OCEAN Challenge

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SCOPE AND AIMS

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

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OCEAN Challenge

The Magazine of the Challenger Society for Marine Science

SOME INFORMATION ABOUT THE CHALLENGER SOCIETY

The Society's objectives are:

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

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

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

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

Holding regular scientific meetings covering all aspects of Marine Science.

Supporting specialist groups to provide a forum for discussion.

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

Membership provides the following benefits:

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

A monthly newsletter (*Challenger Wave*) which carries topical marine science news, and information about jobs, conferences, meetings, courses and seminars.

The Challenger Society Website is
www.challenger-society.org.uk

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The subscription for 2005 costs £40 (£20.00 for students in the UK only). If you would like to join the Society or obtain further information, contact the Executive Secretary, Challenger Society for Marine Science, Room 251/20, Southampton Oceanography Centre, Waterfront Campus, Empress Dock, Southampton SO14 3ZH, UK;
Fax: +44(0)23-8059-6149; Email: jxj@noc.soton.ac.uk

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ADVICE TO AUTHORS

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

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The cover was designed by Ann Aldred Associates.

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King penguin: By courtesy of Ziggy Pozzi-Walker

News & Views

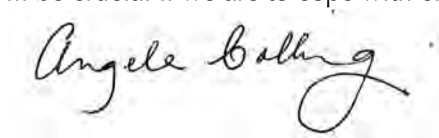
Message from the Editor

Fortuitously, two themes have emerged in the contributions to this issue – first, the management and conservation of the seas around the British Isles against a background of changing climate, and secondly, oceanography in high northern latitudes. Although climate and the environment (marine and terrestrial) were rarely mentioned in the recent election campaign, they may soon begin to become difficult to ignore in public and political life. A recent government report, *Charting Progress: an Integrated Assessment of the State of UK Seas*, discussed on pp.5–7, is a positive step towards a much needed Marine Bill.

Gwyn Griffiths' article 'Measuring ocean temperature: what can we learn from Nansen's exprience on the *Fram* a century ago?' has its origin in Gwyn's talk at the Centenary Meeting on the *Wellington* in 2003. It explains why Nansen's painstaking approach to measurement means that his work in Arctic waters still makes a valuable contribution in the endeavour to understand long-term climate change.

In 'Rapid shifts in Arctic marine climate: observations and archives in a Spitsbergen fjord', Finlo Cottier and colleagues descibe how the local marine climate can change abruptly, in this case from Arctic in character (cold and relatively fresh) to Atlantic (warm and more saline). The resulting change in ecology – a 'local regime shift' – means that biogenic sediments in the fjord may shed light on past, and perhaps future, climatic fluctutations.

We also have a lively report of the first meeting of the Challenger Society Special Interest Group on Biophysical Interactions, written by Daniel Mayor. As other items in this issue highlight, an understanding of biophysical interactions in the ocean will be crucial if we are to cope with climate change and begin to restore fish stocks to earlier levels.



Results from BeachWatch 2004 (or the Curse of the Cotton Bud)

BeachWatch is an annual UK-wide beach litter survey and clean-up, organized by the Marine Conservation Society (MCS). In September 2004, in the largest such event since it began in 1993, over 3000 volunteers worked on 269 beaches – a total length of 145 km – and collected 2469 bags of rubbish (275 594 items), weighing 11 671 kg. When the rubbish was sorted, it was found that about 39% had been left by beach visitors, 14% was related to fishing, about 9% was sewage-related, about 2% resulted from shipping, 1% was fly-tipped and 1% medical. For the remaining 35%, a source could not be attributed. If the data from one beach are removed, the percentage of sewage-related debris falls to 5–6%. The reason: this beach had over 10 000 cotton-bud sticks!

Here are the most commonly recorded items of litter (along with the average number of the item *per kilometre*):

1. Pieces of plastic (1–50 cm) (214)
2. Rope/cord/net (179)
3. Cotton-bud sticks (154)
4. Plastic caps/lids (126)
5. Pieces of polystyrene (125)
6. Small pieces of plastic (<1 cm) (119)
7. Crisp/sweet/lolly wrappers (116)
8. Plastic drinks bottles (88)
9. Cigarette stubs (57)
10. Pieces of glass (53)

Channel Island beaches had the least litter. On average, Welsh beaches had more litter than beaches in Scotland and England. Scottish beaches surveyed had the highest density of sewage-related debris. For beaches surveyed in England, those in the north-east had the least litter, and those in the north-west had more sewage-related and shipping-related debris than any other area. Not surprisingly, beaches in the south-west had the highest level of litter from visitors, and the highest density of fishing-related debris.

Comparison with data for 2002 and 2003 does not reveal any consistent trend, with some regions improving and some getting worse.

The BeachWatch 2004 report is available from the Marine Conservation Society (£3.50 including p&p), and the summary report can be found on the MCS website: www.mcsuk.org

Turtle Conservation Action Plan focusses on leatherbacks

Five of the seven species of turtle have been found in waters around the British Isles. Of these, the leatherback is the only regular visitor, and its conservation in UK waters has been prioritised by a Turtle Action Plan (www.ukbap.org.uk).*

Whereas hawksbills, Kemp's ridleys, loggerheads and green turtles probably arrive off Britain as a result of being blown off course, leatherbacks visit UK waters each year to feed. They are largely pelagic and feed almost exclusively on jellyfish. Unfortunately, they cannot distinguish between jellyfish and plastic bags, or balloons, and starve to death when their guts become blocked with such litter. Like other turtles, leatherbacks are also threatened by habitat destruction, hunting and egg-harvesting on their tropical nesting beaches, and may drown as a result of becoming entangled in fishing gear.

Leatherbacks can grow to great size: a male washed up in North Wales in 1988 weighed 916 kg and was 2.91 m long.

See www.euroturtle.org/turtlecode.

*UK Grouped Species Action Plan for Marine Turtles in UK Waters and the UK Overseas Territories.

Why climate change does not suit cod and salmon

Even in the absence of overfishing, cod populations in waters around the British Isles would be struggling. In fact, it is thought that even with a complete ban on cod fishing, cod stocks would be unlikely to recover in the near future.

It is not simply that cod are cold-water fish and are at the southerly limit of their distribution in British waters. Since about 1987, northward movement of warm-water plankton, and a northward retreat of cold-water plankton, have meant that young cod are finding it hard to survive. Newly hatched larval cod feed mainly on copepods, and a change in the species composition has meant that the mean size of copepods is greatly reduced (it has halved since the beginning of the the 1980s). Furthermore, the main peak in the abundance of copepods now occurs later in the year, by which time the cod larvae are too big to take advantage of them. (By contrast, between 1968 and 1983, the copepod peak exactly matched the needs of the young cod, and cod stocks reached extremely high levels.)

Cod larvae also suffer because euphausid populations have declined. Euphausids are high in energy and are an important source of vitamin A, which cod cannot synthesize.

The changes in temperature and plankton communities have also affected salmon, which are increasingly failing to return to their home waters, particularly at the southern limit of their distribution in Spain, Portugal and, perhaps, the UK.

Meanwhile, a number of warm-water fish and crustaceans are extending their range northwards. These include the portunid crab, bass, horse mackerel, red mullet, pilchard, sunfish and sardine. For some of these species, new fisheries have started in the North Sea.

These findings are described in the goverment report *Charting Progress** (see pp.5–7). As the report makes clear, the marked reorganisation of the ecosystem referred to above was associated not only with a sharp rise in Northern Hemisphere temperature and sea-surface temperature between 1986 and 1988, but also with a highly positive North Atlantic Oscillation Index.†

*For more information, see the reference lists in the report itself.

† A positive NAO Index means strong westerlies blowing across the Atlantic, the Gulf Stream and North Atlantic Current being stronger than usual, with their paths generally further north, all resulting in a warmer, wetter climate for north-western Europe.

SOC is the National Oceanography Centre

On 1 May 2005, Southampton Oceanography Centre became the National Oceanography Centre. It is an integrated Joint Centre owned by the Natural Environment Research Council (NERC) and the University of Southampton.

Website: www.noc.soton.ac.uk Tel: +44-(0)23-8059-6666 Fax: +44-(0)23-8059-6032

Oceana uses US courts in the cause of conservation

Oceana is a marine conservation group with teams of committed experts (scientists, lawyers, economists etc.) in North America, Europe (Madrid and Brussels) and South America. In the US, Oceana has been successfully fighting legal cases – against the Government!

For example, in December 2001 Oceana achieved a significant victory in a major lawsuit to protect New England 'groundfish' (benthic species). The US District Court for Columbia found that the Government violated the law when it failed to: (1) implement the strict requirements of Amendment 9 of the 1999 Sustainable Fisheries Act, intended to prevent overfishing; (2) minimize by-catch (fish and marine mammals caught by accident along with the target fish, and discarded dead or dying); (3) collect adequate records of by-catch, without which the fishery cannot be properly managed. The judge ordered the government to explain how it proposed to tackle the problem, and urged the parties to try to agree a remedy through mediation. Similar cases relating to groundfish in the Pacific were fought successfully in 2001 and 2002.

Oceana's ocean-going catamaran, *Oceana Ranger* is one of the largest catamarans in the world. It is equipped with solar panels, a desalination plant, and tanks for storing sewage until it can be treated in port. *Oceana Ranger* is currently completing an expedition which began in Los Angeles, and involves visiting islands off Mexico, Costa Rica and Panama, passing through the Panama Canal, visiting the Caribbean and Florida, followed by the Bahamas, Bermuda, the Azores, Gibraltar, and finally the Balearic Islands in the Mediterranean. *En route*, researchers, photographers and video cameramen are investigating and documenting seamounts, as well as studying damaging impacts to marine ecosystems, including bottom trawling and mooring of large cruise ships, and illegal catches of dolphins and sea turtles. The expedition is led by Xavier Pastor, the Director of Oceana in Europe.

For more about Oceana and the expedition on the *Oceana Ranger* see www.oceana.org.

CFP strikes again

In January, an edict from Brussels seemed to support requests by Padstow-based and other Cornish fishermen to close an area off the coast of north Cornwall to all but the smallest boats. What actually happened appears to threaten both the lives and livehihoods of Cornish fishermen, in two ways.

Not only has the ban been extended to smaller vessels, less than 10 m long, but the EU has allegedly bowed to pressure from Belgium and will allow large beam trawlers into the area during the period of the ban. This has happened in spite of protests and representations from the fishing industry, MPs and conservationists, who point out that larger trawlers are potentially more damaging to fish stocks and the sea-bed. If the smaller boats want to keep on working they must go further from port and fish in unfamiliar waters, which can be dangerous in winter months.

The Fisheries Minister, Ben Bradshaw, visited the region to discuss the matter with Cornish fishing communities, and a judicial review of the ruling is to be sought.

See p.8 for a report on a radical fisheries management project in the South-West.

2004 a bad year for seabirds

UK Seabirds in 2004, a report compiled by the Joint Nature Conservation Committee, has revealed that last year was the worst breeding season on record for some of our most common species of seabirds, including the black-legged kittiwake, the northern fulmar and the common guillemot. About 45% of all seabirds in the EU nest around Scotland, but experts in Orkney and Shetland are warning that, in a repeat of 2004, thousands of seabirds may fail to raise any young.

Low pollution ranking for UK

According to a new Environmental Sustainability Index devised and compiled by researchers at Yale and Columbia Universities using indicators that cover pollution levels, policy and vulnerability to environmental damage, Britain is placed in 66th place out of 146 countries, below even the US, ranked 46th.

Mickiewicz University in Poland) has developed a computer model which suggests that these extinctions could be caused by the periodic evolution of a 'super predator', which eventually brings about its own demise by decimating its prey.

How to Locate Data from UK Research Cruises

The OceanNET website (www.oceannet.org) contains a searchable database of information about measurements carried out by UK marine scientists worldwide from 1960 to the present, on over 6200 cruises. Details of foreign research cruises undertaken in UK waters are also available. Click onto 'Data catalogues' and then onto 'UK Cruise information'.

UK Cruise Information is an inventory of datasets assembled using the IOC Cruise Summary Report forms submitted to the British Oceanographic Data Centre (BODC) after UK research cruises. You can obtain information about data that might be of interest to you by specifiying a ship's name, and/or dates and/or ocean/sea area, and/or discipline and type of data (e.g. physical oceanography; CTD stations). The data themselves are not available from Research Cruise Information. To access these you would have to use one of the BODC data inventories, and make your request using a web form.

The CTD Profile Index provides details of individual CTD profiles held by BODC. Current Meter Inventories provide information about individual current meter records known to BODC (two databases are maintained, one for UK data and the other relating to additional data from ICES member nations). The Wave Data Index is a map-based interface to the instrumentally measured wave data held by BODC.

Cephalopods even more sneaky than previously thought

Cephalopods are truly masters of disguise. They are well known for using camouflage by changing their skin colour, hiding in a cloud of ink, and even using bioluminescence. Now various cases of behavioural disguise are coming to light. For example, viewers of the recent BBC TV series 'Journey of Life' will have seen reef squid 'hiding' from predators by stiffly holding up their arms so as to resemble coral.

Cuttlefish also indulge in deception. Researchers in Southern Australia closely observed a large mating aggregation of giant cuttlefish, *Sepia apama,* which included small subdominant males mimicking females. These small males conceal their sexually dimorphic fourth arms, position their other arms to mimic those of egg-laying females, and acquire the appropriate mottled appearance. Not only did the male mimics successfully pass the guarding male and approach the female in 30 out of 62 attempts, but the trickery was so effective that large consort males often tried to mate with the mimics.

Sexual mimicry in animals is fairly common, but successful mating by mimics is rare. In this case, however, DNA paternity testing of squid eggs at Royal Holloway showed that the camouflage tactics of the subdominant males could sometimes successfully cuckold the guarding consorts.

These types of data are very hard to obtain, and underwater research has its own problems. Hundreds of hours of diving were necessary to complete the study.

Earliest life an artefact?

Martin Brasier (Oxford University) and others believe that many so-called 'signs of life' in very old rocks are of abiotic origin and not fossils at all. The finding has given rise to some controversy (cf. *Nature*,10 March, p.155), which may not be altogether surprising, and it casts doubt on the validity of Schidlowski's famous diagram (which presents carbon-isotope data for putative organic remains in rocks from Greenland that have been dated at 3.85 billion years). At all events, there is growing doubt that life on Earth appeared as long ago as ~ 3.8 billion years. Even the stromatolites in ancient rocks – often cited as evidence of early life – appear to be of wholly abiotic origin (although modern stromatolites are well-documented accumulations of photosynthesising cyanobacteria).

New cycle in fossil record

What is perhaps most remarkable about a recently discovered 62-million year cycle of ups and downs of marine fossil genera throughout the fossil record, is that it has not been previously identified (*Nature*, 10 March, p.147, p.208). It is not yet clear whether the phenomenon is the result of external forcing or of some sort of 'internal biodiversity cycling'. One possible external cause is the continual variation in the relative areas of continental shelf and deep ocean floor, linked to changes in seafloor spreading through geological time.

The fossil records also show a shorter cycle, with mass extinctions every 26 million years. These have previously been attributed to meteorite bombardments, but Adam Lipowski (Adam

Creationists fight back

The *Guardian* headline read 'Religious right fights science for the heart of America, with the subhead: 'Creationists take their challenge to evolution theory into the classroom'. The creationists intend to put so-called 'intelligent design' at the heart of the debate, and if in the process they can outlaw the teaching of evolution, or at least relegate it to the status of a theory, then so much the better. The movement to discredit teachers of evolution is taking place in the so-called American heartland, centred in the Mid-West.

The teaching of creationism in the US was outlawed in 1987, when the Supreme Court ruled that inclusion of religious material in science classes was unconstitutional. This seems not to have done much to prevent conversion to the creationist cause. One of the most interesting converts must surely be William Harris, a research biochemist, an expert in fish oils and prevention of heart disease at Kansas City's premier teaching hospital. For him, 'the very premise of evolution is intolerable'. By contrast, many Christians who are also scientists find no inherent conflict between an evolutionary understanding of the history of life and belief in a Creator God.

Rescuing Mont St Michel

The historic island off the Normandy coast, which features a 13th century abbey, may become landlocked unless millions of tonnes of sand and silt are cleared from the bay that presently surrounds it. The plan is to spend around £150m on the excavations, and build a footbridge to replace the presently existing causeway that tends to get clogged with parked cars. Could the footbridge detract from the romance of the island?

Lottery money for *Cutty Sark*

The Heritage Lottery Fund will allocate £25m to rescue the *Cutty Sark*, the fastest tea clipper of the 19th century (built 1869), which would otherwise have only a couple of years left as a visitor attraction in Greenwich. The ship's revolutionary design featured an iron frame that is now rusting and expanding and splintering the timbers that surround it.

Managing the marine environment – with the extra twist of climate change

In January, Elliot Morley (now Minister for Climate Change and Environment) gave a keynote lecture setting out the government's 'vision for the environment'. This lecture ended as follows: 'The Government has made a very clear commitment to a Marine Bill, but I cannot be precise about when a Bill might be published ... We want to continue to ensure that the marine ecosystem is managed properly ...'

