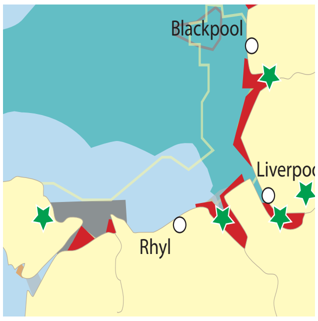

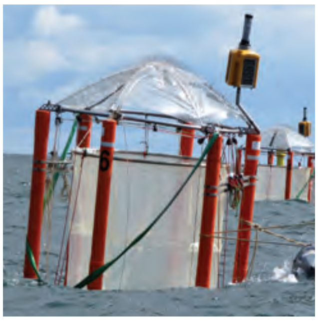

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The maps and diagrams were drawn by The ArtWorks
The cover was designed by Ann Aldred Associates
Cover photograph © Ann Aldred

Message from the Editor

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However, this long-term scenario may not apply to the Gulf of Mexico. First, oil should degrade much more quickly a warmer environment; secondly, rate of degradation depends on the form of the oil, with emulsified oil (known as 'mousse') being particularly persistent. Interestingly, the persistence of the oil in Prince William Sound is at least partly due to the two-layer character of the beaches there. Studies[†] have shown that the oil persists in patches below a gravelly surface layer; this high permeability layer temporarily stored the oil, while it percolated into fine-grained sediments below whenever the water table dropped below the interface between the layers – which happened frequently as the beaches have a relatively small freshwater inflow. Once the oil entered the lower layer it was trapped by capillary forces and remained in the almost anoxic conditions.

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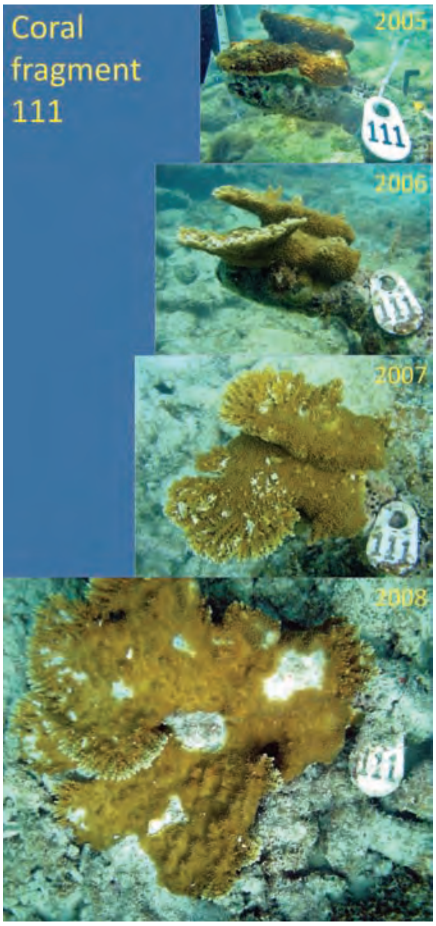
Evaluating the success of coral transplantation

Projects to restore damaged coral reefs are fairly common, but there has been relatively little study of how well various techniques work. A recent issue of *Restoration Ecology* describes an investigation into restoration of *Acropora palmata* (elkhorn coral), an ecologically important Caribbean coral whose populations have suffered severe decline.

Branching corals like *A. palmata* reproduce asexually when fragments that break off during rough weather take hold on a suitable substrate. The experiment investigated the relative success of using four different methods of attaching fragments to the reef: cable ties, two types of epoxy resin, and hydrostatic cement. Some coral fragments were attached at the original site, and some were attached elsewhere. In both cases, fragments grew and died at a similar rate, so moving the fragments out of the original habitat had no deleterious effect. Control fragments left untouched at the original site grew more slowly and were more likely to die than fragments that had been physically attached to the reef. Clearing the macroalgae that dominate degraded reefs had a positive effect on the growth of the fragments.

After four years, transplanted fragments had grown sufficiently to become potentially sexually active. This is good news for coral conservation, because although the methods tested could not be used to remediate large areas, they are cheap and simple and could be undertaken by recreational divers with minimal training, for example to assist damaged reefs where natural recovery is slow.



