimate of the value of marine-related leisure (£5.5 billion of value-added) was derived from British Tourist Authority figures that showed that around 40% of tourism expenditure in the UK occurred at seaside locations. Clearly, this is not a particularly robust means of estimation, and thus questions are raised about the accuracy of the figures quoted.

Nevertheless, many activities taking place in the sea require specialised support from MS&T to gain access to the goods and services located there. For instance, new engineering developments were necessary to enable exploration for, and production of, oil in the North Sea and more recently, in the deeper waters to the west of Shetland.

However, it remains unclear what proportion of the £28 billion value estimated for the marine sector is under-pinned by MS&T, and hence is sensitive to expenditure on research and development. Despite the uncertainties over the precise value of the marine sector, it has been recognised by the government as a significant sector of the economy, and as such has been represented within the government's Foresight Initiative (**Box 5**).

International Collaboration in MS&T

UK MS&T does not take place in a vacuum. There is considerable European and wider international interest in this area. **Box 6** outlines some of the key elements.

The UK contributes substantially to international science and technology planning and programmes. Within the UK, highly developed consultative networks enable delegates to be briefed rapidly, tapping quickly into relevant professional and administrative expertise. Among its responsibilities, the IACMST is required to maintain an overview of national and international activities in MS&T, and to ensure that there are satisfactory arrangements for their coordination. As such, IACMST produces a document every few years summarising UK international MS&T interests

Many of these institutions, initiatives and programmes are supported at a high level by representatives from the UK - both as participants and as organisers. For instance, in July 1999, a UK scientist was elected as the First Chairman of the Intergovernmental Oceanographic Commission of UNESCO, representing Western Europe and North America. Similarly, the SOC hosts the secretariat for the World Ocean Circulation Experiment (WOCE) and the European element of the Global Ocean Observing System (GOOS), while the Royal Institution

BOX 5 MARINE FORESIGHT

The Marine Panel of Foresight was set up more than a year after the other 15 panels. This was because of the need to establish a case for the marine sector to have a separate panel, rather than dealing with marine issues within each of the other panels. Nevertheless, the Panel identified that *"marine activities make a very significant contribution to the UK's prosperity and quality of life"*; employing nearly 800,000 people, and contributing nearly 5% to the UK's GDP. The Panel contrasted this with the Defence and Aerospace sector, which employs 250,000 people, and contributes 3% of GDP.

The Panel noted that the marine market comprised a number of disparate but interdependent, segments (see Figure 1). Similarly it noted the UK's strong academic position; its international commercial links (particularly with the Commonwealth and the USA); its reliance on a technologically advanced navy; the existence of a substantial offshore oil and gas industry; and its strong position in information technology. In this context, the Panel recommended that these areas "*should be capitalised upon for wealth creation and improving the quality of life, enhancing the UK's competitiveness and underpinning the development of marine policy*."

The Panel identified 5 'Foresight Challenges' and set up working groups to examine each specific area.

- **Offshore Energies** – An **Energies from the Sea** Task Force was set up, and a report was published in April 1999, aiming to improve hydrocarbon recovery and deep-water production, and to develop marine-based renewable energy.
- **Maritime Transport and Construction** – to develop efficient intermodal marine transport systems and to re-establish the UK as a major force in design, construction and operation of specialist ships, including high-speed craft.
- **Marine Fisheries and Aquaculture** – to improve aquaculture productivity world-wide through the application of UK biotechnology expertise.
- **Exploitation of Non-living Marine Resources** – to develop comprehensive operational oceanography to underpin marine environmental forecasting services.
- **Coastal Waters and Maritime Leisure** – to increase exploitation of the coastal zone in proportion to population growth in a sustainable manner.

A cross-cutting challenge identified by the Panel was to increase the development of **improved information systems** relating to the management of marine resources and the marine environment. A Task Force to carry this forward was established and is due to publish its strategy for the development of the British marine information industry shortly. Issues examined by the Task Force include forming effective partnerships within the commercial sector and between government, business and industry; improving the UK's monitoring and forecasting capability; improving access to publicly-funded data and models; and re-focusing education and training at the secondary and tertiary levels.

In their responses to the challenges set, the Marine Panel working groups and task forces identified a range of market opportunities and key research priorities. One key issue identified throughout is how the Panel's recommendations will be implemented – the Panel considers that this requires partnerships both between commercial organisations, and between business, academia and government (e.g. in simplifying the procedures for gaining consent for developing renewable energy technologies on the sea-bed).

BOX 6 INTERNATIONAL AND EUROPEAN MS&T

The UK's involvement in international MS&T occurs on three levels:

Global – e.g. through intergovernmental agencies such as the International Council for the Exploration of the Seas (ICES) and the United Nations. Examples of UN agencies and programmes include FAO; the UN Environment Programme's Regional Seas Initiative; the International Oceanographic Commission of UNESCO; the UN Convention on the Law of the Sea; the International Maritime Organisation; the World Meteorological Organisation; the Ocean Drilling Programme; the International Geosphere-Biosphere Progamme; the World Climate Research Programme, and component parts such as WOCE and GOOS; and a Sub-committee on Oceans and Coastal Areas under the Commission for Sustainable Development.

The North-East Atlantic Region – this includes all the Atlantic coastal nations in a region bounded by a line running south from Greenland, as far as the Azores, and then east to Gibraltar. Within this region the Oslo and Paris Conventions aim to prevent pollution arising from disposal from ships and aircraft and discharges from land (including atmospheric emissions). UK involvement includes preparation of a Quality Status Report for the North Sea and adjacent waters by 2000.

European Union – the key activity is in the area of R&D, with the Fifth Framework Programme. This has 3 Programmes with a marine interest, funded to an unprecedented sum of 160M ECUs:

- Energy, Environment and Sustainable Development, which includes Key Actions on *Sustainable Marine Ecosystems* and *Global Change, Climate and Biodiversity*.
- Competitive and Sustainable Growth, which includes a Key Action on *Land Transport and Marine Technologies*.
- Quality of Life and Living Resources – which has a Key Action on *Sustainable Agriculture, Fisheries and Forestry*.