As part of the groundwork for preparing a Marine Bill, Defra has produced *Charting Progress: an Integrated Assessment of the State of UK Seas,** which is supported by five detailed scientific reports. Taken together, these make up a tremendously valuable body of information, bringing together the results of marine monitoring programmes in a summary of the present state of the seas around the British Isles. Although most, if not all, of the information is already available in the published literature, bringing it all together in these linked publications conveys even more strongly the problems we face if we are to honestly attempt sustainable management, and the extent to which climate change is making the task more difficult.

Charting Progress, plus the five detailed supporting documents, can all be downloaded from the web (www.defra.gov.uk/environment/water/marine/index.htm). The report is almost certainly too large to be read in its entirety by (for example) Members of Parliament – even the most dedicated MP interested in conservation would only have time to read the summary report, and perhaps the relevant part of the final report (the regional assessments). However, these publications contain a wealth of information, which would be useful for anyone wishing to know more about the seas around the UK.

The report also contains maps, graphs and references, and details of contacts, which could be a boon for lecturers/teachers wishing to present up-to-date information. For those who are short of time, the most useful section might be the 'State of Plankton' Chapter in Report 3 (Marine Habitats and Species).

*Prepared jointly by the Dept of Environment, Food and Rural Affairs (Defra), the Scottish Executive, the Welsh Assembly Government and the devolved administration in Northern Ireland, and published by Defra (March, 2005).

Charting Progress: an Integrated Assessment of the State of UK Seas (130pp.)

This is in effect the summary publication. It sets out the rationale for the report, explains how it was compiled, and provides summaries of Parts 2 to 5 (see below). It highlights the need for the use of 'indicators of state' in environmental monitoring. Traditionally, the emphasis has been on 'performance indicators', such as concentrations of contaminants in water, sediments or organisms. Though essential, these do not allow an absolute assessment of the overall health of the sea. Indicators of state, by contrast, provide absolute information. For example, seahorses will only live in clean water, so the presence of seahorses is an indicator of good ecological state. Similarly, a measure of fish diversity (commercially exploited species plus non-target fish) provides information distinct from that provided by assessments of stock sizes of particular fish species.

Supporting reports

1. Marine Environmental Quality (168pp.)

This report was produced by the Marine Environment Monitoring Group (MEMG) which consists of twelve bodies involved in environmental monitoring, including CEFAS, Defra and the national bodies, plus smaller specialist organizations such as SAHFOS. It focusses on the impacts of human activities on the marine environment and its resources, and assesses current statuses and trends.

The first chapter on 'Fish and fisheries' – effectively aquaculture, as commercial fisheries are covered in Report 4 – notes that despite consistent improvements in aquaculture technology, and in the efficiency of use of feed, expansion of aquaculture has meant that the total amount of particulate material and nitrogenous effluent has increased over the last 10–15 years.

Sea-lice remain a major problem in salmon farms, and it is thought that the large numbers of lice larvae in the environment may be one reason for the decline in wild sea trout and salmon stocks off the west coast of Scotland.

Overall, there have been reductions in the fluxes of nutrients to the sea, with a 60% reduction in the input of nitrogen to the northern North Sea since 1990, but only a marginal reduction in the southern North Sea. Since 1990, inputs of nitrogen and phosphorus directly from the land have been reduced nationally by 35% and 50%, respectively. However, riverine inputs (which vary with river flow) do not seem to have been reduced. This means that managing the diffuse inputs of nutrients from run-off is all the more important.

Despite nutrient enrichment, there has not been a 'dangerous' explosion of phytoplankton biomass in coastal waters, perhaps because primary productivity has been limited by light availability. Undesirable disturbance of the balance of organisms (e.g. blooms of toxic algae), and declines in water quality, appear to be limited. However, it is important to disentangle changes caused by nutrient enrichment and changes relating to the North Atlantic Oscillation.

As far as hazardous substances are concerned, the picture is mixed. Total riverine and direct inouts of Hg, Cd, Cu, Pb, Zn and γ-HCH (Lindane) to coastal waters have decreased by 20–70% since 1990, and atmospheric emissions of these substances have been reduced by 50–95% since 1990. However, there are still elevated concentrations of some heavy metals in water, sediments and some organisms in the vicinity of industrialised areas and areas with an industrial history.

In areas with high concentrations of hazardous substances in sediments and biota, some fish populations were found to have higher levels of disease (including liver tumours), increased enzyme activity, and DNA damage. Research on endocrine disruption found some feminisation of flounders, although this seems to be declining in some areas. Implicated in these effects are natural substances such as the human female sex hormone, and synthetic chemicals such as nonylphenols. There are indications that there may be a causal relationship between deaths of marine mammals from infectious diseases and elevated concentrations of PCBs and mercury in their blubber.

Also covered in this report are microbiological monitoring (bathing waters, shellfish waters and shellfish harvesting areas), oil and oil-based contaminants, radioactivity, construction and aggregate extraction, navigational dredging and relocation of dredged material, and litter (largely based on the BeachWatch survey; see p.2). Finally, there is a surprisingly short chapter on the introduction of non-native species.

2. Marine Processes and Climate (138pp.)
This describes the present situation, along with current trends and changes. It covers weather and climate, sea temperature, salinity, sea-level, waves, circulation, sediments, and changes in the coast and sea-bed. It is an expanded and updated version of a report produced by the IACMST in 2001, and has many contributors, both scientific institutions and individual experts. (For an interactive web version, see 'Climate Reports' on www.oceannet.org.)

The message it conveys about the effects of global warming around the UK is not straightforward. Generally speaking, waters around the UK have been warming (a rise of 0.5 °C since the 1870s), and sea-surface salinities have been falling. However, while the number of storms around the UK from October to March has increased significantly over the last 50 years, the degree of storminess at the end of the 20th century was similar to that at the start. Furthermore, while winter wave heights in the north-east Atlantic and the North Sea were rising from the 1960s until the early 1990s, since 1994 the mean significant wave height for January–March in the northern North Sea has decreased.

The report highlights some surprising changes in circulation. For example, two pulses of water into the North Sea in 1988/89 and 1998 coincided with unusually strong northward transport of anomalously warm water through the Rockall Trough. Also covered are sediment transport, turbidity and coastal erosion/accretion.

3. Marine Habitats and Species (172pp.)
The report was drafted by a number of organizations, and coordinated by the Joint Nature Conservation Committee (JNCC). It covers habitats, plankton, marine benthos, cetaceans, seals and breeding seabirds.

The report states that natural atmospheric and hydrographic variability – perhaps forced by global warming – seem to be the major contributor to ecosystem change in the shelf seas of north-west Europe. Since the 1940s, there have been considerable changes in many ecosystems around the UK. In 40 years, there was a northerly movement of warm-water plankton, and a retreat of cold-water plankton, over a distance of 10° of latitude. Some plankton species (including dinoflagellates) now bloom earlier in the season. Then around 1986–88 there was a pronounced 'regime shift' – a rapid re-organization of the ecosystem – associated with a sharp increase in Northern Hemisphere temperature and a highly positive North Atlantic Oscillation index (see footnote on p.4).

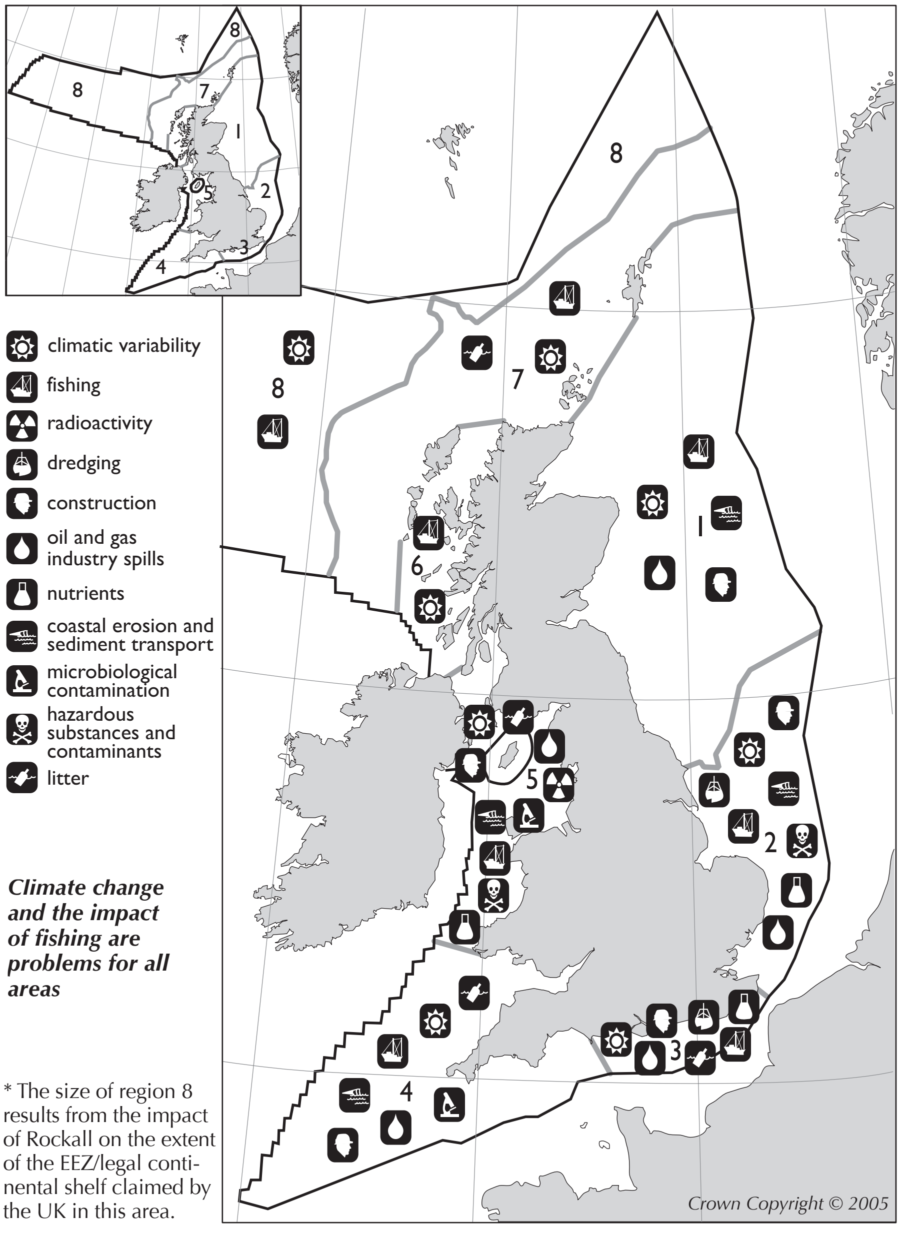
The regime shift is evident in chlorophyll, phytoplankton and zooplankton, fish (including commercially caught species), birds and benthos, as well as in nutrients, oxygen and hydrographic variables.

Interestingly, a sharp increase in chlorophyll levels in the North Sea in the late 1980s was also observed in oceanic waters to the west of Britain. This suggests a climatic cause, rather than an excess of nutrients in the North Sea.

4. Marine Fish and Fisheries
This report was prepared by national Government agencies with responsibilities for undertaking research and providing advice on fish and fisheries:Fisheries Research Services, the Department of Agriculture and Rural Development (Northern Ireland), and CEFAS. Not surprisingly, it makes depressing reading, with one of the few positive points being a substantial increase in stocks of pelagic species such as herring.

During the past 10 years, North Sea stocks of most demersal roundfish and flat fish have deteriorated, with only three of the main commercial stocks being described as 'within safe biological limits'. Cod stocks are at historically low levels, and are subject to emergency management measures, and a 'recovery plan'. In the Irish Sea, populations of cod and whiting have declined, and may crash. Along the South-West Approaches, most stocks are harvested outside precautionary limits.

The main issues for each region (see the key), from the summary report *Regions are: (1) northern North Sea; (2) southern North Sea; (3) eastern English Channel; (4) western English Channel, Celtic Sea and Western Approaches; (5) Irish Sea and North Channel; (6) west Scotland including the Minch; (7) Scottish continental shelf; and (8) the Atlantic North-West Approaches, the Rockall Trough and the Faroe–Shetland Channel.* (The boundaries are variable transition zones, not sharp demarcations.)*



Climate change and the impact of fishing are problems for all areas

* The size of region 8 results from the impact of Rockall on the extent of the EEZ/legal continental shelf claimed by the UK in this area.

Most fish occurring in British waters are in fact not targeted by commercial fisheries, but may nevertheless be caught and killed as by-catch, or may be important to recreational anglers. In the North Sea and Irish Sea, many larger fish, and those caught as by-catch (especially large bodied species such as skate and rays), are now reduced to <10% of their expected abundance in the absence of fishing, and the mean weight of the fish has declined. There is also concern about by-catches of common dolphins in the bass fishery, and harbour porpoises in the North Sea gill-net fishery. On the positive side, monitoring to determine the quantity and composition of discarded by-catch are now in place in many UK fisheries.

Because total allowable catches (TACs) have not proved successful, fisheries management increasingly also includes limiting days at sea and active decommissioning, and technical measures relating to, for example, mesh size. The introduction of square-mesh panels in nets used to catch *Nephrops* (Dublin Bay prawns or scampi) has helped to reduce by-catch of white fish. *Nephrops* themselves are harvested sustainably.

The distribution of fishing activity is patchy, with some areas being repeatedly trawled and others being trawled only once every seven years or so. Perhaps surprisingly, unfished areas with low levels of disturbance are more vulnerable to fishing than naturally dynamic areas that are trawled regularly.

The deep-water fisheries along the western seaboard of the British Isles are developing against a background of limited biological data. Deep-water fish tend to be slow-growing and late to reproduce, and so their populations are particularly susceptible to over-exploitation. Some stocks (e.g. blue ling and tusk) are already considered to be at low levels, with the status of most species uncertain (though likely to be at low levels). Particular management measures may be needed to protect orange roughy, which congregate around seamounts and are heavily depleted.

The British Isles lie across a biogeographical boundary between warmer waters to the south-west and colder waters to the north-east. For this reason, while some fish species are widespread around the British Isles, others are restricted to more northerly or more southerly waters. As discussed in Report 3, over recent years, warmer waters and warm-water plankton have been found increasingly further north, and this change has made it difficult to identify ecosystem changes caused by fishing.

Furthermore, the structure and diversity of fish communities are also affected by pollution, eutrophication and habitat destruction, and the introduction of non-native species. Although time-series datasets have provided valuable insights into changes in the marine environment, the interactions between the different factors are hard to disentangle. However, once stocks have become depleted, other pressures such as climate change become more important.

5. Integrated Regional Assessment (180pp.)
Most of the information in this final report has been set out in more detail in the four previous reports, although there is also an assessment of data on benthos from the National Marine Monitoring Programme, plus some regionally specific information on seabirds. The eight regions used are based on proposals by the JNCC for use in nature conservation strategies. As shown in the map opposite, from a regional perspective, the Irish Sea and the southern North Sea are affected by the most problematic issues.

The *Charting Progress* Report has highlighted a number of gaps in current arrangements for gathering and coordinating information. Defra has responded by announcing two partnerships: the Marine Climate Change Impacts Partnership (www.sahfos.ac.uk/mccip.htm), and the Marine Data and Information partnership (MDIP) (www.oceannet.org/MDIP). The latter has a head-start, because of experience gained through the National Biodiversity Network and the Mapping European Seabed habitaits (MESH) Project (www.searchMESH.net/), undertaken by the JNCC.

Eds

English Nature's Maritime Strategy

English Nature's recent report, *Our coasts and seas – making space for people, industry and wildlife*, is the culmination of over two years of discussions with hundreds of people who use and manage the coasts and the sea for business, recreation and conservation. It builds on the *Maritime State of Nature* report (2002), and shows that the quality of the marine and coastal environment is still declining, with the number and diversity of plants and animals in the sea continuing to be significantly altered by human activities.

The report identifies three key issues to be tackled by a new Marine Bill:

New legislation to bring forward a network of Marine Protected Areas (MPAs)
The network of MPAs should be designed to contribute to the protection and recovery of the whole marine ecosystem, rather than focussing on particular habitats and species. This approach could allow exploited species to recover, afford greater protection to both common and rare species, and result in a healthier environment, more resilient to change.

As envisaged, the network of MPAs would consist of areas with varying levels of protection, including some where all commercial and recreational activies would be forbidden. At least 20–30% of all marine habitats would need strict protection; elsewhere, there will need to be improved sustainable management of on-going activities.

A move from coastal defence to coastal management
Old sea-defences (which are expensive to maintain) and inappropriate development, along with rising sea-levels, are squeezing out habitats such as salt marshes and mudflats. These are not only home to important wildlife, but also buffers between the land and the sea, which is expected to become increasingly stormy.

Flexible management of the coastline should allow coastal habitats and their wildlife to adapt and move, thereby offering greater protection, better conservation, and more opportunities for sustainable tourism.