Left
A researcher measures a transplanted coral fragment
Above
The growth of a transplanted coral fragment between 2005 and 2008

Photos by courtesy of Graham Forrester

*Forrester. G, *et al.* (2010) *Restoration Ecology*, doi: 10.1111/J.1526-100X.2010.00664.x

Another dimension to delta morphology

Many marine scientists will remember being taught the triangular diagram showing that the morphology of a delta depends on the relative influences of river discharge, tidal range and wave action. Thus the Mississippi, with its enormous discharge, produces a delta resembling a bird's foot; the tidally dominated Ganges–Brahmaputra has many elongate sand banks more or less ar right-angles to the coastline; and wave-dominated deltas like the Nile have the characteristic Greek 'Δ' shape, noted by Herodotus in the 5th century BC.

More recently, sea-level rise and engineering have been shown to influence the evolution of delta shape, but the effects of total sediment load and sediment type have generally been considered secondary. The role of sediment cohesion (controlled by sediment size and vegetation type) has not been clarified.

The authors of a recent article in *Nature Geoscience** used a numerical flow and transport model to show that sediment cohesiveness does influence the morphology of deltas. They found that, all other factors being constant, highly cohesive sediments form bird's-foot deltas with bumpy shorelines and complex floodplains, whereas less cohesive sediments result in fan-like deltas with smooth shorelines and flat floodplains. In their simulations, sediment cohesiveness also controlled the number of channels that form within the deltas, and the average angle of bifurcation of those channels.

The authors note that as vegetation tends to bind sediment together, deltas formed before the spread of land plants should be fan-like, and the limited data from the sedimentological record of the Devonian Period (416–359 million years ago) are indeed consistent with this.

*Douglas A. Edmonds, D.A. and R.L. Slingerland (2010) *Nature Geoscience* **3**, 105–109. doi:10.1038/ngeo730

Bacterial nanowires? Researchers* working on samples of anoxic sediment from Aarhus Bay noticed that when they reduced the oxygen concentration of the overlying seawater, hydrogen sulphide built up lower down in the sediment; when the overlying water was oxygenated, the hydrogen sulphide concentration beneath decreased. These changes happened in less than an hour, much faster than would be possible through molecular diffusion or conventional chemical reactions. It's thought that aerobic bacteria at the surface and anaerobic bacteria below were connecting with one another via tiny wires that grow from them. It was known that some bacteria are capable of extracellular electron transfer, and the idea of bacterial nanowires has been proposed before. However, this is the first time that there has been evidence for electric currents flowing through sediment over distances of centimetres, connecting separate biogeochemical processes mediated by different populations of bacteria. It raises exciting possibilities for future investigations and applications. *Nielsen, L.P. *et al.* (2010) *Nature* **463**, 1071–74 (25 February) doi:10.1038/nature08790 Letter

Reprieve for the Naples Anton Dohrn Zoological Station

In late May, the Stazione Zoological Anton Dohrn di Napoli (SZN) was in grave danger of being closed down, as part of the Italian government's financial cuts. Roberto di Lauro, the President of the Stazione, mobilised support from marine scientists and biologists worldwide, and a petition on the institution's website was signed by more than 4000 people in less than four days. Thanks to the intervention of the President of the Italian Republic, Giorgio Napolitano, and the obvious widespread support, the SZN is no longer in imminent danger of closure. However, this could just be a reprieve; there has been a cut of funding of 50% for all cultural institutions in Italy, and research institutes could be next.

The SZN is one of the oldest marine research stations in Europe, and with 300 permanent staff and students, one of the largest. It is strategically sited on the Gulf of Naples, with direct access to the biodiversity of the Gulf through its sites in Naples and the island of Ischia, and through its three research vessels. It also operates a unit for coastal zone management and a turtle research centre, and hosts an historic aquarium. The institute is unique in Europe as although it is under the aegis of the Italian Ministry for Research and Education, it reports to both the Ministry and its own international advisory board which acts as a guarantor for the excellence of its research. A recent research assessment exercise by the Italian government put the SZN in the top 15 research institutes in Italy and in the top 10 for research institutes of a similar size (http://www.civr.it/).

Since its foundation (see below), the SZN's primary interest has been in the mechanisms whereby natural selection operates, and it carries out basic biological and ecological interdisciplinary research on the organisms and ecosystems of the Bay of Naples. The SZN has always strived to apply the latest research techniques and make them available to the international and regional communities. Recently it has played a major role in numerous EC Framework Package networks and infrastructures and as such it is clearly a European and national centre of excellence.