In addition, the EU has a Fisheries Research Programme, which is geared towards providing scientific advice to underpin the Common Fisheries Policy, which is due to be revised in 2002. Also, European Environment Agency, through one of its European Topic Centres, maintains an overview of the status of the marine and coastal environments. The EU is also a partner in EUREKA (along with EFTA nations and Turkey), and this includes the EUROMAR programme, which considers remote sensing, models, data systems, sea-bed models, instruments and carrier systems and atmospheric inputs to the sea.

Finally, there are a number of non-governmental pan-European initiatives concerned with the marine environment, such as WEGEMT, the European Association of Universities in Marine Technology. Also, the European Science Foundation run Boards for Marine and Polar Science. The Maritime Industries Forum involves input from the European Commission, the Alliance of Maritime Regional Interests in Europe and the European Parliament. It has produced an R&D Master Plan, which includes a *Maritime Systems of the Future* Task Force

of Naval Architects provides the secretariat for the European Association of Universities in Marine Technology (WEGEMT). Similarly, a UK scientist holds the Chair of the Joint Global Ocean Flux Study (JGOFS).

Involvement at this level enhances the worldwide reputation of the UK's capability in MS&T, and also helps in the transfer of knowledge from academia to students, industry and government. It is important to recognise, however, that many of these international collaborative science programmes represent 'big science' and require significant commitment, time, money and resources from participating nations.

FIGURE 2 RRS CHARLES DARWIN

Source: NERC

In particular marine science programmes such as WOCE involved the deployment of NERC's research vessels (such as *RRS Discovery* and *RRS Charles Darwin* – **Figure 2**). However, while NERC has been involved at the forefront of WOCE, e.g. by forming the secretariat and deploying *Discovery* for extensive data collection, it has not provided funds for data analysis.

This raises some concerns within the academic community regarding the availability of funds for continued involvement with large international collaborations. A related issue is the process procuring, refurbishing or replacing large infrastructure items for research. In the case of marine sciences, this means research ships - particularly when *RRS Charles Darwin* and *RRS Challenger* are both approaching the end of their useful lives and are due either to be refurbished or replaced. NERC is currently examining options for procuring vessels. Options under consideration include schemes such as the Private Finance Initiative, Public-Private Partnerships and priorities within the 2001 Comprehensive Spending Review.

ISSUES

In 1985 the House of Lords Science and Technology Committee found that the UK was highly regarded internationally for its MS&T. However, the Committee was concerned that in the mid-1980s, research funding for MS&T was declining, and so *"the level of capability in marine science and technology in the UK is being run down almost across the board."* What, then, has changed since 1985?

A Depth of Knowledge

The relative importance of EPSRC's *Coastal, Offshore and Water Engineering* theme has declined slightly over the last 5 years – from 22% of total expenditure in 1994 to 18% in 1998. However, at the same time, its expenditure on its *Energy* theme has increased, some of which is related to marine engineering and technology.

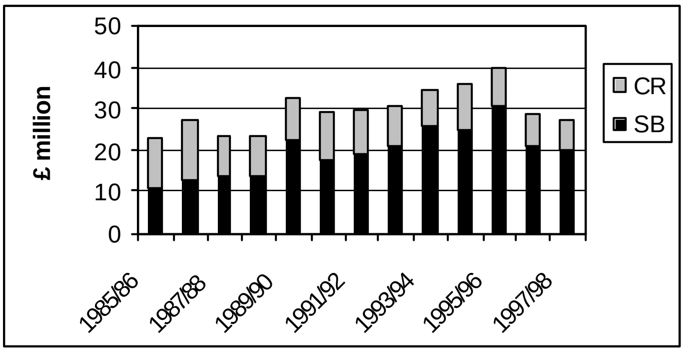
Information from the NERC (**Figure 3**) shows that the funding for MS&T rose in real terms throughout the later 1980s and early 1990s. However, this has turned down again since the mid-1990s, and, with the rebalancing of NERC's budget, this downturn for MS&T funding is planned to continue to at least 2003/04.

Alongside the strategies for each of NERC's Science and Technology Boards, and advice from NERC Council's Resources and Strategy Group, NERC's decision-making on the rebalancing of its budget, was informed by a study by the Science Policy Research Unit (SPRU) at Sussex University of the quality and impact of UK environmental science over the period 1981 to 1994. In the study, '**quality**' was measured by the number of articles published in the scientific literature (i.e. equated to 'quantity' or 'effort'), and '**impact**' by the number of citations each paper received from other researchers. This 'bibliometric analysis' showed a number of key features:

- The quality and impact of UK marine sciences (marine and freshwater biology and oceanography) declined in the mid to late 1980s, but staged a comeback' in the early 1990s.
- In international comparisons of quality (averaged over the period 1981-94) UK oceanography did not perform well, while marine and freshwater biology performed much better.
- In international comparisons of impact, both UK oceanography and marine and freshwater biology performed well – scoring above the average for the nations considered (Australia, Canada, France, Germany, US and EU).
- Overall, combining both impact and quality (or effort), the marine sciences did not appear to do as well as most other UK environmental sciences (**Figure 4**).

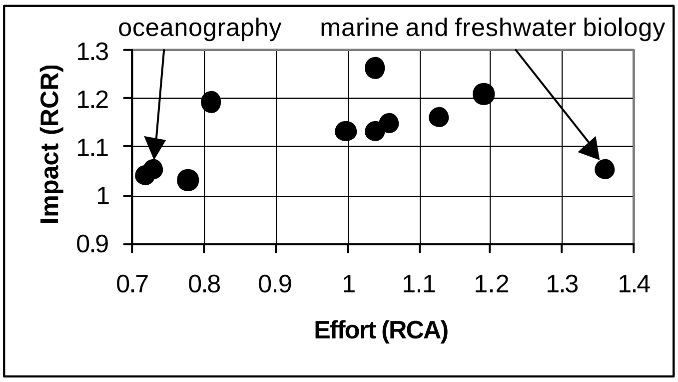
However, it is worth recognising that any bibliometric analysis is subject to a number of important limitations. While SPRU generally considers that the exercise has a role to play in analysing the strengths and weaknesses of the UK environmental sciences, it points out that "*considerable care is needed in the application of the technique*".