Marine spatial planning
As the sea becomes more congested, there is a growing need to balance often conflicting marine uses, while protecting and managing the marine environment. Currently, there is no overview of new developments, so that if, for example, a wind farm, port expansion and gravel dredging were all being proposed for a region at the same time, they would each be evaluated by the appropriate regulator, but there would be no assessment of the combined effect, which could be more harmful than any of the activities individually. Effective coordinated planning would ensure that such assessments are undertaken at the right time.

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A fine new kettle of fish: investing in a radical fisheries management initiative

Jennifer Storemski

A radical project based in the South West of England aims to find the most effective way of sustaining fish stocks whilst taking into consideration the interests of the local communities of Cornwall, Devon and Dorset, the regional economy and the environment. Many groups have attempted to address the management of fish stocks in European waters, but there has always been a tendency to seek one-dimensional solutions which reflect the backgrounds of their proponents. Some of the proposals have focussed solely on technical measures, such as reduction in mesh size, closing certain areas to fishing, or banning a specific method of fishing in particular areas. Primarily, proposals have focussed on the economic impact of particular fisheries management measures, e.g. the introduction of individually owned transferable fishing quotas, which are portions of the Total Allowable Catch allocated to a nation, or portions of quotas owned by a community.

Through the Invest in Fish South West (IFSW) initiative, launched in April 2004, commercial and recreational fishermen, environmental NGOs, statutory agencies, fish merchants, fish processors and restauranteurs, are working together to establish the best way to manage the fish stocks of the Celtic Sea, English Channel and Western Approaches. The three-year project is the first within a wider national initiative, led by WWF-UK, the National Federation of Fishermen's Organisations (NFFO) and Marks & Spencer. The pilot project will provide an example for similar regional initiatives elsewhere in the UK and Europe.

One of the greatest challenges of the project will be to balance the interests of the stakeholder groups, while ensuring that the strategy they choose ultimately meets the underlying aim: to provide the best plan for sustaining fish stocks in the region and hopefully permit larger stocks, greater catches, and greater profits than are possible today. The project is determined to meet this ambitious challenge with the help of the Centre for the Economics and Management of Aquatic Resources (CEMARE) at the University of Portsmouth, and the Centre for Environment, Fisheries and Aquaculture Science (CEFAS), Lowestoft.

The area covered by the Invest in Fish South West Project

The ports shown in Ireland and mainland Europe are some of those for which data have been gathered for use in the project

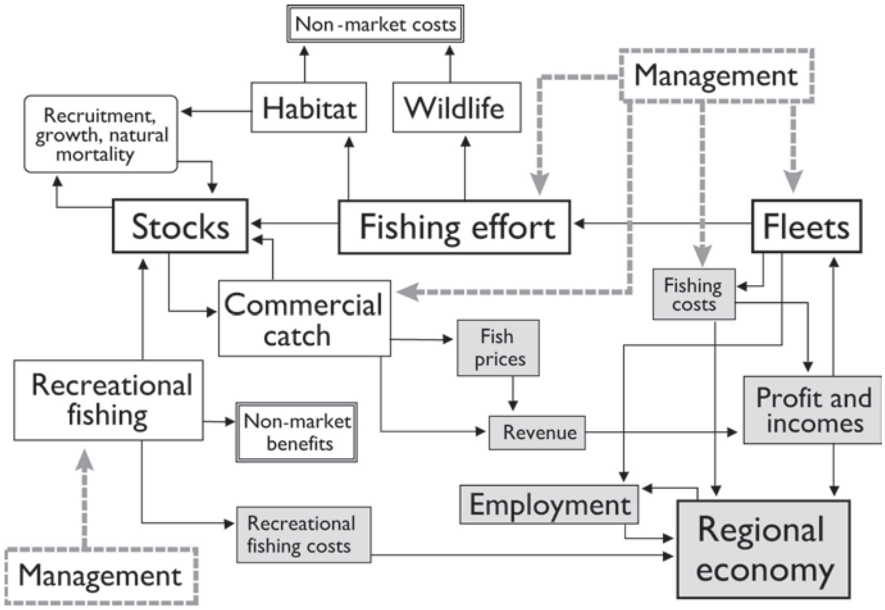
Scientists and economists from CEFAS and CEMARE are currently developing a bio-economic model which will become one of a range of ways for evaluating various fisheries management options proposed by stakeholders within the IFSW initiative. At the heart of the model is a sophisticated computer programme designed to provide the best possible indication of the costs and benefits (social, economic, biological and environmental) of these options for the region over time (see the box opposite).

Members of the IFSW project team like to compare the model to the computer game 'Sim City' in which you change various environmental factors to try out different ways of developing a city, as if you were, say, the Mayor of New York. The model allows stakeholders to see the effect of possible decisions over time (how they will affect fish stocks, the environment, local earnings and the regional economy), giving those involved the opportunity to see how ideas might actually work in practice.

The IFSW multidisciplinary approach will enable the steering group to be creative, and explore options they may not have considered before. For example, recreational anglers could propose that sea bass were excluded from commercial fisheries, meaning that only anglers could fish for this species. CEFAS and CEMARE would input this option into the model and run it for different scenarios and time periods, thus obtaining the best possible indication of the long-term costs of the option. Options with less definite outcomes can also be explored, and the levels of uncertainty associated with them identified.

Sean Pascoe, Director of CEMARE and Professor of Natural Resource Economics at the University of Portsmouth, notes that 'No previous model development has ... had the direct involvement of such a wide range of stakeholder and interest groups. The resulting model will form a common framework over which

How the Invest in Fish Model works



The components of the IFSW model. Management controls directly affect not only commercial fleets and their activities, but also recreational fishing by sea-anglers (who contribute about £165 million to the economy of the South West annually). 'Fishing effort' encompasses time spent fishing, types of fishing gear used and financial cost.

The diagram represents the key components of the model and the links between them. The introduction of management measures will change some of the relationships and thereby change the way the fishery develops over time.

For example, the introduction of a seasonal closure will reduce the amount of fishing effort (see caption) that vessels can expend. This reduced effort will result in fewer fish being caught by commercial boats. The reduction in catch will have two impacts: first, it will result in a larger stock surviving the year than would have been the case had the restrictions not been imposed, with potential benefits the following year; secondly, it will result in lower revenues to the industry (the extent of which may be offset to some extent by price changes as the availability of fish for the market decreases). The lower revenue will lead to reduced profitability for the fishing fleet, and may result in some vessels changing their fishing activity (use different methods and/or fishing in different areas). The lower profitability will also have knock-on effects in the regional economy.

The reduced effort may also result in less habitat damage and other influences on the environment. Effects on wildlife are included by incorporating impacts on cetaceans and by-catch species generally – the model includes information on all species caught within the region, wherever data exist. Direct environmental impacts of different fishing gears are ranked and scored by marine biologists and fisheries experts on a scale of 1 (high) to 10 (low); for example, sea bass pair-trawling* might have a score of 1 in respect of its effects on dolphin by-catch, while beam trawling might have a score of 10.

Benefits (in terms of reduced damage) could potentially be measured through a reduction in the non-market costs associated with fishing (costs borne by society as a whole but not the fishing industry, e.g. loss of coral reefs), provided estimates of these costs can be made. Further, these (reduced) environmental impacts can have (beneficial) consequences for the regeneration of the stock through influencing the natural processes that underpin the stock (e.g. recruitment (addition of young fish), growth, natural mortality etc.).

In the following years, the improved stock should result in improved catches even if the same seasonal closures remain in place. This will feed through to higher revenues, profits and regional impacts. It will also affect the way the fishing fleets behave, more vessels choosing new types of gear and fishing in different areas that prove more profitable.

The model aims to capture these interactions and measure the impacts in order to evaluate the short-term and longer term impacts of management changes on fleet profitability, the regional economy, the environment and other stakeholders (such as recreational anglers).

The results generated by the computer for the various fisheries management options will be reviewed by the steering group, who will question the assumptions and debate the implications. As the simulations may be varied at any point, it will be possible to refine the results, by running variations of certain manangement options, to compare the costs and benefits for the environment, the regional economy and local communities.

*See *Ocean Challenge*, Vol. 12, No. 2, p.3.

the impacts of management options on the different groups can be explicitly measured, allowing consensus to be built on real information rather than supposition.'

To date, only limited attempts have been made to develop bio-economic models of English Channel fisheries, and even fewer for the Celtic Sea. These fisheries are dominated by small fishing vessels, many of which fish for non-quota species, i.e. those not regulated by the European Commission's quota system, which restricts the amount of fish European fishing boats can land within specific fishing regions. These small vessels have generally operated 'under the radar' of fisheries managers, whose attention has focussed on quota species and the larger fishing vessels. This in itself brings additional challenges to the modelling, because for these small vessels there are no systematically collected data on economic aspects, catch or fishing effort (i.e. time spent fishing, type of gear used, etc.). Furthermore, for non-quota species, there are no established methods for deriving the necessary biological data relating to fish life-cycles, and the project can draw on only a limited number of previous studies.

Previous studies of the English Channel have relied on simple biological models that would not be sufficiently robust to adequately address the needs of this project. The IFSW model being developed by CEMARE and CEFAS is based on previous English Channel models, but is unique in that it will measure the costs and benefits to the region of various options *over time*; past English Channel models have been static equilibrium models, which estimated the eventual sustainable (i.e. stable) catches, and profits, for any given level of fishing effort, but did not map the path taken to get there, nor indicate how long it might take. Nor did they indicate or quantify any short-term losses or deleterious effects that might be incurred in achieving a long-term solution. This is obviously a critical issue for the fishermen who would ultimately be affected by any given strategy.

Structure of the model, and methods of information-gathering

Key components being incorporated into the IFSW bio-economic model include the commercial fishing sector, the recreational sector and the regional economy. The model will estimate the environmental effects associated with the various fishing activities in order to provide a clear picture of how different fisheries management options will affect the environment (see box on previous page). It will also predict the effects on yearly fishing fleet profitability, the local economy and, of course, fish stocks. In this way, the model can be used to help develop the best management strategy, as potential problems can be identified and alternative approaches examined. It will also attempt to include as much information as possible from other countries whose vessels fish in the area.

CEMARE is now preparing a variety of assessment methodologies for evaluating different management scenarios on the basis of three subsets of the model, which will eventually be integrated together. These address:

- **Biological effects** of certain fisheries management options on the English Channel (based around previous work) and the Western Approaches.

- **Socio-economic effects** of certain management options on the regional economies of south-west England, Ireland, France and Spain. Data currently being collected from fishermen should provide a fair understanding of how much money is earned during different months, and how much is earned by means of different fishing methods.

Socio-economic data are also being collected on anglers – for example, how much would they be willing to pay for the opportunity to fish for certain species? This type of information will allow IFSW to estimate how a particular management measure (e.g. allowing sea-anglers the sole right to fish for bass) would affect fishermen financially, and how the local economy would benefit or suffer.

- **Secondary effects** within the regional economy. For example, if beam-trawling were banned, this would have a knock-on effect on the fuel companies, those who work on the trawlers and maintain them, people employed in markets selling the fish, and retailers and processers who depend on the fish supplied by beam trawlers.

CEMARE will then feed into the model data collected via a multitude of research projects commissioned by IFSW. Topics addressed by these research projects include:

- Earnings and operational costs of all UK and foreign fishing fleets within the Celtic Sea, English Channel and Western Approaches. These fleets include vessels using beam trawling, otter trawling and gill-netting, inshore vessels (boats under 10 m) and shellfish vessels.
- Information about sea-anglers, their demographics, what motivates them, and their socio-economic impact on the region.
- Effects of fishing on the marine environment, which are being evaluated by Falmouth-based marine environmental consultants, MER.
- Interactions between fishing and marine mammals, which are being investigated by the Sea Mammal Research Unit (St Andrews).

Results from the model will ultimately provide a cost/benefit analysis which will be presented to the IFSW steering group members. There are ten such members, who are leaders within the following sectors: commercial fishermen, sea-anglers, retailers, statutory agencies, envivonmental NGOs (e.g. WWF-UK, the Wildlife Trusts, the Shark Trust), restauranteurs, fish processors and the regional development agency. The steering-group members act as representatives of these stakeholder groups, not simply of their own organizations.

Depending on the outcomes of the modelling, individuals from the group are likely to propose that additional fisheries management options are explored, until a consensus is reached. The final strategy will be based on the findings from the model, as well as discussion between members, other interested parties and experts (all with the aid of a facilitator). Once the options and strategy are decided, they will be set out in a report which will include a projection of the associated costs and benefits over time and any short-term investment required for implementation (along with estimates of the various uncertainties). Invest in Fish South West aims to reach a consensus during 2006.

The project has recently released reports from various research projects undertaken over the last year. These have explored: the opinions of fishermen in the South West; the economic contribution of sea-anglers to the economy of the South West; and interactions between sea mammals and commercial fisheries; there is also a review of the institutional and regulational framework affecting South West fisheries. All these reports are being made available on the website.

More information about the project can be found at www.investinfish.org. If you have any questions or concerns, please contact the project office at +44-(0)1736-333-733 or info@investinfishsw.org.uk. Postal address: Invest in Fish South West, Barn C, Boswednan Farm, Tremethick Cross, Penzance, Cornwall TR20 8UA.

The ES *Orcelle*: the shape of ships to come?

A model of the ES *Orcelle*, a revolutionary cargo ship, was recently unveiled at World Expo 2005 in Japan. 'ES' stands for 'Environmentally sound Ship': the *Orcelle* – named after an endangered species of dolphin – has no conventional engines, and releases no harmful emissions into the atmosphere and no pollution into the sea. It has been designed by the Scandinavian shipping company Wallenius Wilhelmsen, and takes pride of place at the North Nordic Pavillion at Expo.

The *Orcelle* is a car-carrier with a cargo deck stowage area of 85 000 m^2. It would be capable of transporting up to 10 000 cars on eight cargo decks, three of which would be adjustable to accommodate vehicles of different heights and widths. Although its weight would be similar to present-day carriers (21 000 tons, deadweight 13 000 tons), the absence of ballast-water tanks, together with the use of lightweight materials, including aluminium and thermoplastic composites, means that the cargo deck area can be large in relation to the weight of the vessel, allowing it to carry about 3000 more tons of cargo.

The vessel will be powered by solar energy, wind and waves. Solar energy will be harnessed through photovoltaic panels in the vessel's three sails, which also help to propel the vessel using wind power. The rigid sails will be made of special lightweight composite materials. They will be capable of folding upward and outward, and will rotate about the masthead to attain the best position for extracting energy from the wind through the creation of drag or lift, or a combination of the two. When not in use for wind propulsion, the sails may be tilted, laid down, or in other ways directed to maximize collection of solar energy. The solar energy will be transformed into electricity for immediate use, or stored.

Wave power is harnessed through a series of twelve fins, and will be extracted through relative movements between the waves, the fins, and the vessel. The energy extracted can be used to generate hydrogen, electricity or mechanical energy. The fins double as propulsion units, and are driven by wave energy or by other renewable energy sources on board. Energy generated by vertical movement of the fins may be transformed into mechanical energy for immediate use in orienting them. Energy from other movements of the fins may be harnessed to generate hydraulic energy that may be used immediately or stored. Other promising systems for storing mechanical energy are being investigated, including use of flywheels.

Propulsive power will also be provided by two variable-speed electric propulsion systems known as 'pods', which will replace the traditional stern propeller and rudder. Each pod will have a motor, gearbox and propeller in a single compact unit. The pods will be positioned one at each end of the hull, providing power plus 360° manoeuvrability.

About half the energy will be generated by fuel cells, which produce electricity by combining hydrogen and oxygen, with water vapour and heat as by-products. Currently, the production and storage of hydrogen (at high pressure and/or low temperature) are obstacles that need to be overcome if viable fuel-cell technology for ships is to be developed.

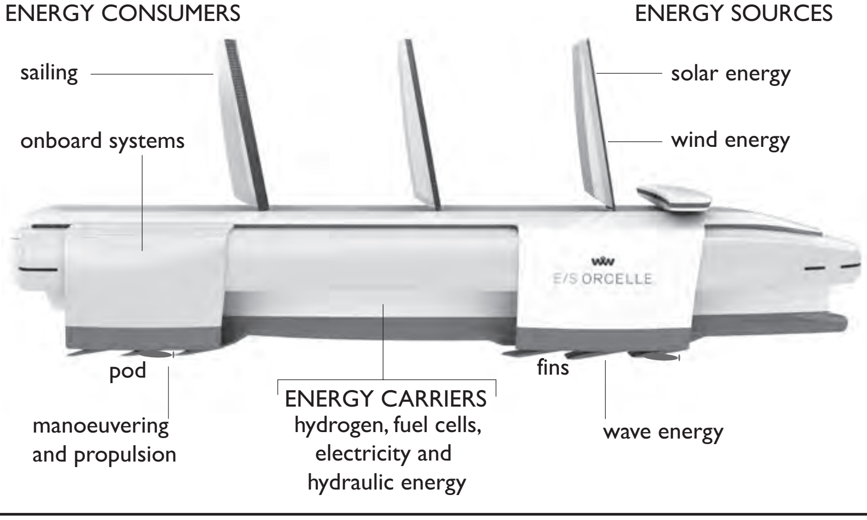
The *Orcelle* has a pentamaran hull, made up of one long slender main hull and four supporting sponsons. This design should eliminate the need to take on, and release, ballast water, and so minimize the transport of alien species between ports (*Ocean Challenge*, Vol. 13, No.2, pp.26–31).