A research project coordinated by the SZN, awarded by the European Strategy Forum on Research Infrastructures, led to the creation of the European Marine Biological Resource Centre (EMBRC), which will allow scientists to use state-of-the-art technologies to study the composition, physiology and diversity of marine organisms – work of relevance to biomedicine and the life sciences in general. Furthermore, the SZN is involved in 'ASSEMBLE' – the Association of European Marine Biological Laboratories – which aims to create a network of marine biological research stations around the European coastline, collectively providing access to a comprehensive set of marine ecosystems and to a wide variety of model marine organisms, including experimental organisms suitable for work in genomics and proteomics (the study of an organism's complete complement of proteins). Finally, the SZN is a member of the consortium that led to the founding of the Institute of Biology and Molecular Genetics (BIOGEM).

Historical note: Many marine scientists will first have come across 'Anton Dohrn' through the seamount of that name in the Rockall Trough, between Ireland and the Rockall Plateau. The seamount was named after the vessel which discovered it, which itself had been named after the far-sighted biologist Felix Anton Dohn (1840–1909). Dohrn – a strong supporter of Darwin's ideas – was perhaps the first person to appreciate the value of research stations where scientists based elsewhere could work for a period, collect material, make observations and undertake experiments, supported by a permanent infrastructure and support facilities. The Stazione Zoologica was built at Dohrn's expense, in the beautiful Villa Comunale, and was opened to visiting scientists in September 1873; when Dohrn died in 1909 more than 2200 scientists from Europe and the United States had already worked there. The model has been copied in various places around the world. In Britain, marine laboratories that originated around this time include the Dunstaffnage Marine Station (SAMS), the Gatty Marine Laboratory (p.18), the Marine Biological Association of the UK, the Dove Marine Laboratory (Newcastle University), the Fisheries Research Laboratory, and the Bangor Marine Station.

Compiled with the kind assistance of Antonietta Spagnuolo

Damselfish are tending their gardens across the oceans

It has been known for a while that herbivorous damselfish compete for and protect areas of habitat that support their preferred algae, driving off other herbivorous fish and sea-urchins. Damselfish can only eat certain types of algae, because they lack the organs and enzymes that would allow them to digest more fibrous species.

Research published in 2002 described how *Stegastes nigricans*, a species of damselfish living off Japan, weeds its territory to encourage the growth of a particular species of filamentous red alga. Now a survey* of 320 territories of 18 damselfish species from coral reefs around the Indian Ocean, the Red Sea, the south-western Pacific, and the Great Barrier Reef, has shown that weeding by damselfish is widespread, although the protected algal species varies slightly. Some damselfish grow a mixture of algal crops, while others maintain monocultures with higher yields per unit area. Animals living amongst the algae are also an important part of the damselfishes' diet.

A damselfish guards its garden

*Hata, H. , K. Watanabe and M. Kato (2010) *BMC Evolutionary Biology*, **10**, 185. doi: 10.1186/1471-2148-10-185

Interactive marine map launched

The Marine Conservation Zone (MCZ) Project is working with people who use the sea to choose MCZs in English inshore waters, and waters offshore England, Wales and Northern Ireland (see p.15). As part of this consultation and information-gathering process, the MCZ Project has developed an interactive map (www.mczmapping.org), to which people can upload information about their marine activities, locations of marine wildlife, notable habitats and geological features. All data will be analysed and will inform recommendations for potential MCZs. A regional version of the map has already been successfully used in the south-west.

The deadline for uploading data is 30 September 2010. Details of species and habitats that MCZs will be designed to protect can be found at: www.naturalengland.org.uk/ourwork/marine/protectandmanage/mpa/mcz/features/default.aspx

Testing times for Atlantic bluefin tuna

In October 2009, scientists with the International Commission for the Conservation of Atlantic Tuna (ICCAT) warned that the Atlantic bluefin tuna's spawning biomass is less than 15% of what it was before industrial fishing. They argued that a global ban on Atlantic bluefin tuna fishing was essential if commercial extinction of the species was to be avoided. This warning was not heeded at the ICCAT meeting in November, and another chance to prevent the bluefin's decline was lost in March this year, when an EU proposal to suspend international trade in Atlantic bluefin tuna until stocks recover was rejected at the UN Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

There are two distinct populations of Atlantic bluefin – the western Atlantic bluefin, which spawns in the Gulf of Mexico, and eastern Atlantic bluefin, which spawns in the western Mediterranean. ICCAT manages the eastern and western bluefin as separate stocks, although tagging studies have shown that the two populations mingle considerably, particularly in the rich feeding grounds of the north-west Atlantic. Bluefin are particularly vulnerable to commercial fishing during spawning, when they congregate together in large schools.