FIGURE 3 NERC MARINE SCIENCE FUNDING (Constant £)



CR = commissioned research; SB = science budget
Source: NERC

FIGURE 4 A MAP OF THE UK ENVIRONMENTAL SCIENCES



RCA = revealed comparative advantage (UK vs world papers)
RCR = relative citation ratio (UK vs world citations)
RCA and RCR values of 1 indicate world average.
Source: Katz, J.S. and Plevin, J., 1998. Environmental Science: a bibliometric study. Research Evaluation, volume 7, number 1, April 1998, pages 39-52.

In particular, the SPRU study used a '**citation window**' (i.e. the period recorded between a paper being published and being cited) of 3 years. The length of this window affects the relative performance of different scientific disciplines; reflecting the different publication and citation 'cultures' of different academic communities.

SPRU acknowledges that the 3-year window is designed to pick up dynamic and fast-moving scientific areas (such as virology). This necessarily reflects on slower-moving sciences– something that is apparent in the marine sciences (particularly when large-scale, international collaborative programmes are being undertaken). NERC reports that the maximum publication rate may not be achieved until 5-6 years after an oceanographic expedition has finished.

Also, SPRU notes that much environmental science is also conducted outside of the published academic literature, and therefore, will not be included in the bibliometric analysis. In particular, research for government bodies and industry rarely finds its way into the scientific journals[7]. Indeed, MAFF has only recently begun to collate outputs from the last 10 years of its own marine environmental research on fisheries, marine pollution and ecotoxicity.

It remains open therefore, **whether UK marine science performs as poorly relative to other UK environmental sciences than the bibliometric analysis suggests**. However, the bibliometric analysis was an important element in the rebalancing of NERC's science budget. Therefore, questions arise over whether the method used to judge the relative worth of marine science research was evenhanded across the environmental sciences, and thus **whether the decision to plan for a decrease in NERC's marine science budget was reliably informed.**

One option might be to repeat the analysis using a broader citation window to show up the slower-moving sciences. Another option might be to collate data on the quality and impact of a broader range of scientific outputs than the narrow selection picked up in the bibliometric analysis. Here, NERC is currently collecting data on what it calls 'output and performance measures' (OPMs). Current OPMs include assessment of: success rates and demand for non-thematic grants; publication output; prizes and science achievements; demand for data sets; use of services and facilities; involvement in international collaborations; and knowledge transfer and exploitation. NERC states that many of the OPMs indicate that marine sciences perform well in terms of scientific productivity and cost-effectiveness. For instance, the UK achieved greater funding success than any other EU country in the EC MAST Programme under the Fourth Framework Programme. Here, financial support was nearly double the UK's *juste retour*, with UK coordination of 22 (26%) of MAST projects, and UK involvement in 66 projects (77% of the total).

Overall, the UK has maintained its very high reputation in MS&T – as evidenced by the location of international project offices at NERC centres. Similarly in marine engineering and technology, the Institute of Marine Engineers, based in London, is recognised world-wide as the leading professional institution in the field. Also, the United Nations International Maritime Organisation (IMO) is based in London, and the London maritime insurance, certification and trading industry is perceived as being among the best in the world. Similarly, much of the research into marine engineering and technology undertaken in the UK is also recognised as being of international quality. For example, the Department of Marine Technology at the University of Newcastle-upon-Tyne was given the highest possible rating (5*) in the most recent Research Assessment Exercise.

One issue arises, however, over an apparent mismatch between the proportions of students entering MS&T to study biological sciences, and those studying physical sciences and engineering. This phenomenon has been dubbed 'the Cousteau Effect' as marine biology is perceived as more glamorous and less difficult than physical oceanography and engineering. Concern has been expressed by academics and business representatives that the Cousteau Effect may erode the UK's ability to maintain its position as a world leader across the full range of MS&T disciplines, and will continue to fail to provide MS&T graduates with the backgrounds that industry actually requires. NERC has stated that it is aware of this problem, and it is attempting to attract numerate graduates to its training programmes in the areas concerned.

Organisation and Strategy

One of the key concerns expressed by the House of Lords Science and Technology Committee in 1985 was that UK MS&T was **fragmented**, with activities and responsibilities split between many different government departments, agencies and local authorities. The Committee had suggested establishing a Marine Board with executive responsibilities to be based within the (then) Science and Engineering Research Council (SERC).

In its response to the Committee, the Government "*accepted the need for greater coordination and the need for research to be undertaken within the framework of a forward-looking strategy*". However, it pointed to the difficulty of "*devising a single strategy which covers the whole diverse field of marine research*". In the event, it rejected the proposal for a Marine Board, stating that this proposal seemed "*not to recognise fully the span of interests engaged in the United Kingdom marine science and technology…*" so that a Marine Board located within the Research Councils would "*have limited national influence*". On the other hand the Government accepted "*the case for a joint committee to focus the research requirements of different bodies, including industry*". Consequently, in 1988 the government established CCMST, and stated that it would "*provide an essential framework of basic, strategic and applied research*

[7] One exception to this is research funded by DETR, which encourages its contractors to publish in refereed journals as a quality control measure.

priorities strongly linked to technological developments and industrial need".

In 1990, CCMST noted a number of changes since the Lords' 1985 report, such as increased funding for MS&T research (see Figure 3); reorganisation of marine science within NERC under a Marine and Atmospheric Directorate; and the establishment of SOC. As discussed earlier, CCMST had recommended that a coordinating body be established and, in its response to CCMST's report, the Government stated that there was a "*case for maintaining some form of overall coordination*" for MS&T and to steer particular tasks. This overall coordination would, the Government believed, complement the existing interdepartmental coordination in component areas of MS&T. The result of this was to set up IACMST, with members drawn from the relevant government departments and research councils. Its objectives were to be "*to ensure arrangements for efficient information exchange between all of the relevant publicly-funded agencies in MS&T, and to maintain an overview of national and international activities*".