The *Orcelle* is described as a 'concept' and Wallenius Wilhelmsen have no immediate plans to build a prototype. However, the company (which currently has around 60 freight vessels) says that it will continue to work with others to develop the technologies embodied in the design. It views the ES *Orcelle* project as the start of a long-term programme which it hopes will be matched by other leading shipping companies, so that the ideas it represents will become practical options for new car-carriers within the next two years.

While developing sustainable technologies can only be a positive activity, it is ironic that the efforts are directed at transporting cars. However, experts in fuel-cell technology predict that cars using hydrogen as an energy carrier could be on the market by 2020.

Eds

Right: *Bow view of the* Orcelle.
Below: *Side view, highlighting the energy sources, the energy carriers, and the ways in which energy is consumed. The vessel would be 250 m long, with a beam of 50 m and a height of 30–40 m. Its optimum speed would be 15 knots, with a maximum of 20 knots.*



Dolphin challenges

Helen Bailey

Few people can remain unimpressed as a 4 m long dolphin jumps clear of the water. Adults and children alike stand staring at this spectacle, willing the animal to do it again. Yet despite the huge public interest in whales and dolphins (cetaceans), relatively little is known about them. They are highly mobile creatures, capable of travelling at high speeds and remaining under water for long periods of time. This presents many challenges for those trying to study them – including me! My PhD involves identifying the factors that determine dolphin distributions so that appropriate conservation management plans can be developed.

There are still many areas of the world where we have little information on where whales and dolphins occur, where they breed or how they feed. This makes it very difficult to predict the impact of human activity on the animals. Consequently we need to gain a better understanding of which areas are most intensively used by dolphins and why. More effective conservation management strategies can then be developed and the impact of human activities kept to a minimum.

Figure 1 *A bottlenose dolphin 'porpoising' in the Moray Firth. (Courtesy of Lighthouse Field Station/University of Aberdeen)*

Bottlenose dolphins

One of the most intensively studied cetacean species is the bottlenose dolphin – the 'Flipper' dolphin. Bottlenose dolphins occur all around the world, including off Australia, New Zealand, the Bahamas, Florida and Scotland. They are highly adaptable and their behaviour in each location varies as a result of differences in prey and habitat types.

There are differences in the appearance of bottlenose dolphins between populations. In the tropics, they are generally about 2.5 m long, whereas in cooler climates they tend to be much larger, reaching about 4 m long. Lower water temperatures mean that they need a thicker layer of blubber and tend to have shorter flippers. Together with their greater size, this maximizes the volume producing heat, whilst minimizing the area over which the heat is lost. Because of the effect of water temperature on size and shape, bottlenose dolphins in the cooler temperate climates of Britain and New Zealand resemble one another more than they do bottlenose dolphins in the tropics.

The oceans have undergone dramatic changes during the last century, mainly as a result of human activities. Physical, chemical and biological factors can all act to influence the distribution of dolphins, directly or indirectly. For

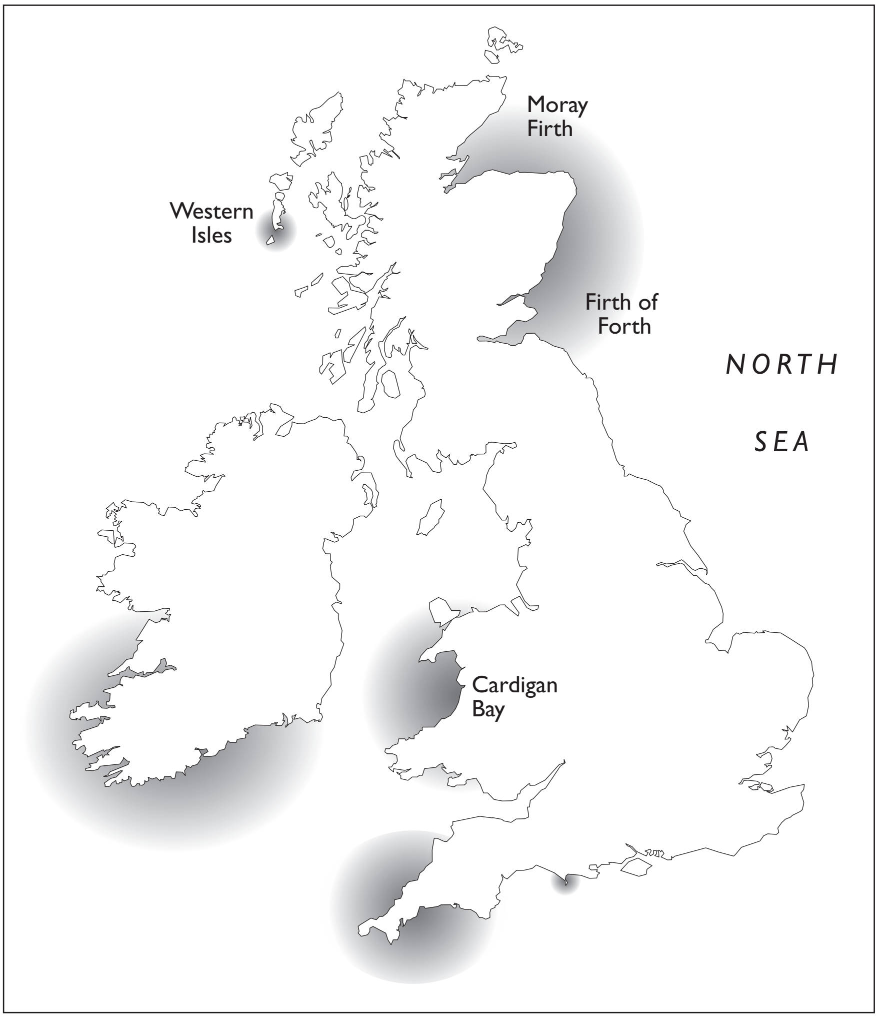


Figure 2 *Distribution of bottlenose dolphins around the UK.*

example, the range of temperatures over which warm-blooded marine mammals can survive may directly limit their geographical distribution. A range of factors can affect dolphin distribution through their effect on the distribution of prey species.

Dolphins are capable of ranging over large areas or even of shifting their range if conditions become more favourable elsewhere. Evidence for this was provided during the 1982–83 El Niño. Bottlenose dolphins previously thought to be resident off San Diego moved northwards 400 miles to Monterey Bay in response to the warm-water incursion caused by El Niño and the consequent movement of the dolphins' prey. Although some dolphins returned south after the event, many remained and the population structure was altered as a result.

How best to protect bottlenose dolphins around the UK?

Bottlenose dolphins are found at several locations around the British Isles. There are populations off Wales, off the south-west coast of England, and off the western and north-eastern coasts of Scotland (Figure 2). The dolphins are important not only because they are top predators in the marine community, but also because they have strong economic and social roles in our own communities. They attract large numbers of people to the areas concerned, generating valuable employment and economic activity in coastal towns.

Efforts to protect marine species frequently involve the protection of particular key areas. Bottlenose dolphins (and harbour porpoises) are listed under Annex II of the *European Union's Habitats Directive* and the UK is therefore required to consider establishing Special Areas of Conservation (SACs) for them – a promising step forward in the conservation of these small populations. The inner Moray Firth (north-east Scotland) and Cardigan Bay have both been under consideration for designation as SACs, as two populations of bottlenose dolphins are believed to spend the majority of their time in these areas (cf. Figure 2). Careful management of these particular areas should provide the best protection for the populations. In March 2005, the Moray Firth officially became an SAC on the basis of its poulation of bottlenose dolphins (Figure 4).

The distribution of dolphins around the UK does change, however. Over the last century, the historical pattern of strandings down the east coast of the UK (Figure 3) suggests that the population off the north-east coast of Scotland was not always an isolated

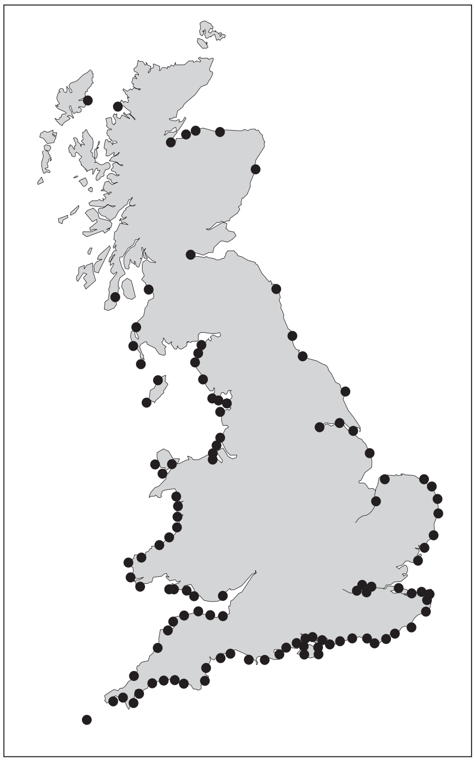


Figure 3 *Map showing the locations of bottlenose dolphin strandings reported around the UK from 1914 to 1992.*

one. In contrast to expectations, genetic studies have revealed that this population is more closely related to the animals off Wales than to its nearest neighbour population off western Scotland (Figure 2). This suggests that the cold waters around the northern tip of Scotland may provide a barrier to the movement of dolphins from one side of Scotland to the other.

Over the last 15 years, changes in distribution have also been observed on a smaller scale off the north-east coast of Scotland. The population here used to be most frequently seen within the Moray Firth, but is now known to range as far south as St Andrews. How can we tell they are the same dolphins? In the same way that fingerprints are used to identify humans, nicks and scratches on dorsal fins can be used to identify individual dolphins. It is difficult to determine, however, whether the trend towards more southern sightings reflects more time being spent by the dolphins in those areas or a rise in the number of people looking for them.

One attempt to differentiate between these possibilities makes use of the fact that bottlenose dolphins in the Moray Firth can attack and kill harbour porpoises. The reason for this violent behaviour is unclear, but could be related to competition for food. The incidence of porpoise carcases attributed to bottlenose dolphins has become significantly more frequent in the more southern areas since the late 1990s, suggesting that the dolphins have indeed extended their range.

The aim of my PhD work is to identify the factors that drive dolphin distribution, so that plans can be made to manage their conservation. The distribution of bottlenose dolphins in inshore areas is well known, but few surveys are performed more than a few kilometres offshore. As part of my project, an effort is being made to remedy this within the Moray Firth, to allow us to build up a more complete picture of the distribution of bottlenose dolphins, and identify key areas where they are active.

The various factors affecting the distribution of dolphins operate over a range of temporal and spatial scales. For example, at small spatial scales, narrow deep channels and tidal fronts seem to be important areas, but it is not known precisely how the dolphins use these features to improve their foraging success. Since dolphins spend the majority of their time underwater, and most feeding occurs out of sight, it is extremely difficult to identify precise feeding sites and their spatial scale.

The surveys we are carrying out in the Moray Firth SAC (Figure 4) involve both visual observation and acoustic recordings. Bottlenose dolphins produce a range of sounds, including whistles,

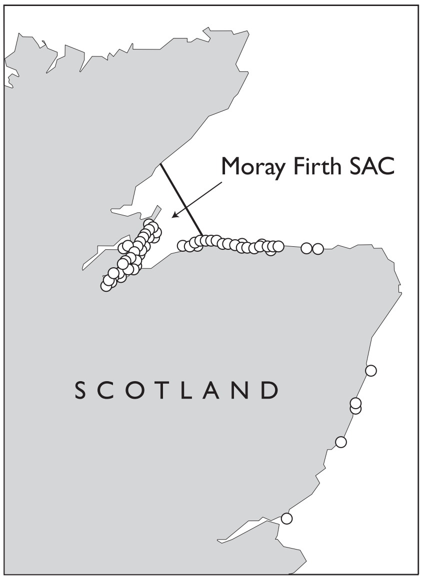


Figure 4 *The location of the new Special Area of Conservation for bottlenose dolphins. The circles represent sightings during the current project.*
(As well as the possible SAC in Cardigan Bay, bottlenose dolphins also spend time in a prospective SAC off the Lleyn Peninsula (north of Cardigan Bay), although they are not the primary reason for this area being proposed as an SAC.)

clicks and squeaks. Preliminary results indicate that narrow channels and mouths of estuaries are 'hotspots' for dolphins. This may be because food is more abundant at these sites, or that it is easier to catch there. Bottlenose dolphins have mainly been sighted close to shore, but have been recorded up to 9 km offshore.

In contrast, harbour porpoises have been encountered throughout the Moray Firth. They produce very narrow-band echo-location clicks at 130 kHz, which is many times above our hearing range, and specialist equipment is therefore required to detect them.

Using a surveyor's theodolite, which measures horizontal and vertical angles, I was able to obtain fine-scale movement paths of bottlenose dolphins within a 'hotspot' area. These surveys were conducted from land so that I would not disrupt the dolphins' behaviour. I compared these dolphin movement patterns to those expected if the animals were moving randomly, and found that there were two distinct movement modes: directed movement and intensive searching. Directed movement occurred almost in straight lines, whereas intensive searching occurred within a localised area, generally less than 200 m across, and the animal remained within this area by increasing its turning rate. These modes are consistent with what would be expected if the animals were trying to maximize their foraging efficiency in areas where prey was patchily distributed. The directed movement towards foraging areazs may also suggest prior knowledge of good feeding sites, and that these dolphins have a preference for feeding areas that are predictable.

The importance of predictability of food resources has also been demonstrated in seabirds, along with various spatial scales of activity. More generally, understanding the physical mechanisms controlling the distribution of food resources within the dynamic sea can tell us much about the factors driving predator distributions.

Dolphins live within a complex marine ecosystem and it is only by combining information about the dolphins with information about their environment that we will begin to understand the processes underlying their distribution. This knowledge will enable us to improve our ability to predict the impact of human activities and provide ways of reducing such impacts. As offshore developments (e.g. wind farms) grow, this type of information will become increasingly valuable.

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Tagged whales surpise MAR-ECO observers

In April, MAR-ECO scientists from Norway and Portugal tagged three large baleen whales (one large adult blue whale and three Sei whales) off the Azores. The whales are being tracked by satellite to determine whether they use the Mid-Atlantic Ridge as a migration corridor. They have been observed travelling fast in straight lines between potential feeding areas, and apparently searching for food (krill and other zooplankton) in the deep (4000 m) trench of the Charlie Gibbs Fracture Zone (CGFZ). In May, the Sei whale surprised observers by leaving the CGFZ and swimming fast towards the northern tip of Newfoundland.

MAR-ECO is part of the large Census of Marine Life programme, and will be running until 2008. Its aim is to improve understanding of the occurrence, distribution and ecology of animals and animal communities along the Mid-Atlantic Ridge between Iceland and the Azores. The animals being studied include, fish, cephalopods, crustaceans and a wide range of gelatinous animals, living either near the sea-bed or in mid-water above the ridge. The project involves biologists, oceanographers and engineers from 16 nations, and is coordinated by researchers at the Norwegian Institute of Marine Research and the University of Bergen.

To follow the whales' progress see:
http://www.mar-eco.no/taggedwhales

Fish to Eat and Fish to Avoid

In 2002, the Marine Conservation Society published *The MCS Good Fish Guide*, written by Bernadette Clarke, the MCS Fisheries Officer (reviewed in *Ocean Challenge*, Vol. 13, No. 1, p.36). Now the information is available via the internet at FISHonline. There are entries for over 120 different species and stocks, information on the status of fish stocks, and on labelling schemes. There is also a glossary of terms that may be unfamiliar, a guide to different fishing methods, and maps of the world's fishing areas.

The best choices for a meal are sustainably farmed/harvested clams, cockles, king scallops, mussels and oysters, line-caught Pacific (Alaskan) salmon, and scampi or Dublin Bay prawn (pot- or creel-caught from northern stocks only). There are nearly thirty species in the list of 'Next best' choices, and a somewhat longer list of 'Fish to avoid'. A good proportion of the latter are deep-water species which are increasingly seen on the fishmonger's slab (e.g. orange roughy, roundnose grenadier). Deep-water species are slow-growing and late to mature and reproduce, and so are particularly vulnerable to overfishing; furthermore, deep-water fisheries are largely unregulated and poorly managed. The 'Fish to avoid' list also includes more commonly eaten species such as brill, haddock, grouper, grey mullet, Atlantic cod, American plaice, and monkfish (another deep-water species).

For quick reference, for each species FISHonline provides a 'sustainability rating' of 1–5, and there is also information about whether it is from a fishery certified as environmentally responsible; or, by contrast, is:

- vulnerable to exploitation and/or assessed by the World Conservaton Union (IUCN) as threatened, and/or
- from overfished stocks and/or from stocks where data are deficient, and/or
- from poorly managed or unregulated fisheries, and/or
- caught using methods which are detrimental to other marine species and to the habitat.