Over recent decades, fishing pressure on bluefin tuna has increased as a result of a lucrative market for bluefin sushi and sashimi in Japan; a more recent trend is for bluefin to be caught for fattening up on 'ranches', ready for the Japanese market.

In the Mediterranean ...

During the fishing season, groups of spawning bluefin are spotted by light aircraft, and purse-seiners (vessels that use large nets that hang vertically in the water and are used to encircle shoals of fish) are directed to the schools. This year, the purse-seining season began on 15 May and was planned to continue until 15 June, but on 9 June the EU Fisheries Commissioner imposed an early end, in both the Mediterranean and the eastern Atlantic, because the Commission's central control room and ICCAT inspectors had calculated that the purse-seiners were about to reach their quota – despite poor fishing weather in May. Unfortunately, the ban will have a limited effect. The President of the Union of Mediterranean Tuna has said that as eight of the 17 French ships had so far caught only 62% of their quota, fishing would continue. Ships flying non-European flags will of course still be fishing after the end of the EU fishing season.

In the Mediterranean, the bluefin tuna fishery is the only one managed by means of a 'total allowable catch' (TAC) which is decided annually by ICCAT, but TACs set well above sustainable levels advised by fisheries scientists, poor compliance by much of the fishing industry, and lack of enforcement, have meant the measures have completely failed to protect the stocks (as for many other stocks in EU waters).

... and in the Gulf of Mexico

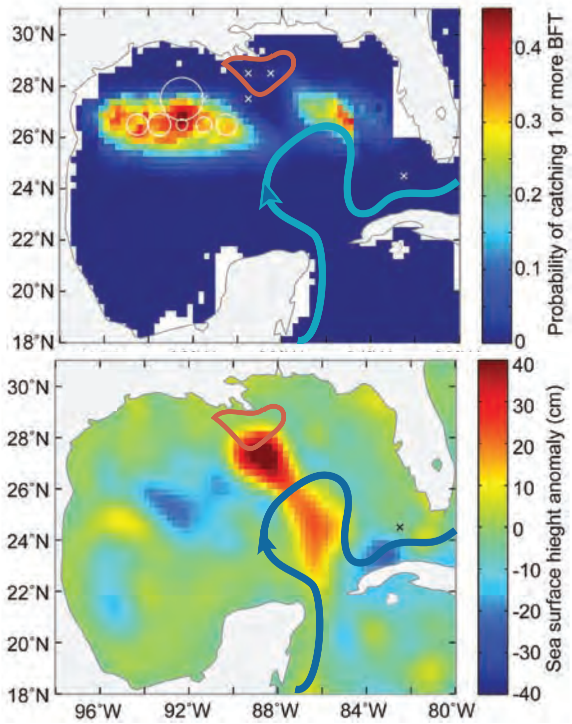
The western Atlantic stock of bluefin tuna has been considered overexploited since 1982. In the Gulf of Mexico, targeted fishing of bluefin has been banned for over 20 years, but the population has not recovered.

There are, however, frequent accidental catches on pelagic longlines, and data on these, plus electronic tagging, have been used to investigate differences in the behaviour of Atlantic bluefin tuna and yellowfin tuna. The researchers* analysed environmental preferences and spatio-temporal distributions of bluefin and yellowfin tuna in conjunction with oceanographic datasets, and developed a model to determine the relative probability of catching bluefin and yellowfin tuna at a given place and time (cf. upper map, for bluefin).

The model showed that bluefin tuna favour Gulf waters from January to June, in contrast to yellowfin tuna, which are widely dispersed throughout the Gulf all year round. The bluefin tuna head for two specific regions within the Gulf of Mexico – one in the eastern Gulf to the north of the clockwise Loop Current, and the other in the western part of the Gulf (upper map). Both regions lie above the continental slope. Within these areas, bluefin prefer to spawn in cyclonic cold-core eddies (lower map), which are more productive than the surrounding warm Gulf water.

As bluefin spawn in April and May, the Deepwater Horizon oil spill may have had serious consequences for them, particularly as the spawning area over the continental slope overlaps with the area affected by the oil (cf. maps). Bluefin release their eggs in the top 15 m or so of water, so eggs — as well as juvenile and adult fish — are exposed to oil and dispersant chemicals. The dispersants may be particularly damaging to the eggs, which are composed mainly of oils.