Despite CCMST's recommendation to include business and the universities, the government went on to say that the IACMST would be able to obtain outside advice and run joint projects through the existing mechanisms operated by government departments and Research Councils.

CCMST had addressed the Lords' concern over fragmentation and had recommended a broadly-based coordinating body with representation from the public and private sectors. In reality, however, after CCMST ceased in 1990, IACMST was set up without this broad remit. Initially, however, IACMST did have an independent Chairman from industry. It is now chaired by a representative from the Office of Science and Technology within DTI, and has one independent member from industry. The business community is also represented at IACMST open meetings.

The apparent 'cinderella' attitude to things 'marine' may be partly explained by the context of the marine environment and maritime sector within government. As explained earlier, the sea has long played an important role in many aspects of life in the UK. To a large degree this has led to marine matters becoming the legitimate responsibility of many government departments and agencies as an integral part of their own policy agendas. This 'entrenchment' or 'internalising' of marine issues within government has created the situation where the sea is recognised as important in many areas, but none where it is a paramount. The activities where it features most strongly are perhaps in the MoD through the Royal Navy and MAFF in areas such as flood and coastal defence and fisheries. Nevertheless, even here, the sea is acknowledged as being worthy of concern, but is not generally regarded as high on departments' lists of priorities.

Indeed, one criticism of the Lord's report was that it had not recognised this entrenchment, and that research is aimed at three objectives, each led by a different set of organisations:

- **Science-driven** – led by the Research Councils.
- **Policy-driven** – led by government departments.
- **Regulation-driven** – led by government agencies.

Despite this history, questions remain over **how far the fragmentation of MS&T identified in 1985 has been addressed via the IACMST rather than through a coordinating body**.

Opinions differ, with NERC suggesting that fragmentation has decreased as a result of the formation of SOC, and the amalgamation of POL, DML and PML into CCMS. Similarly, it regards the establishment of IACMST and bilateral arrangements such as its concordats with DETR and MAFF, and the CAROS initiative with the Navy as helping to reduce fragmentation – although it acknowledges that more could still be done.

On the other hand, industry bodies and some academics are more sceptical of the progress made to date. Some have suggested that the reorganisation of NERC in 1994 (which led to the loss of NERC's Marine and Atmospheric Sciences Directorate) has 'hamstrung' UK MS&T. They argue that this created a number of smaller, competing groups such as CCMS, SOC and the universities, and removed an influential catalyst with expert knowledge in, and direct control over the whole of NERC's marine science portfolio. Similarly, some observers regarded the work of CCMST as laying the foundations of a comprehensive and coordinated approach to MS&T in the UK that would bring together government, academia and industry. However, as discussed above, the current arrangement is through IACMST, but this does not have the executive coordinating function and direct industrial input envisaged by CCMST. Thus, although IACMST is able to fulfil its terms of reference to maintain an overview and aid information exchange and discussion, it is argued that the current arrangement does not meet the objectives set out by the Lords in 1985 or the CCMST in 1990.

The issue remains, therefore, over **how greater coordination could be achieved in UK MS&T beyond that provided by IACMST and nearer to the comprehensive system envisaged by CCMST in 1990.**

It is worth noting, however, that as described earlier, marine R&D is dominated by DERA and NERC – with the two organisations accounting for 84% of government expenditure in this area. As there is already some cooperation between these two bodies, the desire for greater coordination elsewhere in the public sector could be viewed as tinkering at the margins. However, the scope of this interaction is narrower than the interests of each organisation and so it still raises questions of how MS&T can be effectively coordinated.

It is also important to recognise that government expenditure is only 47% of UK marine R&D. Therefore, more effective coordination might be achieved if the commercial and higher education sectors were brought within the cope of a coordinating body – much as CCMST proposed in 1990. Similarly, greater industrial involvement in the EC Framework Programmes would be of help.

Research Support and Policy

MS&T research is funded mainly by DERA (£168M in 1994/95) and NERC (total marine spend around £50M, but science budget expenditure around £20M). EPSRC also sponsors research to the tune of around £6M per year. DERA is responsible for developing and evaluating marine-based defence technologies, while in the civil sector, NERC's marine research is aimed mainly at increasing understanding in the natural processes in the seas and oceans. EPSRC's research focuses more on understanding the engineering principles necessary for the practical application of marine sciences; dealing mainly with the technological aspects of activities in the sea. The following analysis concentrates on civil R&D expenditure, although some reference is made to the situation in the defence sector.

As Figure 3 shows, funding for marine sciences within NERC has decreased in recent years after a period of growth. This decrease is set to continue as the marine share of 'directed funding' (i.e. the core and thematic programmes) is due to be kept constant in cash terms until 2003/04 (i.e. a real terms decrease). It is useful to note, however, that such funding for marine science is not the only potential source of revenue for marine sciences within NERC. Other funding routes are available, such as through the 'non-thematic' mode, whereby researchers submit proposals for research that are not necessarily tied into any of NERC's thematic priorities or core programmes. Similarly, as part of the rebalancing exercise, the NERC Council has set aside monies for which any of the Science Boards may bid for cross-board or even cross-Research Council projects. Finally, researchers are also able to gain funding from other Research Councils, other government schemes (such as LINK and the Teaching Company Associate (TCA) scheme), and commissioned research – i.e. fulfilling commercial contracts with government departments or industry.

However, faced with a shrinking pot for core marine sciences, if the current marine science capability is to be maintained or improved, many (including NERC) have acknowledged that researchers will have to seek funds from these alternative sources[8]. This raises questions about the increasing commercialisation of research. In particular, over the rights and wrongs of such an approach, but also over the practicalities, such as ensuring that academics have the necessary business acumen (or at least access to it). Also, this issue highlights the conflict between where a researcher's priorities should lie between undertaking research or fulfilling commercial contracts.