So that you don't need to carry the *Good Fish Guide* (or wireless laptop) around with you when you go out for a seafood meal, the MCS has produced a wallet-sized *Pocket Guide to the Fish to Eat and Fish to Avoid*. This is available free of charge from the MCS, Unit 3, Wolf Business Park, Alton Rd, Ross-on-Wye, Hereford, HR9 5NB; Tel. 01989-566017; Email: info@mcsuk.org (please supply Ist or 2nd class stamps, or appropriate postage for multiple copies).

Global warming: real or just a scare story?

John Wright

Lately I have re-discovered articles and reports about global warming and species extinction, dating back to before 2000. They appeared at quite frequent intervals in broadsheet newspapers, as well as on radio and TV. Now they can be seen and read almost weekly, but there is little evidence that – apart from a dedicated minority of committed people – anybody really notices this spate of articles and documentaries. They contain graphic descriptions of (to name a few) biodiversity loss, oceanic pollution, impending scarcity of water resources, lack of sanitation in developing countries, soil erosion, persecution of minorities, genocidal conflicts, trafficking endangered species and human beings (especially women and children) ... and so on.

There's plenty of social and environmental and biodiversity legislation, but with so much political (and public?) inertia and apathy, the laws are rarely enforced. Even when they are, criminals who destructively exploit the environment are given risibly small fines or short terms of imprisonment. When poaching or trafficking can net millions, what do a few months in prison or fines of a few tens of thousands matter? The more endangered the species, the higher its value, the greater the profit. Nobody can seriously believe that penalties presently imposed on poachers and traffickers are a deterrent. What's more, there's so much greed and corruption in the world, and now that ten new states have joined the EU (including countries recently escaped from the 'Russian Empire'), things may not get better soon.

More recently I've encountered articles that deny the reality of global warming, plus I've just read Michael Crichton's latest novel (*State of Fear*), the central feature of which is scepticism about global warming, a scepticism supported by numerous graphs and a vast bibliography that lists (among others) both Bjorn Lomborg (of *Sceptical Environmentalist* fame) and Wilfred Beckerman, the scourge of anyone daring to favour sustainability over continued economic growth (on a finite planet). The story rattles along quite well and comes to a satisfactorily bloody end: the goodies win and the baddies get their come-uppance, having attempted to use a cavitation device – the workings of which are not properly explained for dumbos like me – to generate a submarine earthquake and tsunamis aimed at coastal California. Rather eerily, the site chosen for this climactic event – the Solomon Islands – is not all that far from where the Boxing Day tsunami of 2004 originated.

Most of the graphs in Crichton's novel display several decades of *cooling* at urban centres in North America, as well as at cities in Canada, Chile, Europe, Japan, and Pakistan – were they selected with that in mind? He seems not to be fond of environmentalists; for on pp.484–6 one of his characters produces a tirade about mistakes made by the people who set up America's first national park, which was Yellowstone. Before that (pp.451–60) another character (an obsessive professorial figure) explains why people in rich countries have been persuaded into a 'state of fear' about environmental catastrophe and terrorism by the so-called politico-legal–media (PLM) complex.

Crichton's thesis that global warming is a myth put about by scaremongers plainly has some support: At the end of January this year a meeting of climate change sceptics was held at London's Royal Institution, sponsored by a group called the Scientific Alliance that is allegedly linked to ExxonMobil. Contributors comprised – among others – our own David Bellamy, along with a Stockholm University oceanographer who 'challenges predictions that future climate change could raise global sea-levels'. And there's another book, entitled *Meltdown*, by Patrick Michaels of the Cato Institute, where the view is propounded that there is a global business trying to scare the world into worrying about climate change (see *New Scientist,* 8 January, for a review). Perhaps Michaels provided the basis for the obsessive professor who blames the PLM complex for the 'state of fear' in Crichton's novel.

Not long ago I wrote about 'global dimming'. It concerned cloud-forming aerosols that reflect solar radiation back to space, effectively 'dimming' the Sun. (*Ocean Challenge*, Vol.13, No.3, p.11). Shortly afterwards a BBC2 'Horizon' programme with the same title ('Global dimming') suggested that we might have underestimated the degree of global warming caused by the CO_2 we've added to the atmosphere, and that when industrial pollution (soot, dust, ash) is brought under control – some hope! – the atmosphere may warm a good deal more than data from climate models might imply. It's a scary thought for those who believe that global warming is real. Soon afterwards, *The Guardian* for 10 Feb. this year had an article about placing devices throughout the oceans to create vast amounts of spray and make cloud-condensation nuclei, thereby protecting the planet from further warming. It's a notion about as far-fetched as that of collecting carbon dioxide from power stations dand pumping it into abandoned oil and gas wells.

So: is global warming a real threat, more dangerous than terrorism, as claimed by Tony Blair? On balance, I go by the article in *Science*, entitled 'The Scientific Consensus on Climate Change' (3 Dec. 2004, p.1686) which summarises more than 900 papers in refereed journals, all in general agreement, *viz*: 'The IPCC's conclusion that most of the observed warming of the last 50 years is likely to have been due to the increase in greenhouse gas concentrations accurately reflects the current thinking of the scientific community on this issue.' But I still don't know if climate change is a bigger threat than terrorism, even though we are likely to be engulfed by avalanches of wierd weather – and I suspect nobody else does either. However, it may be worth reading *New Scientist* for 15 Feb., pp.38–43.

Does the apparent inertia of EU politicians and governments in these matters mean they're on the side of the sceptics? Could their inaction merely be a sop to industry (especially American industry), which regards the Kyoto agreement as a hindrance to its competitive position. At all events, little or nothing is being done, except possibly to emit more CO_2.

In mid-December last year came news of government funding for additional runways at Stansted, Luton and Heathrow airports, in spite of protests from local residents. Now that Britain has presidency of the G8 nations, will we see more action on curbing CO_2 emissions? I doubt it, which at least chimes with the opinion of some economists, including Lomborg himself, that money spent combatting climate change is money wasted, that aid for developing countries should focus on alleviating HIV–Aids, povery and debt. Does Britain's government *really* believe global warming is real? Are they serious about renewable energy, and if so why is there such emphasis on upland (and offshore) wind farms, why so little interest in power from waves and tidal currents? Is nuclear power still on the agenda? Do tell us if you know the answer.

RAPID SHIFTS in Arctic marine climate

observations and archives in a Spitsbergen fjord

Finlo Cottier, Suzanne MacLachlan and John Howe

Understanding our changing climate – past, present and future – is a leading scientific motivation for contemporary oceanographic research. Much endeavour has been directed towards unravelling the complexities of the global climate machinery, including the role and response of the oceans. In the Nordic Seas, there is a convergence of waters from three principal sources: the Atlantic, the Arctic, and glacial meltwater. Globally, the balance of these components controls critical aspects of the thermohaline circulation, particularly deep-water formation and the transport of heat. Regionally, the balance dictates whether the marine climate of a system will be more 'Atlantic' (warm and salty) or more 'Arctic' (cold and fresh). Recent work by researchers at the Scottish Association for Marine Science (SAMS) has shown that the coastal waters off western Spitsbergen are susceptible to massive and rapid shifts in this balance.

(a)

Changes in the equilibrium of water masses are important not only for the transport and redistribution of heat and salt, but also for species composition, ecosystem structure and biogeochemical fluxes within a region. In essence, associated with swings in the relative dominance of regional water masses, there is the potential for huge changes in the climatological, hydrological and ecological state of a system.

On the western shelf of Spitsbergen, at the northern extremity of the Nordic Seas, water from the Atlantic, the Arctic and the land are in a perpetual dynamic balance. Figures 1(a) and (b) show how this fjordic region links glacial meltwaters with oceanic Atlantic and Arctic Waters. Local hydrographic conditions over the shelf and in fjords are determined by responses to variations in these terrestrial and oceanic realms, and to external forcing by wind and tidal currents. In effect, the regional marine climate of the western shelf of Spitsbergen is highly susceptible to large variations in the delivery of different water masses.

Figure 1(a) *The oceanographic setting of the Svalbard Archipelago, of which Spitsbergen is the largest island. White arrows represent currents carrying Arctic water (cold and relatively fresh) and grey arrows represent water of Atlantic origin (relatively warm and saline). Sea-ice is exported from the Arctic Ocean into the Greenland Sea in the East Greenland Current.*

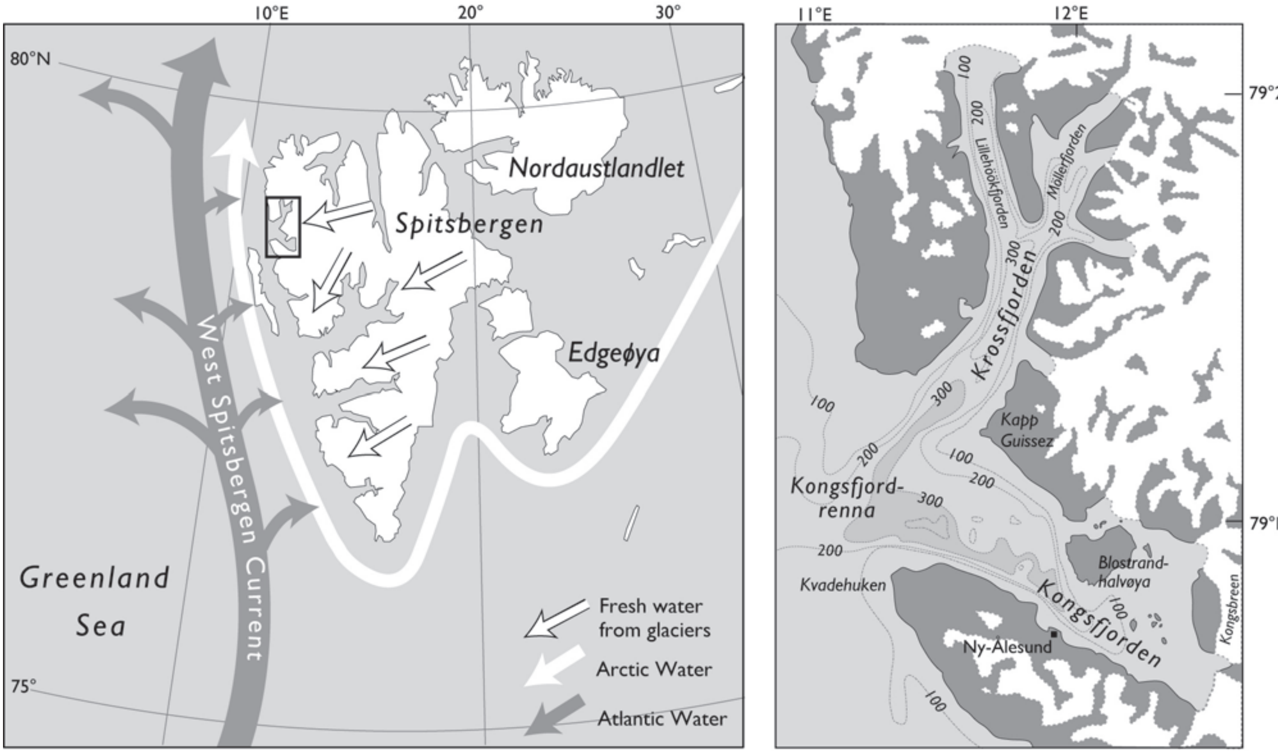


Figure 1(b) *Map of the Svalbard Archipelago illustrating the transport of Atlantic Water and Arctic Water along the west coast of the main island of Spitsbergen, and the discharge of fresh water from glaciers. The box in the north-west corner of Spitsbergen locates Kongsfjorden and Krossfjorden, where hydrographic and sediment data have been collected.*
(c) *The bathymetry of Kongsfjorden and Krossfjorden, and the location of the settlement of Ny-Ålesund (Figure 2) on the southern shore of the former. (By courtesy of the Norwegian Polar Institute)*

Whilst fjords respond to change, they are also capable, through their relatively high sedimentation rates, of retaining detailed records of past hydrographic variability. Sediments deposited throughout the fjords of Spitsbergen, and on the adjacent shelf, preserve an archive that documents the changing marine climate of the region.

Scientists from SAMS, in collaboration with Norwegian colleagues, have studied the dynamical hydrography of the north-west Spitsbergen shelf. The aim of the research was to understand the important processes controlling seasonal modification and exchange of water masses between shelf and fjords. Building on this information, the marine climatology of the region, on time-scales ranging from millennial down to interannual, can be interpreted using sediment cores obtained in the fjords. Understanding past and present hydrography can enable us to assess future change in these coastal waters.

Hydrographic observations

Spitsbergen is the largest island in the Svalbard archipelago, and in the north-west of the island is Kongsfjorden ('King's Fjord'), a site of intensive international research in the natural sciences, and the location for this research. The fjord is about 20 km long, between 4 and 10 km wide, and shares a common mouth with Krossfjorden to the north (Figure 1(c)). These fjords are linked to the shelf edge by a 200–300 m-deep trench called Kongsfjordrenna (*renna* is Norwegian for 'channel') which cuts across the shelf. In contrast to many fjords, there is no significant topographic constriction at the common mouth.

Both Arctic and Atlantic waters flow along the western coast of Spitsbergen, and both may influence conditions in the fjords

An archetypal fjord is a long, narrow body of water where the hydrography is modified by exchange with shelf waters, freshwater input, surface heat fluxes, tidal currents and wind. Arctic fjords may be regarded as an extreme variant on

NERC has maintained a summer research station at Ny-Ålesund for over 10 years

Figure 2 *The research station at Ny-Ålesund (cf. Figure 1(c)). It has been designated an international centre for environmental research. Close to the coast in the lower centre of the photograph is the new Arctic Marine Laboratory, currently nearing completion (see p.22).*

this classic model, experiencing intense seasonality, sea-ice formation, high levels of freshwater input through glacier discharge, and persistent and strong orographic winds.

As latitude increases so does the Coriolis parameter, with the result that rotational effects are more significant in Arctic fjords. Whilst a typical mid-latitude fjord may support relatively simple axial currents, a comparable Arctic fjord will sustain inflow and outflow on opposite sides, so forming a well developed gyre.

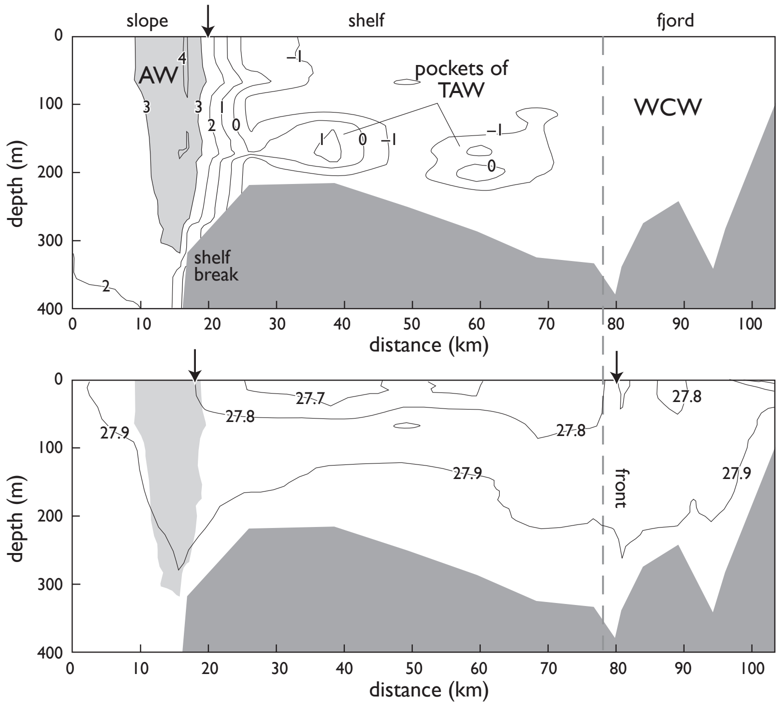
In a marine domain that stretches from glacier fronts to the deep ocean, there is inevitably a broad distribution of water temperature and salinity (*T–S*). Individual water masses are identifiable by their characteristic *T–S* signatures and occupy distinct regions on a *T–S* diagram (cf. Figure 5). The coldest, saltiest and therefore densest of these water masses is formed during winter when intense cooling and sea-ice formation together produce a homogenous water mass at a temperature close to freezing point. This Winter-Cooled Water (WCW) is found throughout the fjord in early spring.

At the opposite end of the temperature spectrum is Atlantic Water, which flows northward in the relatively warm and salty West Spitsbergen Current. With the Gulf Stream as its progenitor, its pedigree can be traced back through the Norwegian Atlantic Current (Figure 1(a)) and the North Atlantic Current, and it is recognized as the major pathway of heat to the Arctic Ocean (estimated at up to 50 TW, i.e. 50×10^{12} watts).

Inshore of the West Spitsbergen Current, and on the shelf, is Arctic Water (ArW), which is separated from the Atlantic Water (AW) by a strong salinity and temperature front. This rather fresher and much cooler water water has a very similar *T–S* signature to Winter-Cooled Water, but it originates in the Arctic Ocean and flows clockwise around Svalbard (Figure 1(b)). Mixing across the front between the Arctic Water and the Atlantic Water produces a secondary water mass referred to as Transformed Atlantic Water (TAW).