On a more positive note, the authors point out that it would be possible to use spatial management techniques to protect the bluefin tuna. At any given time, bluefin spawning areas could be determined from oceanographic data (continually gathered by satellites and weather buoys). Fishing for yellowfin tuna, which are widely distributed, could be banned from those areas without compromising the yellowfin fishery. *Ed*



***Upper** Probability of catching one or more bluefin tuna in the Gulf of Mexico in May 2005: circles: actual relative bluefin tuna catch per unit effort; crosses: locations where at least one longline set was deployed but no fish were caught.*
Brown: site of Deepwater Horizon oil spill; blue line: approx position of the Loop Current (our additions).

***Lower** Sea-surface height anomalies on 15 May 2005. Blue tones indicate depressions in the sea-surface corresponding to the centres of cyclonic (anti-clockwise) cold-core eddies.*

*These maps and related information are taken from Teo, S.L.H. and B.A. Block (2010) Comparative influence of ocean conditions on yellowfin and Atlantic bluefin tuna catch from longlines in the Gulf of Mexico in the online journal PLoS ONE 5(5): e10756. doi:10.1371/journal.pone.0010756.

New early warning system for Indian Ocean tsunamis

The catastrophic tsunami of Boxing Day 2004 demonstrated the urgent need for a new generation of fast and reliable tsunami early-warning systems for the Indian Ocean area, and elsewhere. This tsunami was generated by an earthquake of magnitude 9.2, the second-strongest ever measured. The reason that it was particularly destructive was the proximity of the site of the earthquake in the Sunda Trench/Arc subduction zone to the coastlines of the Indonesia archipelago. The first tsunami waves – some of them 30m high – reached landfall just 20 minutes after the earthquake itself. In these circumstances, systems like the Pacific Tsunami Warning system would not have provided sufficient warning time.

DEWS: building on GITEWS

In the wake of the Boxing Day disaster, the GITEWS project (German–Indonesian Tsunami Early Warning System) was initiated. The project, involving nine German institutions, was led by GFZ, the German Research Centre for Geosciences. GITEWS became operational in 2005, and has performed very successfully, with involvement of local scientists and technicians in raising awareness of the danger of tsunamis being a key component.

Since 2007, the infrastructure, extensive sensor networks and experience developed through GITEWS have been used to produce an early warning system for the whole Indian Ocean. Known as DEWS (Distant Early Warning System). This project is funded mainly by the EU, and a consortium of 20 partners including public and private organisations from several EU member states, and depends on close cooperation between Indonesia, Thailand and Sri Lanka. DEWS now deploys a sustainable system to detect and analyse seismic events in the Indian Ocean, swiftly assess their potential to unleash a tsunami, and warn all of the at-risk countries in time to save lives.

The strategically deployed detectors include broadband seismometers, land- and ocean-surface based GPS instruments, tide gauges and ocean bottom pressure sensors. Using a variety of diferent kinds of sensors produces complementary information that allows more accurate assessment of the risk of a tsunami. The data generated by the suite of instruments is streamed via communication satellites to a central station in Jakarta, Indonesia, for processing and identification of any anomalies. State-of-the-art software called SeisComP3, developed by GFZ, determines the location and magnitude and of a seismic event in four minutes. The former systems needed 11 or 12 minutes to detect a signal and locate the source.

Once the system detects an earthquake powerful enough to create a tsunami, it begins to analyse the risk of a tsunami, and model its characteristics. If waves are detected from ocean bottom pressure sensors or (newly developed) GPS buoys at the sea-surface), a tsunami may already have been generated. The question of where and with what run-up height then needs answering very fast. Even with powerful computing capabilities, modelling an event as complicated as a tsunami in real time would take far too long. This problem was solved by using libraries of earthquakes of different magnitudes and source locations, coupled with detailed simulations of the waves they would create around the entire Indian Ocean coastline. When an actual earthquake occurs, the DEWS system automatically finds the simulation that best fits the event, and uses that to determine which coastal areas are at risk.

Communication is the key

The most accurate predictions of tsunamis are worthless if the populations at risk cannot be warned in time. The DEWS system has a component to compose and distribute messages and another to monitor whether messages have been properly received. Of necessity, it is a multilingual system that can distribute different messages to different populations in more than 20 different languages.