In its Strategy for Science, NERC gave priority to strengthening its funding for basic science across all areas. However, only in marine science has funding for strategic and applied sciences declined in real terms. While increased emphasis on basic research may help to boost the underlying academic value of the science, many observers have expressed concern that these trends might lead to the loss of an overall strategy for marine research that is targeted at the nation's needs. Others argue that basic research has its own value to the economy by:

- Stimulating the underpinning research necessary to tackle problems that may emerge, to ensure sustainable management of the seas and oceans.
- Providing suitably trained scientists, engineers and technicians that can play their parts in the economy.
- Establishing and maintaining networks of academics to aid in the transfer of knowledge.
- Developing new tools and equipment that may themselves have spin-off value.
- Creating new knowledge that is of general cultural

[8] **However, as Figure 3 shows, the amount of money available from commissioned research is also shrinking.**

value, such as increasing understanding and appreciation of the environment.

Again, with reference to the House of Lords 1985 inquiry and CCMST's report in 1990, many have expressed concern that the level and direction of research funding and support for MS&T is returning to the earlier situation. In particular the Lords' report had recommended that "*support for marine science and technology from the Science Vote should be increased substantially and be paralleled by an increase in funding of commissioned research. Without this investment the UK will not be able to compete at the international front rank*".

Similarly, CCMST concluded that much of the research necessary to achieve the objectives of a national strategy for MS&T either is, or should be funded by Government, and implemented by government departments, Research Councils or Higher Education Institutions. CCMST was not asked to provide a costed plan, but it did estimate that to meet the objectives there would be an increased cost over and above current provisions of £20-30 million (in £1990 terms) excluding the costs of satellite remote-sensing projects, supercomputers and the replacement of research ships. CCMST regarded this "*as a small premium relative to the risk involved in making major policy changes on the basis of inadequate scientific knowledge and understanding*".

Figure 3 showed that, in real terms, NERC's science budget allocation for marine science increased from around £10m in 1985/86 to £30m in 1995/6. Clearly, this sum represents a significant part of the increase recommended by CCMST in 1990.

However, the recent and projected downturns in funding (with consequent pressure to take on more commissioned research if it is available – see footnote 6), and the shift towards funding basic research instead of the core programmes, raise questions over whether this momentum will be lost, and **what could be done to maintain a strategic direction in research**.

Balancing Research Priorities

A related issue is the extent to which public funds should be directed towards applied research and the development of commercial products. The 1993 Science and Technology White Paper created a new backdrop for government-funded science, engineering and technology that firmly committed government to targeting public money at supporting basic and strategic research. The Government expressed the view that near-market 'applied' research should be funded largely by industry, although it would provide some support through collaborative ventures such as the LINK programme.

Nevertheless, many observers have raised concerns that such schemes aimed at bridging the gap between basic and applied research are not sufficient In particular, industry has shied away from LINK projects, because, firstly it does not see why it should fund research for the public good, and secondly because of inappropriate complexity. While this is seen as a particular problem in MS&T, the concern is also generalised across many other areas of science, engineering and technology.

Moreover, the Government launched the Foresight Initiative to help academics and business realign their research priorities aimed at improving the competitiveness of UK industry and thus contributing to wealth creation and the quality of life. For MS&T specifically, the Foresight programme came somewhat late. This arose because of the difficulty in convincing the then Government that the marine sector was worthy of its own panel, since many of the other panels also had legitimate marine interests – again reflecting the historical entrenchment and internalisation of marine issues within public bodies.

Those involved in Marine Foresight have expressed concerns that insufficient government funding is available to allow the Foresight process to move very much beyond being a 'talking-shop'. Thus, under the Marine Foresight Panel, the various Task Forces involved have identified numerous areas where substantial effort is needed to implement their recommendations. However, they suggest that the support offered by OST in both cash and kind is not sufficient, and hence undue responsibility is being placed on industry's shoulders, despite the potential value to the UK's economy of investment in the priority areas identified.

There are considerable R&D funds available through the European Union's Framework Programmes. Box 6 outlined the marine components of the latest (5th) Framework Programme (FP5) where 160M Ecus are available. Nevertheless, the UK Marine Technology Focal Point for FP5 (set up by DTI) is concerned that UK industry is not sufficiently motivated to apply for these funds. Here, it is pointed out that under FP4, the budgets for MS&T programmes (particularly *Wealth from the Oceans* and *MAST*) were underspent.

Some from industry lay much of the blame for this at the door of red tape and complex application procedures. Industry is also reluctant (in some quarters) to invest money in research it perceives to be only for the public good, and with no direct benefits available to commercial organisations. However, it is also acknowledged that these funds require some input (35-50%) from businesses themselves, and many are reluctant (or unable) to commit such funds.

Market Support

- **Potential For Growth**

As the earlier discussion indicated, there are some doubts over the accuracy of the estimate that the marine sector is really 'worth' £28B. Similarly, it is unclear which activities are specific to the marine environment, and hence underpinned by MS&T, and so are sensitive to expenditure on R&D. One option might be for IACMST or the Foresight Marine Panel **to re-examine the economic analysis, and to identify components most sensitive to R&D spend**. This would enable a clearer view to be gained of the role that MS&T plays in the marine sector. Once this is known, more informed decisions could be made regarding the direction, coordination and funding of MS&T in the further development of the marine sector.

Box 5 highlighted a number of potential areas for developing thriving markets based soundly on MS&T. These included energy from the sea, marine information systems, marine-based leisure and aquaculture. For instance, in the field of marine information systems, the Marine Panel suggested in its 1997 report that the development of operational oceanography (i.e. an ocean forecasting service akin to weather forecasting) is expected to lead to the creation of 5000 jobs, and an environmental forecasting business with an annual turnover of some £400M. In the UK, the Meteorological Office and a number of private companies are already active in developing the infrastructure for and applications of operational oceanography (in what has been a 'Wet Office'). Similarly, for energies from the sea, improvements in oil and gas recovery, developments in offshore technologies for more hostile waters, and renewable energies are identified as priority growth areas for early in the next century.