During 2002, SAMS and the Norwegian Polar Institute completed an extensive observational programme in the vicinity of Kongsfjorden. The UK's *James Clark Ross* was in the area in mid-summer, and the Norwegian ships, *Lance* and *Håkon Mosby* were operating there in April and September respectively. Large-area CTD surveys were complemented by data recorded by instruments moored at the fjord mouth from April to September.

During this period of observation the hydrography of the region underwent a massive shift from being Arctic-dominated to a system that was Atlantic-dominated. This is clearly illustrated by two contrasting CTD sections taken across the slope and shelf into the fjord in April and September. In April (Figure 3), the water on the shelf and in the fjords was primarily Winter-Cooled Water, separated from the water of Atlantic origin in the West Spitsbergen Current by strong temperature and salinity fronts at the shelf break. Some Atlantic Water had leaked across the *T–S*

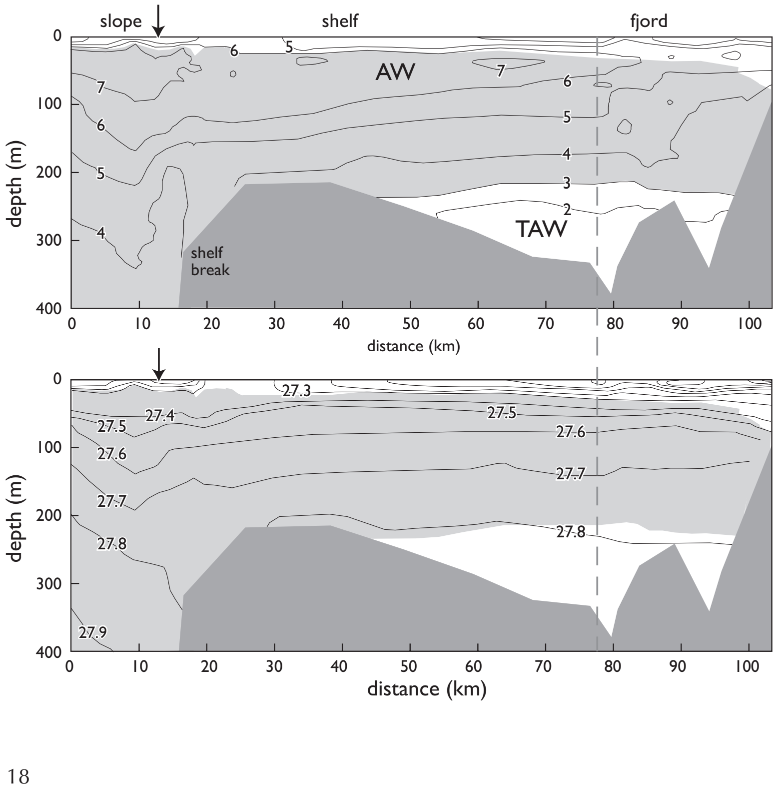


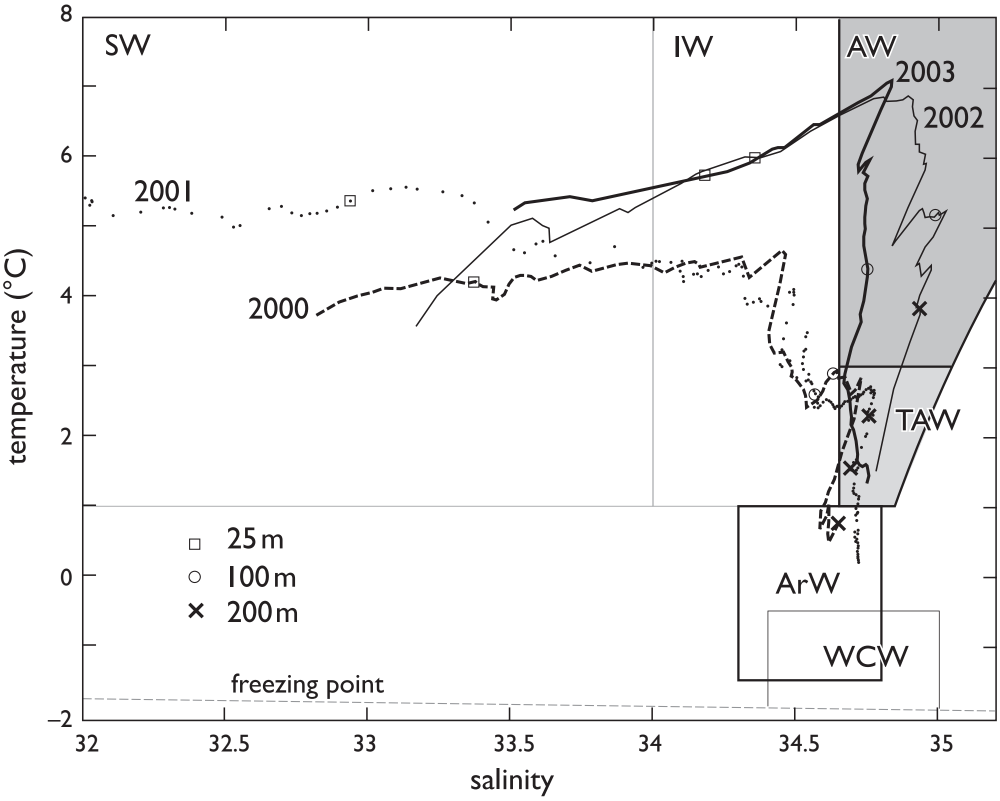
In April 2002, pockets of transformed Atlantic Water were observed on the shelf; if they travelled across the shelf, they would encounter the density front at the fjord mouth and be steered back out over the shelf

Figure 3 *Distribution of temperature (top panel) and density (lower panel) in April 2002 along a section that extends from the continental slope (left) to the head of Kongsfjorden (right). The vertical dashed line indicates the position of the fjord mouth. Most of the water on the shelf and in the fjord is Winter-Cooled Water (WCW). The grey shading in the water column seaward of the shelf corresponds to the presence of Atlantic Water (> 3 °C). The small arrows above the water surface indicate the postions of the fronts at the shelf-break and the fjord mouth.*

Figure 4 *Distribution of temperature (top panel) and density (lower panel) in September 2002 along a section from the slope (left) to the head of Kongsfjorden (right). The vertical dashed line indicates the position of the fjord mouth. The grey shading in the water column corresponds to the presence of Atlantic Water; below this is Transformed Atlantic Water. The small arrow indicates the postion of the shelf-break front.*

By September, the shelf and fjord were flooded with Atlantic Water





In September 2002 and 2003, waters at the mouth of Kongfjorden were 2.0–2.5 °C warmer than in September 2000 and 2001

Figure 5 *CTD data presented on a* T–S *diagram showing the presence of different water masses at the fjord mouth in September, for the years 2000 to 2003. Data for 2002 and 2003 show the presence of Atlantic Water (AW) and Transformed Atlantic Water (TAW) in the fjord. The other water masses shown are Surface Water (SW) formed from glacial and sea-ice melt, Intermediate Water (IW) (a mixture of SW and AW/TAW) and Winter-Cooled Water (WCW).*

front and mixed with the Arctic Water to form two small pockets of Transformed Atlantic Water over the shelf. A weaker density front (only apparent in the density section in Figure 3) separated the waters of the shelf from those of the fjord.

By September the scene was quite different (Figure 4). Atlantic Water now occupied the entire shelf and most of the fjord. The salinity and temperature fronts at the shelf break were much weaker and there were no density fronts at the fjord mouth. Within the fjord there were three distinct layers: relatively fresh water dominated the upper 25 m, with Atlantic Water below, and Transformed Atlantic Water filled the deep basins.

The sequence of events that effected this extensive hydrographic shift began with Atlantic Water from the West Spitsbergen Current penetrating the front at the shelf break. Results from the Bergen Ocean Model* indicate that this occurs most readily when the front becomes unstable during periods of northerly winds. The depth of water is critical to the stability of the West Spitsbergen Current, but the current can be moved westward, down the slope, into deeper water, through Ekman transport generated to the right of the northerly winds. To regain its original the water depth, the current responds by moving eastward, up the slope, into shallower water. It is these wind-induced, east–west oscillations of the West Spitsbergen Current that initiate frontal instabilities that grow, break away as eddies, and propagate eastward across the shelf, bringing water of Atlantic origin to the mouth of the fjord.

Assuming this mechanism can occur year-round, why should intrusions into the fjord of water of Atlantic origin be restricted to summer only? The reason is that during winter and spring, the density front between the fjord and the shelf (cf. lower part of Figure 3) acts as a barrier to the intrusion of Atlantic Water. The effect is to steer pockets of Atlantic Water away from the fjord and back across the shelf. Consequently, during the early part of the year, the density front inhibits the exchange of water between the shelf and fjord, a process termed geostrophic control. This control mechanism contrasts with that of many fjords and sea lochs where it is the presence of a shallow sill that usually inhibits exchange with shelf waters.

During spring, the surface waters become warmer (through heating) and fresher (through ice-melt) causing the geostrophic control to decrease in strength. Mooring data show that vertical mixing of the surface waters gradually decreases the density of the water column at the fjord mouth. However, the rate of density decrease in the upper layers is greater than that in the deep water. This increases the vertical stratification and also reduces the density contrast with the shelf. If water densities within the fjord begin to match those on the shelf, and the front breaks down, there is rapid penetration of Transformed Atlantic Water and Atlantic Water into the fjord.

*See www.mi.uib.no/BOM.

The rapidity with which water of Atlantic origin can occupy the fjord is apparent from CTD profiles obtained before and after the main period of inflow. During an 11-day period in late June the heat content of the water column at the fjord mouth increased by nearly 1 gigajoule m^{-2} (10^9 joules m^{-2}). To achieve this by surface heat fluxes alone would require a rate of heating of nearly 1000 W m^{-2}, twenty times the typical value for that time of year. In other words, advection of a warm water mass must have been the dominant reason for the increase in heat content.

CTD profiles from Kongsfjorden collected over successive years suggest that by late summer intrusions of Atlantic Water and/or Transformed Atlantic Water are fully developed. The *T–S* diagram in Figure 5, based on CTD casts from 2000–2003, illustrates that in summer the system adopts one of two modes. Either the shelf and fjord are only weakly Atlantic in character, i.e. there is no Atlantic Water present, only Transformed Atlantic Water in the deep basins (as in 2000 and 2001), or the water column is strongly Atlantic in character with a core of Atlantic Water at ~50 m and Transformed Atlantic Water restricted to the greatest depths (as in 2002 and 2003). These can be regarded as 'cold' or 'warm' years respectively, and determine the marine climate for that summer season, influencing ecosystem structure and subsequent sea-ice formation.

The integrated effect of this cross-shelf exchange phenomenon may be of more general oceanographic significance, because similar exchange mechanisms may act along the greater part of the northern Norwegian and western Spitsbergen shelves. Heat is lost from the warm West Spitsbergen Current, both vertically through the surface and also laterally by advection as Atlantic Water mixes into the Greenland Sea to the west and 'leaks' onto the west Spitsbergen shelf to the east (cf. Figure 1(b)). Estimates of heat loss indicate lateral losses from the West Spitsbergen Current to be nearly three times those from the surface. In other words, transfer of Atlantic Water onto the shelf appears to act as a heat sink from the West Spitsbergen Current, so modifying heat transport to the Arctic.

Our data show that Kongsfjorden can experience a massive and rapid influx of Atlantic water in mid-summer, flipping the system from one that is Arctic in character to one that is predominantly Atlantic. One could say that the local marine climate has undergone abrupt change. According to common perception, abrupt changes constitute a switch from one state to another once a critical threshold has been passed. Is it reasonable to refer to this change in hydrography in such terms?

The answer would seem to be 'Yes'. The changes we observe are perhaps distinct from those of a simple seasonal cycle in that there is a complete exchange of unique water masses rather than continuous modification. Further, a density threshold (i.e. the breakdown of the shelf/fjord front) triggers the exchange so that the system switches from one quasi-stable mode to another. Finally, rather than returning to its initial state by following the same path in reverse, it displays some degree of hysteresis. In these respects, the changes we have described could be termed an abrupt climatic shift – albeit regional and restricted to the marine environment.

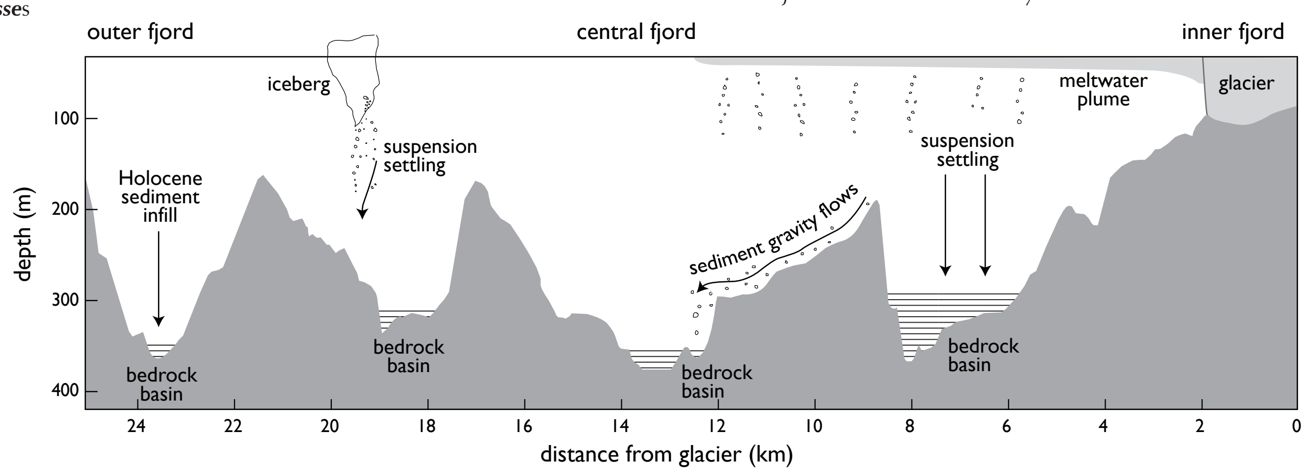
Archives in the sediment

Marine sediments preserve an important record of climate history. Crucially, interpretation of these records draws heavily on our understanding of present-day circulation and exchange. Sediment records from Kongsfjorden provide a means of assessing past change in the marine climate by understanding the relative contributions of waters of different origin to the hydrographic balance.

The fjord comprises a series of deep (>350 m) bedrock basins, containing thick accumulations of relatively young sediments, separated by shallower areas having much thinner sediment cover. Figure 6 is a cross-sectional transect that follows the deepest parts of each basin. The bathymetry and sediment structure along the transect were derived from an acoustic survey taken from *James Clark Ross*. The survey revealed evidence for past glacial advances and retreats and the effect of recent physical oceanographic processes on sediment layering.

The sediment layers in the deep basins of Kongsfjorden record past glacial advances and retreats and the effects of recent physical oceanographic processes

Figure 6 *Transect along Kongsfjorden, following the deepest parts of each basin. Most of the great thickness of sediment in the inner basins was deposited at the end of the last glacial period. Rain-out from the plume of glacial meltwater has supplied most of the sediment accumulating in the fjord over the last 10 000 years.*



The thickest sediments are found in the inner basin, closest to the glaciers at the head of the fjord, where accumulations of glacial material, from both moraine deposits and meltwater, and ranging in size from boulders to clay, can be more than 100 m thick. Further seaward, basin deposits are between 20 and 60 m thick and consist primarily of moraines, deposited when glaciers retreat, or ice-front surge deposits, which result when sea-bed sediments are redistributed as glaciers advance. Core samples indicate that the main depositional processes since the end of the last glacial period about 10 000 years ago (i.e. during the Holocene) have been sediment rain-out from above, and reworking by sediment gravity flows at the sea-bed (cf. Figure 6). At present, rain-out from the glacial meltwater plume supplies most of the sediment, which accumulates at a rate of about 1 mm yr^{-1} in the central basins of the fjord. Such sediment accumulations have the potential for providing a high-resolution record of the marine climate within the last 5000 years.

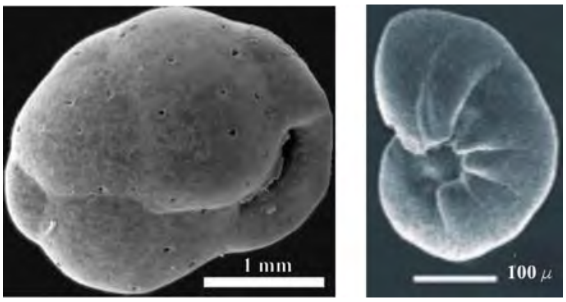
The principal proxy used to reconstruct hydrographic conditions from the sediment material is the remains of benthic foraminiferans preserved in the sediments. Two complementary analyses are used: species composition and oxygen isotope ratios of formaniferans' calcareous shells (see Box). Initial species counts indicate that *Nonion labradoricum* has dominated the sediments from the central and outer fjord during the recent past. Hydrographically, this probably relates to the presence of relatively temperate Transformed Atlantic Water occupying the depths of the central and outer basins. In contrast, the inner basin is typically occupied by *Cassidulina reniforme* assemblage, indicative of a more Arctic water mass. Preliminary results from assemblage analyses, and from variations in $\delta^{18}O$ values, indicate that the influence of Atlantic Water may have been stronger during the last millennium.