However, the Marine Panel and its Task Forces believe that to realise the potential in these areas considerable public and private investment is needed in a broad range of strategic and applied research areas. This includes public funding of large-scale demonstrators for offshore renewable energy. In this particular context, EPSRC has recently started a new programme on renewable energy technologies (which will include offshore sources). Similarly, DTI has recently announced an increase in its funding for wave energy research. To date, however, NERC has yet to respond with a complementary initiative that would provide the science base to underpin the engineering and technology developments required.

The Task Forces have set out 'roadmaps' for the development of the necessary technologies over the coming decades, but these have not yet been costed, although they are seeking to do this.

- **Marine Foresight – A Future?**

A further issue arises over **the future of the Marine Panel** under the new Foresight 2000 initiative launched in April 1999. Here, the Marine Panel has been excluded from the list of sector panels, but efforts are being made to allow the Panel to continue. OST has said that a decision will be taken in September 1999 on how Marine Foresight might best be taken forward. Essentially, the options are to:

- Wind up the Panel.
- Continue the Panel as part of the mainstream Foresight process.
- Continue the Panel as an Associate Panel, working alongside the national programme.

The Marine Panel and OST report that a number of organisations have recently offered (or agreed to consider the possibility of providing) support for an on-going Marine Panel. This would provide a channel of communication between the national Foresight programme and the marine sector – something that OST has said it would welcome. Thus, whatever the actual decision, OST is keen to ensure that the work of the Marine Panel to date is fully integrated into the other sector panels.

The Chairman of the Marine Foresight Panel has commented that the most important factor in ensuring that the recommendations of the Marine Panel are carried forward is the **need to gain and demonstrate the active commitment and participation from industry itself**. The establishment of the Marine Foresight Panel has catalysed a greater focusing and involvement of the diverse marine industries than would have otherwise occurred. However, at the moment, the Chairman reports that it is proving difficult to gain widespread commitment and leadership from across a highly fragmented industry. Nevertheless, he reports that some progress is being made – for example in developing the concept for an all-electric ship.

- **Government Support for the Marine Industries**

Finally, there is some concern within the marine sector that despite the level and direction of research funding and support, there is little or no support for the marine industries from within DTI. **Box 7** sets out the marine responsibilities within DTI. This shows that there is some support for specific aspects of the marine sector industry.

The above discussion has shown the term 'marine industries' covers a very wide range of businesses and processes. Overall, however, while many of the aspects of the marine sector are covered to some extent by existing DTI units, there is no single focus for the sponsorship and promotion of the marine industries as a whole. Questions arise therefore, over **whether DTI should provide a clearer focus for the promotion of the UK science-based marine industries**. One option towards addressing this might be for DTI to review its marine-related trade promotion interests with a view to consolidating and expanding the work in this area of the separate units identified in Box 6.

OST's view is that many of these have more in common with respective 'land' industries than with each other, and so little would be gained from amalgamating the existing units under a single marine industries directorate. Nevertheless, OST reports that the relevant directorates within DTI are likely, over the summer, to consider the idea of bringing the marine industries into a clearer focus.

One outcome from such a review could be to set up a single directorate for the promotion of the marine industries, but alternative options might have more direct benefits. For instance, promoting:

- Cross-fertilisation between the civil and defence ship and boat-building industries.
- UK capabilities in offshore renewable energy.
- UK marine science-based services – such as marine surveys, marine environmental consultancy, ocean forecasting services and marine information systems.
- Improving the links between the Marine Foresight Panel and IACMST (e.g. duplicate membership by the respective Chairs or Secretaries).

BOX 7 MS&T SUPPORT WITHIN DTI

The DTI aims to help business to compete successfully at home, in the rest of Europe and throughout the world. It includes industrial sponsorship, export promotion through British Trade International, science and technology and support for small firms.

Apart from the funding of MS&T via the Office of Science and Technology and the regulation of offshore hydrocarbons by the Oil and Gas (OG) Directorate, commercial marine interests within DTI are represented within four units:

- **Infrastructure and Energy Projects Directorate (IEP),** is part of British Trade International, and was formed by the merger of the Oil, Gas and Petrochemicals Supplies Office (OSO) and the Projects Exports Promotion (PEP) Directorate. IEP is responsible for ensuring the UK onshore and offshore supplies industry competes effectively at home and overseas. It maintains close contact with oil and gas companies on UK Continental Shelf (UKCS) developments and seeks to enhance or sustain UK industrial capability.
- **BREEZE (British Exclusive Economic Zone Exports)** - The BREEZE Team is part of IEP, and helps British companies sell expertise and equipment to overseas governments to help develop, manage and administer their offshore waters.
- **Engineering Industry Directorate (EID),** formerly known as the Engineering, Automotive and Metals Directorate (EAM). The EID is responsible for the commercial shipbuilding, boatbuilding and marine equipment industries. EID administers formal support schemes for shipbuilding (the Shipbuilding Intervention Fund, the Home Shipbuilding Credit Guarantee Scheme and the Shipbuilding and Ship Repair Innovation and Technology Support initiative), and boatbuilding (the Boatbuilding Innovation and Technology Support Initiative). It also promotes the competitiveness of its industries by encouraging greater industry awareness of competitiveness factors and the need to address them. It also advises on EU funding for marine-related projects.
- **British National Space Centre (BNSC) -**BNSC is responsible for the co-ordination of UK civil space activities and management of space R&D programmes.

IN CONCLUSION

The 1998 International Year of the Oceans was the culmination of 40 years of growing interest in the marine environment. The UK pioneered MS&T, and has built a very high international reputation in this area. The 'marine' sector is a broad term for a range of activities taking place in the sea. From scientific research to the construction and operation of offshore structures and vessels. The economic value of this sector has been estimated to be around 5% of the UK's GDP, and a large potential has been identified for growth in a wide range of marine products and services. Much of this growth, however, will need to be underpinned by marine science and technology (MS&T). To maintain the UK's capability in MS&T and to help realise the potential economic gains from the sector, there appears to be a need for greater cohesion and coordination of MS&T within industry, academia and government.

APPENDIX 1
THE FUNDAMENTALS OF MARINE SCIENCE AND TECHNOLOGY

The seas and oceans cover around 70% of the earth's surface, and contain over 95% of the world's water. This led Arthur C. Clark to remark in 1990

> *"How inappropriate to call this planet Earth when it is clearly Ocean"*

While our proximity to the coast makes us most familiar with shallow inshore waters, it is another interesting statistic that over 75% of the sea is more than 1000m deep. Much of the deep ocean is inaccessible and unexplored, and better maps exist of the Moon than of most of the seafloor.

Nevertheless, **marine science** aims to understand more about the workings of the seas and oceans including the seabed and subsurface. **Marine technology** addresses how vessels, structures and equipment can be developed to operate in the marine environment.

Marine Sciences

Since the earliest days of marine science (see **Box A1**), the traditional boundaries between disciplines have become more blurred, and have led to the concept of an **Earth system science**. This is helped by advances in computer modelling that can now better represent the interactions between the many different factors operating throughout the oceans and seas. This enables marine science to move from a descriptive exercise into a predictive activity that will aid the sustainable use of the marine environment.

Key elements in marine science include:

- **The composition of sea water**. This is fundamental to understanding both the source of ocean currents and the distribution of life in the ocean. Much of this hinges on understanding how the salinity (saltiness) of the sea varies around the world. Salinity varies from a value of 0 in freshwater (there are no units[9]) to over 40 in the Persian Gulf, with most oceanic water having a salinity of around 30.

- **The movement of water.** Salinity affects the density of seawater, and this influences how it moves both vertically and horizontally. For example, as ice forms in polar regions, the remaining sea water becomes more dense, and so it sinks to the bottom. As it does this it sets in motion the entire system of deep ocean (thermohaline) currents that are fundamental to the climate system. Also the origins, dynamics and interactions of waves and tides is important, as is the effect that the shape and depth of the sea bed (bathymetry) has on controlling water movements.

- **Sea-floor processes** are also a key element in marine sciences, and covers aspects such as the structure and origin of the sea floor, processes shaping the sea floor (such as the formation of new oceanic crust in hydrothermal vents along mid-ocean ridges); the record of past global environmental changes 'frozen' in marine sediments; and the nature and distribution of natural resources, geohazards and pollution.

- **Marine biological systems**. As well as the physical and chemical processes occurring in the marine environment, the sea is home to a very diverse and abundant range of organisms, including bacteria, viruses, plants and animals. Marine biology aims to identify, classify, describe and understand the ecology of these organisms, and to examine how they affect and are affected by chemical and physical processes. Examples include the unusual biology of organisms that live close to the hydrothermal vents; the growth of coral reefs, and their effect on waves, currents and tides; and marine-dwelling algae that emit gases as part of their metabolism that can affect the climate. Also, it is necessary to understand the biology and ecology of marine species, many of which are of commercial importance, e.g. fish and shellfish. Thus, much effort is put into monitoring and predicting fish stocks to conserve commercial fisheries.

BOX A1 THE VOYAGE OF HMS CHALLENGER

In 1870 Wyville Thomson, Professor of Natural History at Edinburgh University persuaded the Royal Society of London to ask the British Government to furnish a ship for a prolonged voyage of exploration across the oceans of the globe.

On 7 December 1872, the expedition put to sea from Sheerness aboard the corvette *HMS Challenger* with a crew of 200, 20 naval officers and six scientists (including an artist). Between 1872 and 1876, the 200-foot, 2300 ton, three-masted square-rigger surveyed 68,890 nautical miles across the oceans, making measurements at 362 stations of depth, temperature, current speed and direction. Also, samples of sea water, seabed sediments and animals were collected. A 50-volume report of the voyage was produced, and became the foundation of modern scientific oceanography.

Source: Challenger Society for Marine Science

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9 Salinity is defined as the ratio of the conductivity of a sample of seawater relative to that of a known standard.

Marine Technology

Marine Technology encompasses a very broad range of topics, and so its definition is difficult. However, one scheme for considering this spectrum is to consider marine technology related to its end-user. Here, for instance, technologies can be developed to support marine sciences, and examples include the development of sampling equipment such as grabs and corers, and measuring equipment such as salinometers (to measure salinity), and fluorimeters (which can measure how turbid the water is).

The other side of the coin is technology used to support engineering applications, such as the placement and operation of offshore oil rigs, coastal defence works, pipelines and cables; and the construction and operation of ships, boats and other vessels (**Box A2**). By way of illustrating the diversity of the field of marine technology, academic courses that would come under this umbrella term include:

- Coastal engineering
- Maritime engineering
- Marine systems technology
- Marine sports technology
- Subsea engineering
- Offshore engineering
- Underwater engineering
- Marine engineering
- Maritime technology
- Naval architecture
- Ocean engineering
- Small craft engineering
- Petroleum engineering
- Ship science

Essentially, then, marine technology is aimed at engineering, and as such is a subject founded on physical sciences. Here, four underpinning themes are apparent:

- **Mathematics** is the 'language' of engineering. It is necessary to be able to represent the real world as mathematical equations that provide a basis for analysing and predicting the behaviour of vessels and structures in the dynamic marine environment. An example is the application of non-linear mathematics, founded in theories of chaos, to understanding and predicting the behaviour of a vessel moored to a quayside in choppy waters.

- **Fluid Mechanics** (as applied in the marine environment) is the study of the behaviour of sea water. It is necessary to understand how sea-water interacts with vessels and structures placed in the sea. As well as the above example of the moored vessel, other examples include how vessels generate bow waves and wakes, and what effect these have on the vessel's movement. Other examples include the movement of water around an oil rig.