Concluding comments

Contemporary CTD data indicate that the hydrography of Kongsfjorden can switch to a state that is either strongly or weakly influenced by Atlantic water. Consequently, it is an ideal site for studying and monitoring change in the Arctic marine environment. Currently very little is known about the influence of Holocene climatic fluctuations on Svalbard, mainly because of the lack of high-resolution records across this region (such records are mainly limited to lake sediments and ice cores, as there are very few trees on Svalbard).

By combining oceanographic observations with estimates of the ancestral hydrography from the marine sediment record, SAMS is contributing to the determination of Holocene climatic variability in the region. Understanding the processes that determine the chronology and magnitude of the shift from Arctic to Atlantic conditions provides a valuable tool for interpreting past and future change with implications, across many marine disciplines.

Benthic foraminiferans record climate change



The tiny calcareous remains of benthic foraminiferans in sediment cores can tell us about changing climatic conditions in various different ways. Methods used in our study were:

Species composition The relative abundances of different species contributing to the remains at a given depth in a sediment core vary according to past climatic conditions. Through comparison with their modern distribution patterns, particular benthic species can be correlated with particular bottom-water conditions. For example, foraminiferal assemblages dominated by the calcareous benthic species *Nonion labradoricum (right)* show a positive correlation with temperature and salinity, indicative of a more temperate water mass. In contrast, *Cassidulina reniforme* (*left*) shows a negative correlation, indicating that the species favours colder and rather less saline waters. Temporal changes in relative species abundances enable a record of bottom-water conditions to be constructed.

Oxygen isotope ratios The $\delta^{18}O$* signature in the carbonate tests of foraminiferans varies with the $\delta^{18}O$ value of the water they lived in, but differs from the water value by an amount that is temperature dependent. The mean $\delta^{18}O$ of the oceans varies with the quantity of 'isotopically light' ice stored on the continents (i.e. with the size of the ice caps), so the $\delta^{18}O$ value of foraminiferans is a combination of the global (ice-volume) and local (temperature) components. Typically, Arctic Water has a $\delta^{18}O$ value of −1, while Atlantic Water has a $\delta^{18}O$ of 0.3; $\delta^{18}O$ of glacier ice is −21.

*The $\delta^{18}O$ value of a water sample or of a carbonate shell is a measure of the ratio of the abundance of the two isotopes of oxygen ($^{18}O : {}^{16}O$) within it, relative to the ratio in a standard. $\delta^{18}O$ is defined as follows:

$$\frac{(^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{standard}}{(^{18}O/^{16}O)_{standard}}$$

Further reading

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Saloranta, T.M., and P.M. Haugan (2004) Northward cooling and freshening of the warm core of the West Spitsbergen Current, *Polar Research*, **23**(2), 79–88.

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Svendsen, H. *et al.* (2002) The physical environment of Kongsfjorden–Krossfjorden, an Arctic fjord system in Svalbard, *Polar Research*, **21**(1), 133–66.

Finlo Cottier is a research associate in the Marine Physics Group at the Scottish Association for Marine Science (SAMS). His current research interests are in the multidisciplinary aspects of Arctic marine systems, particulary those in coastal and shelf areas.

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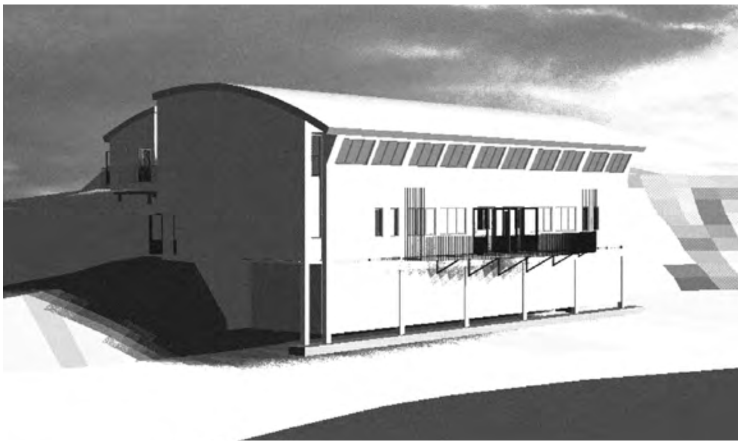
SAMS high-latitude work to be supported by new Arctic Marine Lab on Svalbard



Architect's drawing of the new Arctic Marine Laboratory on Spitsbergen

Through their five-year core programme funded by NERC, the Scottish Association for Marine Science (SAMS) has been actively engaged in high-latitude science since 2001. Most of their work has been conducted in sub-polar seas close to the Norwegian margin, up to a latitude of 80° N. Areas addressed include biogeochemical cycling, pollutant transport, biological community structure and function, and exchange physics in domains that range from the sediments through the entire water column to the ocean–ice–atmosphere boundary.

SAMS' commitment to Arctic marine science is manifest in its membership of a consortium of users of the Arctic Marine Laboratory at Ny-Ålesund in Spitsbergen, Svalbard (see p.17). The Laboratory, planned to open in June 2005, will be an experimental facility for research in marine ecology and physiology, as well as physical sciences like physical oceanography and marine geology.

Biophysical interactions in high-latitude oceans

Dan Mayor

Animal migrations are a well-known phenomenon which, for many zooplankton biologists, can be exemplified by the vertical migrations undertaken by many of the minute animals that live in the world's oceans. As if in homage to the achievements of these tiny creatures, marine scientists from the far reaches of the British Isles, as well as Canada, Norway and Denmark, recently descended upon the British Antarctic Survey's headquarters in Cambridge, to attend the first meeting of the Challenger Society's Special Interest Group on Biophysical Interactions (SIGBI), held on 20–21 April.

The cue for many of these enigmatic individuals to leave the confines of their laboratories could be sensed as early as Tuesday morning: the swarming process had begun! As the conference made its unofficial start that evening, all sensory apparatus homed in on the bar of Churchill College, desperately searching out the nectar of life. The SIGBI two-day symposium was held in association with the NERC Marine Productivity Thematic Programme, serving as the final official gathering for the marine scientists involved.

Although many of those attending could be described as the work-horses of investigations into marine productivity, when you take them to water, there seems to be no difficulty in getting them to drink. The premature closure of the bar, however, brought about a rather abrupt end to the first night. Not wanting to be beaten by the bell for a second time, the following evening a group of hardy seafarers set sail into the bright lights of Cambridge. Judging by a few faces the following morning, their voyage had been an arduous one.

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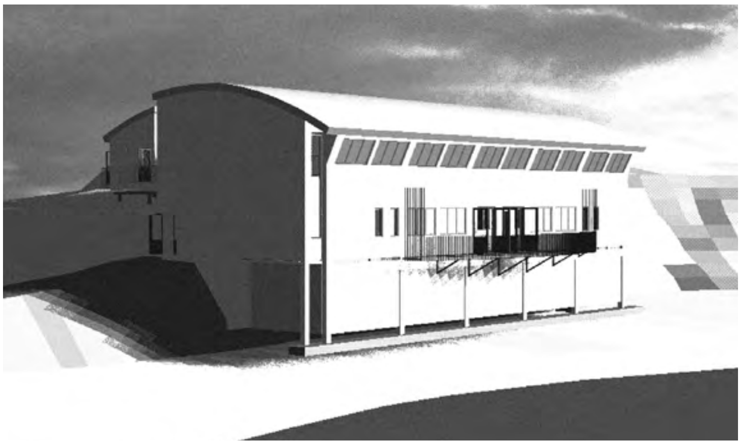

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As this was the first time that a meeting of the SIGBI had been convened, there was a distinct air of anticipation as the attendees filed into the conference room on Wednesday morning. The underlying theme of the meeting was how environmental factors influence the compositions and productivity of marine communities in high-latitude oceans, particularly the northern North Atlantic and the Southern Ocean. With these locations in mind, it was hardly a shock to find that the book of abstracts was littered with the names *Calanus finmarchicus* and *Euphausia superba*. The breadth of science covered in the talks and posters was truly impressive, ranging from molecular to basin-wide scales. All of the presentations were made in a clear and accessible manner, and it came as a welcome surprise to find that there was not a sverdrup in sight!

Perhaps the most striking feature of all the work presented during the meeting was the truly multidisciplinary nature of contemporary marine science. Several of the presentations focussed on broad-scale ecosystem analysis, and clearly involved the synthesis of data provided by biologists, chemists, physicists and numerical modellers.

The keynote talk of Angus Atkinson (BAS) was particularly enjoyable in this respect. He used an array of physical and biological data to examine the factors responsible for, and the possible implications of, the observed decline in the abundance of Antarctic krill. It appears that the Southern Ocean is undergoing a 'regime shift' – a rapid reorganization of an ecosystem from one relatively stable state to another – changing from a krill-dominated system to one in which gelatinous species (e.g. salps) play a leading role. This decline in krill numbers appears to be caused by a reduction in the area seasonally covered by sea-ice, under which juvenile krill overwinter, but the exact reasons for the decline are still under debate.

At present it is thought that foreign species cannot take hold in the Southern Ocean because of the extreme water temperatures. However, high-latitude areas are thought to be some of the fastest warming parts of the planet, raising the question as to how long native species can maintain their dominance.

Mike Heath (Fisheries Research Services, Aberdeen) described how the abundance of *Calanus* has drastically declined in parts of the North Atlantic (particularly the North Sea) over the past 50 years, indicating that there are clear parallels between Antarctic krill and *Calanus finmarchicus*. The reduction in *Calanus* has yet to be understood, although it is hoped that data from the Marine Productivity Programme and the Continuous Plankton Recorder will provide insights into the reasons behind this trend. Are gelatinous animals increasing their abundance in response to the decline in *C. finmarchicus*? And if so, what are the implications for the functioning of the North Atlantic ecosystem and its fisheries?

The application of numerical models to further understand biological processes was another theme that recurred throughout the meeting. Øyvind Fiksen (University of Bergen) presented the second keynote talk, providing examples of how seemingly complex interactions between animals and their environment can be represented numerically. Who would have thought that fish odour could change not only the behaviour but also the reproductive strategy adopted by zooplankton?

Several talks addressed the use of models to examine the driving factors behind the observed distributions of zooplankton, integrating data from several disciplines. Sally Thorpe (BAS) presented a physical model that described the circulation of water around the Antarctic continent, and examined the implications of this for the transport of krill. By incorporating sea-ice motion into this model, she was able to realistically produce the observed patterns of krill abundance, again demonstrating that the seasonal coverage of sea-ice is an important factor in driving the distribution of krill.

Other modelling studies addressed the distribution of *C. finmarchicus* over an annual cycle in the North Atlantic. Despite the complex interactions between *Calanus* and the environment, the model presented by Dougie Speirs (University of Strathclyde) was able to recreate many of the features of *Calanus* populations observed during the Marine Productivity cruises in spring, summer and winter. Interestingly, to improve the match between the model and observational data, an environmental cue was invoked as the stimulus for *Calanus* exiting its over-wintering stage – a good example of how models can provide insights into large-scale biological processes.

Several, if not the majority of the talks made at least some reference to satellite-derived data, serving as a testament to our continuing dependence upon remotely sensed information. What a pity the North Atlantic is so cloudy in winter. Stephanie Henson (National Oceanography Centre, previously SOC) explained how satellites can be used not only to provide basin-wide information on primary production, but also to quantify nutrient availability for phytoplankton. Significant developments in making reliable estimates of primary and new production from satellite data were also evident, as Gavin Tilstone (Plymouth Marine Laboratory, PML) clinched the award for the longest animation of the conference (seven years if I remember correctly!). Clearly the role of remote sensors is set to increase in future studies.

At the other end of the marine productivity scale bar, Penny Lindeque (PML), discussed how robots have been used to identify the different species of *Calanus* present in the North Atlantic – what with measuring production from space and undertaking molecular work with robots, one really has to wonder how long it will take before the next 'regime shift' occurs, only this time it will represent the change in dominance between man and machine!

If these presentations served to illustrate the breadth of the spectrum of marine science funded by NERC, then the depth of this work was demonstrated by the talks and posters that presented data relating to the thousands of zooplankton samples that were collected over an intensive year of fieldwork during the Marine Productivity Thematic Programme – without doubt, a truly mammoth undertaking. Sadly, the end of the meeting marked the end of the Programme itself – of course, that is not to say the end of the numerous friendships that have been forged. Nor does it mean an end to the new links between different institutions and people that have been nurtured by this programme. If anything, enthusiasm amongst the 'Mar Prodders' is higher than ever, as they look forward to a prosperous future. Here's to that future, and 'one for the road'!

Daniel Mayor completed his PhD on the interactions between *Calanus finmarchicus* and its food as part of the Marine Productivity Thematic Programme, and is currently working as curator of the *Discovery* Collection at the National Oceanography Centre, Southampton.

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MEASURING OCEAN TEMPERATURE

What can we learn from Nansen's experience on the *Fram* a century ago?

Gwyn Griffiths

Between 1893 and 1896, Fridjof Nansen led a daring expedition on the *Fram* towards the North Pole. He deliberately allowed the vessel to become icebound north of Siberia, sure in the knowledge that currents would take the ship across the Arctic Ocean towards Svalbard. As the *Fram* drifted with the ice, a series of hydrographic stations were made, whose results are important to this day. *Furthest North,* Nansen's narrative of his expedition on the *Fram* was a global best-seller, with its tale of adventure and the challenge of reaching the North Pole; the second UK edition of *Furthest North* was published by George Newnes, a media mogul of the late Victorian era. Nansen's six volumes on the scientific results of the expedition are considerably less well known than *Furthest North, y*et Nansen was first and foremost a careful and observant scientist. It is the third scientific volume, and particularly Part IX on the 'Oceanography of the North Polar Basin', that is relevant to this article.

Thermometry undertaken on the Norwegian North Polar Expedition 1893–96

In his introduction to 'Oceanography of the North Polar Basin', written in January 1902, almost nine years after the expedition sailed, Nansen wrote:

> I have now learnt that future investigations in physical oceanography will be of little or no value if they are not made with a much higher degree of accuracy than has generally been the case hitherto.

Nansen returned time and again to the importance of the basic measurements of physical oceanography: temperature, salinity, specific gravity (the term he used), and to currents, and in particular the accuracy of the measurements. This was not through some fascination with ultimate accuracy or technological complexity; rather, it was because his clear vision and understanding meant that he saw that these measurements could be of long-term interest to science – but only if they were of sufficient accuracy.

He felt the lack of accuracy in his instruments to be most regrettable:

> This is so much the more to be regretted as not only secular changes in the circulation of the sea, but possible secular variations in the temperature of the atmosphere or the surface of the earth can probably be most easily determined by the variations of the mean temperature of the ocean.

What foresight! Yet accuracy (i.e. correctness) was not the only issue; his measurements lacked *precision*, i.e. the necessary sharpness of definition.

To collect water for salinity samples and gas analyses, and for temperature measurement, the expedition used an insulated water bottle designed by Professor Otto Pettersson (Figure 1). Temperature was obtained by immersing a mercury-in-glass thermometer into the water bottle after it had returned to the surface. On the performance of the water bottle, there was some disagreement between the expectations of the designer, Pettersson, and the at-sea experience of

Author's Note: *In the spring of 2003, Jane Read, on behalf of the Council of the Challenger Society, asked me to give a talk at the Centenary meeting of the Society. Apart from the general requirement that it feature a review of technology over the last hundred years, the scope was up to me. The talk made a number of sweeping statements of personal opinion, but also looked in more detail at particular aspects of ocean technology and their application by scientists over the last 100 years. This article focusses on a cluster of slides prepared for the talk on the topic of thermometry, in particular the measurements of temperature in the Arctic Ocean on the pioneer voyage of Fridjof Nansen on the* Fram *from 1893 to 1896.*

For more information see http://www.soc.soton.ac.uk/Discovery/.

the oceanographer, Nansen, who wrote that:

> According to my experience, Pettersson's statement is hardly correct, that the insulation of the water bottle is sufficient to give directly correct temperatures from depth of as much as 400 or 600 metres.