BOX A2 EXAMPLES OF MARINE TECHNOLOGY

Structural Adhesive Bonding
Adhesive bonding offers the opportunity to replace welding of steel structures, to reduce distortion, effectively eliminate residual stress, and to improve fatigue performance when compared to welded connections. Avoidance of hot-work leads to safer construction in hazardous environments.

Biofouling Resistant Surfaces
Underwater instrumentation suffers biofouling and loss of performance when immersed in the sea for extended periods. This results in poor data quality or a need for frequent maintenance. For good data quality, biofouling resistance should prevent the formation of the layers of bacteria, algae and their secretions.

Smart Materials for Subsea Buoyancy Control
The aim is to be able to produce a material whose density and stiffness may be altered so that its buoyancy can be varied. This will have applications in the offshore oil and gas industry as well as in oceanographic surveying.

Defect Assessment in Offshore Structures
A methodology has been developed to enable defects in steel offshore structures and associated systems to be identified and assessed. Topics addressed included (among others) toughness and the growth of short cracks; failure of tubular connections; fatigue damage and static strength of damaged stiffened shells; repair procedures; and inspection strategies.

Small Waterplane Area Twin Hull (SWATH) Research
SWATH ships are essentially catamarans that have a 'waist' in the profile of the hulls near the waterline. This creates a bulbous hull below the waterline, so making the ships less responsive to waves. As such, they are capable of operating in rougher sea conditions than conventional vessels, and, for example in a ferry, this improves comfort for passengers and crew.

Fast Ships
There is growing realisation of the economic advantages to be gained from high-speed ships, for both passenger ferries over relatively short distances and freight transport over longer distances. While there is market demand for larger and faster vessels, the early generations of fast ferries have had a number of problems: poor reliability, high running costs, and poor performance in bad weather.

Source: Glasgow Marine Technology Centre

- **Structural Analysis** is the study of the behaviour of a structure subject to a range of forces. Examples here include the need to know how the energy in a wave is dissipated when that wave strikes an object in the sea, such as a breakwater, oil rig, or vessel. Essentially, structural analysis is necessary to ensure that structures and vessels will survive the rigours of the sea.

- **Design** is the defining core of engineering. It is what allows the physical scientific principles in the above themes to be translated into practical solutions to real-world problems.

APPENDIX 2
A RECENT HISTORY OF UK MS&T

Because of its long history and diverse nature, the marine sector has become 'entrenched' within the responsibilities of a large number of government departments, research establishments and local authorities. However, following an analysis by the Science Minister in the early 1960s, NERC was established in 1965 to take on a general responsibility for the "*preservation, improvement and proper utilisation of minerals, water, land use or such biological resources such as fisheries*." NERC's original terms of reference specifically included the role of supporting a wide range of the environmental sciences, including many covering the marine environment, such as marine biology, oceanography, geology, nature conservation, fisheries and meteorology. While NERC took on the general responsibility for maintaining the excellence and relevance of the environmental science base, many other bodies maintained involvement in MS&T. For instance, the (then) Nature Conservancy Council was responsible for protecting sites of ecological importance; the (then) Science and Engineering Research Council helped to develop marine technology and engineering; and government departments (e.g. the Ministry of Defence, the Ministry of Agriculture, Fisheries and Food and the Department of the Environment) maintained an interest in MS&T in pursuit of their policy aims.

Chronology since 1985

1985 House of Lords Science and Technology Committee published its report, and found that:

- Research was fragmented between government, research councils, universities, and the military.
- Apart from military work, civil MS&T was under-funded in comparison with Japan, France and the USA.
- The work carried out across many organisations was diffuse and poorly co-ordinated, with responsibilities often confused.
- There was no coherent means of identifying medium and long-term research priorities.
- NERC, the main civil provider of MS&T research, was overly centralised in its decision-making.

The Committee concluded that "*the prospects are not encouraging*." It found that the "*level of capability in marine science and technology in the UK is being run down almost across the board…in direct contrast to many of our international competitors*." Thus, it recommended setting up some form of co-ordinating body to bring the undoubtedly valuable research together and to promote wider appreciation of the value of MS&T.

1986 NERC established a Director of Science for Marine and Atmospheric Sciences to develop for the first time, a coherent strategy for research in its own laboratories and in the universities.

1988 Responding to the Lords' report, the Government set up the Co-ordinating Committee on Marine Science and Technology (CCMST). A joint venture was agreed between NERC and Southampton University to form the Southampton Oceanography Centre (SOC).

1990 CCMST published its report on MS&T in the UK, setting out its vision of a national strategic framework.

1991 CCMST was wound up and the Inter-Agency Committee on Marine Science and Technology (IACMST) was set up. Its objectives are to ensure arrangements for efficient information exchange between all of the relevant publicly-funded agencies in MS&T, and to maintain an overview of national and international activities. It has a limited role to coordinate UK MS&T where no other mechanism exists.

1993 The Government published its Competitiveness White Paper, setting out new missions for the research councils. Construction of SOC commenced.

1994 NERC reorganised: the Directors of Science were replaced by Directors of Centres - i.e. the Centre for Coastal and Marine Sciences (CCMS) and Southampton Oceanography Centre (SOC). This left no marine expertise at NERC headquarters.

1995 IACMST was reviewed and its continuation ensured subject to review at the end of 1997. An international conference was held on sustainability of the oceans under Agenda 21. The Marine Foresight Panel was established. SOC commenced work. The Environment Agency was established.

1996 IACMST published its analysis of the value of MS&T to the UK economy.

1997 Marine Foresight Panel published its first report.

1998 International Year of the Oceans (IYO). IACMST coordinated the UK's contribution to IYO, and was reviewed and its continuation agreed, subject to review in 2001. The Marine Foresight Task Forces published reports on leisure and fisheries. The Government published "*British Shipping – Charting a New Course*" and "*Cleaner Seas*". NERC published "*Looking Forward*" its strategy for marine science and technology.

1999 Foresight 2000 commenced – with no specific Marine Panel envisaged. Marine Foresight Task Forces published reports on *Energies from the Sea* and *Marine Environmental Information.*

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