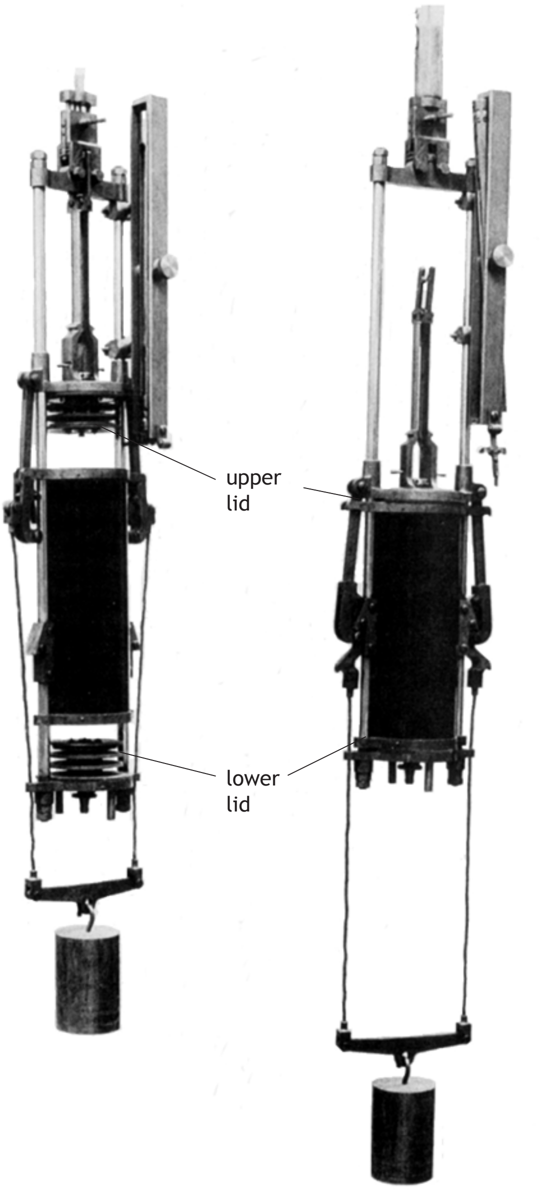
Such disagreements about oceanographic apparatus between engineers and scientists, designers and users, still occur today, and undoubtedly will continue in the future.

Faced with a number of deficiencies in his equipment, Nansen made careful corrections to his temperatures to try and achieve an acceptable accuracy. One correction involved the temperature change on decompression. As far as he knew at the time, no direct experiments had been made on the rise in temperature produced by compression of seawater (as distinct from the experiments of Joule on distilled water, reported in 1860). When samples of water were retrieved from depth using the Pettersson bottle, the sample would cool as the water expanded under decreasing pressure. On the basis of work by Ekman and Tornøe in the 1870s, Nansen's estimate was a 0.023 °C cooling on retrieval from a depth of 600 m.

Other corrections concerned the influence of air temperature on the sample in the insulated water bottle, and the heating or cooling of the sample as the water bottle was hauled through strata of different temperature. For example, Nansen found a correction of +0.07 °C necessary for samples that had been retrieved from 500 m because of the cooling that had taken place as the bottle passed through colder waters on its way to the surface.* The 'zero correction' and scale errors for the thermometers used to measure the temperature of the retrieved samples were almost invariably less than 0.01 °C, except when the scale of the much-used thermometer No. 7 (made by a Dr Franz Müller of Bonn) 'became loosened' and a correction of +0.25 °C had to be made.

Reversing mercury-in-glass thermometers made by Negretti and Zambra provided deep-sea measurements beyond the usable depth of the insulated water bottles. In these thermometers, the glass tube containing the mercury had a kink at the bottom of the mercury column, so that when the thermometers were reversed at the chosen depth, the mercury column broke, so 'preserving' the temperature measurement.

Fram had eight of these thermometers aboard. Five proved reliable. The three thermometers with the finest graduation (0.1 °C) had very narrow bores, and the mercury often failed to break on reversal. Nansen considered that the thermometers with 0.2 °C graduations could be read to 0.02 °C (i.e. the precision was 0.02 °C), provided that particular care was taken to avoid error due to parallax when reading the scales. Unfortunately, variations in the break-point of the mercury meant that he considered the accuracy to be only ± 0.05 °C. He was clearly disappointed. This problem with the variability of the break-point continued to occur periodically with Negretti and Zambra thermometers over the next 50 years. Herdman and Pemberton, commenting in 1958 on Negretti and Zambra reversing thermometers made in the 1930s, wrote that 'the behavior of the whole batch was generally erratic'.



Despite the insulation, the temperature of water captured in a Pettersson bottle would be affected by the temperature of water passed through on retrieval

Figure 1 *An insulated water sampling bottle as designed by Otto Pettersson and modified by Fridjof Nansen, of a type similar to that used on the* Fram *during the Norwegian North Polar Expedition of 1893–96. The photograph on the left shows the bottle as it would be on deployment; that on the right shows the bottle closed on reaching the intended depth. In this version of the bottle, closure was triggered by a 'messenger' weight being sent down the wire to which the bottle is attached, causing the lid to drop onto the top of the cylinder; this in turn released the cylinder from its weak support hooks, allowing it to fall onto the lower lid, aided by the underslung weight*

Courtesy of the Musée Océanographique de Monaco. Photographer: Y. Berard.

* In contrast to the hauling rate of 60 m per minute typical of modern CTD winches, it was not uncommon for these insulated water bottles to be retrieved at 400 m per minute.

Was there an alternative to reversing thermometers?

Should Nansen have tried to use an emerging temperature measurement technology instead of water bottles and mercury thermometers? After all, the technique used today for deep ocean temperature measurements, with an accuracy of 0.005 °C or better, and a typical precision of 0.001 °C, has its roots in the early 19th century. In 1821 Sir Humphry Davy discovered that the electrical resistivity of metals depends on temperature. This physical principle was employed for a differential thermometer designed by the Siemens brothers and used on the *Porcupine* in 1869. Two coils of platinum wire formed two arms of a Wheatstone bridge, with a galvanometer to indicate the balance point. One coil formed the *in situ* sensor, which was lowered over the side of the vessel and connected to the remainder of the apparatus by a thin two-conductor cable. The other coil was immersed in a bath of water on board the ship. The measurement procedure was to warm or cool this bath of water until the galvanometer showed the bridge to be balanced, the assumption being that at the point of balance the temperature of the water bath would be the same as the temperature at the *in situ* coil. The temperature of the water bath was read with a mercury thermometer. On a moving ship, observing the galvanometer proved difficult, as did adjusting the temperature of the water bath.

The instrument met with some success on the *Porcupine*, and later also on the *Challenger* (1872–76), the *Blake* (1881) and *Valdivia* (1898–99). However, the measurement process was far too cumbersome to be practical in routine use. The indirect measurements by electrical resistance and direct measurements by mercury thermometers were generally found to be in agreement, although no detailed numerical comparisons were provided. Indeed, it is difficult to see how, at that time, measurements via electrical resistivity could have been shown to be more accurate.

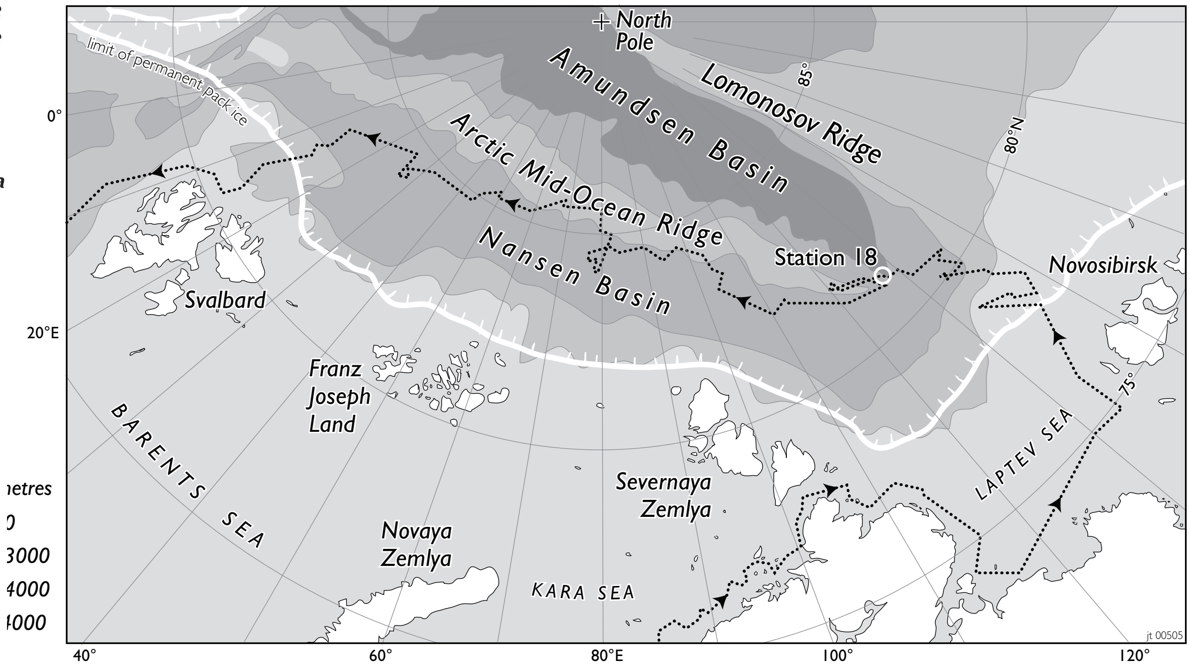
There is no mention in Nansen's foreword to his Report that he even considered using electrical resistance thermometry. It is doubtful that it would have improved his temperature measurements, and it would have certainly added to the complexity and time taken to make measurements. The technique would not come into its own for oceanographic *in situ* measurements until the 1960s, when precision resistors with low temperature coefficients could replace the second coil in a water bath, and stable electronic circuitry could replace the galvanometer. Since then, platinum resistance thermometry has become standard, embodied within the CTD – the conductivity (for salinity), temperature and depth instrument which is the workhorse of the physical oceanographer.

Comparison of *Fram* measurements and modern data

In one respect, Nansen was right to be disappointed with his instruments, for the limited precision of his deep-sea measurements on this expedition limit their usefulness in forming comparisons with modern data. However, his temperature measurements in the upper 1000 m of the Arctic Ocean do provide an excellent source for comparison. To illustrate these two different situations, let us examine the data from *Fram* station 18, in what is now known as the Amundsen Basin (Figure 2). Here, temperature profiles were made from 13 to 16 August 1894 as the ship drifted within the pack ice. The position varied from 81° 44′ N, 127° 55′ E to 81° 6′ N, 128° E over the four days, and the bottom depth was about 3870 m.

Figure 2 *The track of the* Fram *(broken line) during the expedition in which it was frozen into the Arctic pack-ice. Bathymetry is indicated by shading (see key).*

Because station 18 was just within the deep water of the Amundsen Basin it is useful for comparison with recent climatological data collected nearby (cf. Figure 3)



Unfortunately, making comparisons with modern data is not straightforward. Observations from the ice-covered waters of the Amundsen Basin are uncommon, with the exception of a mass of observations from the 1970s, when Russian oceanographers occupied many hydrographic stations over the Eurasian Arctic. The most readily available temperature profile data is the annual average on a 1° by 1° grid from the *World Ocean Atlas 1998*, which has been extracted for 81° N 126° E using Java Ocean Atlas,* this being the closest location available. The average tends to reflect measurements made from the 1970s to the mid 1990s, representing the modern era. Lack of exact correspondence of location is not a major limitation, as water properties evolve slowly with space in the deep Amundsen Basin. The important fact is that the observations were in a similar water depth (which they were) and in the Amundsen Basin. Many of the measurements in the database would have come from modern instruments using platinum resistance thermometry with a typical accuracy of better than 0.005 °C, but measurements from reversing thermometers would also be included.

Figure 3 shows the temperature profiles for the modern annual average temperature and the profile from *Fram* station 18. Below 1500 m, well within the water mass known as Arctic Bottom Water, the root mean square difference between the two datasets is 0.06 °C. This is very similar to Nansen's expected error, and makes it difficult to draw any conclusions about changes in the deep water of the Amundsen Basin using the *Fram* data alone.

In contrast, the change in temperature of Arctic Intermediate Water, a water mass found between 150 and 900 m depth, is well above the instrument error. *Fram* station 18 showed the temperature maximum of 0.32 °C within the Arctic Intermediate Water to be at a depth of 400–450 m. The modern mean climatology (long-term average) has the maximum temperature of 1.71 °C at a shallower depth of 300 m. The maximum temperature difference between the two datasets is 1.74 °C at a depth of 200 m. This suggests a significant warming of waters from the North Atlantic over a century. However, significant interannual variability in the characteristics of water of North Atlantic origin means that it would be unwise to suggest that the actual warming was as great as indicated by this comparison of *one* station in 1894 with a modern average. Nevertheless, Knut Aagaard and James Swift found recently that the maximum temperature of Atlantic water recorded in this area by *Fram* was several tenths of a degree colder than the low end of observations made in the second half of the 20th century.

Recently, Igor Polyakov and his colleagues have used Nansen's data to begin a detailed analysis of the variability of the temperature of Atlantic water in the Arctic Ocean over the last 100 years. Their paper points to two warm periods, one in the 1930s–40s and another in recent decades. There appears to be an oscillation with a period of 50–80 years rather than a simple linear trend. Nansen's data from 28 hydrographic stations made during 1893–96 were of value to this study not only because of their quality, but also for their quantity. For, over the next 60 years, data from only 515 stations, made during various expeditions across the entire Arctic Ocean, were recorded in the archives of the Arctic and Antarctic Research Institute in St Petersburg, Russia.

Nansen's aim of making a set of measurements with a legacy for the future has certainly been justified.

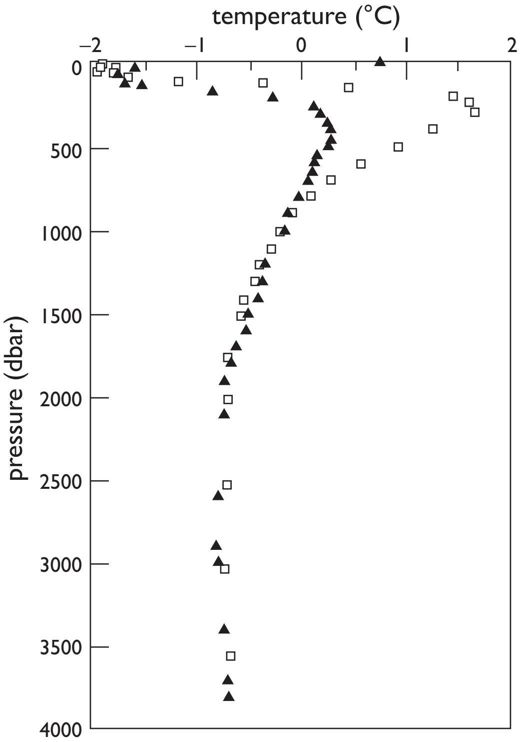


Figure 3 *A comparison of temperature measurements made in the Amundsen Basin of the Arctic Ocean from* Fram *(triangles: Station 18 on 13–16 August 1894) near 81° 30′ N, 128° E, with modern-day climatology (squares) at 81° N, 126° E. The 0.05 °C uncertainty associated with* Fram*'s deep-sea reversing thermometers precludes conclusions being drawn on trends in the temperature of Arctic Bottom Water, but the warming of Arctic Intermediate Water (~ 150–900 m) is very clear. The* Fram *measurements showed a warm layer of + 0.8 °C at the very surface, reducing rapidly to – 1.4 °C at a depth of 2 m.*

Comparison of modern data with measurements made on the* Fram *shows a warming of intermediate water, but nothing conclusive about deep-water temperatures

See 'Arctic' at http://odf.ucsd.edu/joa/data/woa98text.html

Reflection

Nansen's measurements from the *Fram* have provided us with a valuable legacy, not only a snapshot of the temperature and salinity of the deep Arctic Ocean in the late 19th century, but a legacy of careful measurements and attention to detail in calibration that has been a hallmark of physical oceanography. As he surmised, and as he regretted, his instruments proved insufficiently accurate or precise for us today to reap the full benefit of his observations. Nevertheless, the observations of the intermediate Atlantic waters are a valuable resource in assessing changes within the Arctic over a century.

Acknowledgements

I acknowledge the helpful comments of Knut Aagaard and Roger Colony on the comparison of Nansen's observations with modern climatology. The photographs in the title graphic are reproduced by courtesy of the Fram Museum, Oslo, Norway.

Further reading

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Archives of Natural History, Vol. 32 (2), to be published in Oct. 2005 will be a Special Issue on

A Century of Discovery: Antarctic Exploration and the Southern Ocean

Gwyn Griffths and David W.H. Walton (Associate Editors); Charles Nelson (Editor)

This is a well illustrated, peer-reviewed volume containing an eclectic range of articles on the history and development of ocean and polar science since the *Discovery* Expedition of 1901–04, Details of the Volume will appear at www.shnh.org/PUB ANH main.htm

Copies will be issued free to members of the Society for the History of Natural History, and will also be available from the Associate Editors (gxg@noc.soton.ac.uk); the cost is expected to be about £20 + postage)

These articles in the volume arise from the Symposium of the same name, held in 2004 (http://www.soc.soton.ac.uk/Discovery/abstracts.html).

Solution to the Maritime Crossword Challenge

The sender of the winning solution was **David Pugh**, Chester.
He will receive a copy of
A Century of Discovery: Antarctic Exploration and the Southern Ocean
described above.