From the Indian Ocean to Europe

European shores are not immune from tsunamis: one could occur at any time in the north-east Atlantic or the Mediterranean, with Greece, Turkey and Portugal being the countries at greatest risk. A DEWS-type system would be invaluable, and preliminary steps toward that goal will be taken by other EU-financed projects such as TRANSFER, NERIES and SAFER. To be of most use in the north-east Atlantic (and elsewhere), the system would need to be able to deal with tsunamis that are caused by volcanic eruptions or landslides, as well as seismic events.

The need for a new profession

Perhaps the single greatest innovation flowing from DEWS is the realisation that minimising infrastructure damage and loss of life from a disaster – natural or man-made – requires an enormous amount of technical knowledge and a high degree of coordination. As a result, the consortium is advocating the development of a new profession – that of the 'early warning engineer' who would have the knowledge and skills to be able to take care of the whole early warning field. Courses in this area are already being offered at major universities around the Indian Ocean, and by the University of Bologna, Italy, and the Helsinki University of Technology, Finland.

The DEWS project received funding from the Sixth Framework Programme for research. See also: http://cordis.europa.eu/ictresults/index.cfm?section=news&tpl=article&BrowsingType=Features&ID=91371

The DEWS system being demonstrated during the 2009 DEWS project conference, in the presence of decision-makers from various local and regional authorities from around the Indian Ocean.
The phone message says: 'Your location is threatened by a tsunami. Seek immediate shelter!'
(Photo by courtesy of DEWS)

Metabolomics

A new tool for monitoring environmental change

Ulf Sommer and Mark Viant

One of the challenges currently faced by environmental scientists is finding reliable measures to describe the influence of external pressures such as climate change on plants and animals in the wild. Traditional approaches, such as counting individuals in their natural habitat, are often inadequate, because they do not readily detect sublethal stresses – i.e. stresses that can degrade the health and fitness of organisms without actually killing them. Furthermore, measures such as 'alive' and 'dead' cannot provide any insight into the underlying causes of the stress. A solution to this problem lies in a new technique known as 'metabolomics'.

Metabolomics addresses the entire composition of small biochemical molecules (or metabolites) in a given cell, tissue, biofluid, or whole organism. It involves determining the concentrations of all the metabolites present – there are thousands of such compounds, including glucose, cholesterol, urea, and ATP. Changes in their concentrations can occur in response to a changing environment, for example by changes in water or air temperature, water acidity, food supply, the influence of environmental pollutants, or other organisms. Traditionally, only certain subsets of the totality of metabolites present – the metabolome – could be investigated in a targeted approach. These might consist of sugars or amino acids, or even single metabolites. Today it is possible to analyse a large proportion of the metabolome in one go, in an untargeted approach, using sensitive, high-resolution techniques such as nuclear magnetic resonance (NMR) spectroscopy and Fourier transform – ion cyclotron resonance mass spectrometry (FT-ICR MS).

The Natural Environment Research Council (NERC) has recently funded a new metabolomics facility at the University of Birmingham to facilitate just this approach. The facility represents one of five nodes within the NERC Biomolecular Analysis Facility (NBAF; www.nbaf.nerc.ac.uk). We are using the University's world-class NMR and MS instrumentation as well as advanced computational approaches in order to obtain the high-quality datasets needed to identify the often subtle changes in organisms' metabolomes that are indicative of environmental stress. This 'discovery-driven' research can be used to generate novel hypotheses about biochemical stress-response mechanisms, which can be tested in subsequent targeted experiments.

Metabolomics can investigate effects ranging from instantaneous changes to those occurring over evolutionary timescales, the latter enabling studies of genetic adaptation. In a typical experiment, a control group of organisms is compared to one or more groups under environmental pressure. Metabolites of the whole or parts of the organism are extracted, and analyzed by NMR spectroscopy and/or FT-ICR mass spectrometry. These datasets are then compared using different means of statistical analyses to detect any significant molecular changes between groups; changes which then can be followed by more targeted approaches.

Environmental scientists from across the UK who are conducting research within the NERC scientific remit (http://www.nerc.ac.uk/funding/application/topics.asp), and who meet Principal Investigator status (http://www.nerc.ac.uk/funding/available/researchgrants/eligibility.asp), are eligible to apply to NERC to gain access to this state-of-the-art metabolomics facility. Applications to conduct small-scale pilot projects are strongly encouraged. For more information, including how to apply, please visit our website at http://www.biosciences-labs.bham.ac.uk/nbaf-birmingham, or contact the Facility Director, Dr Mark Viant (m.viant@bham.ac.uk), or Facility Manager, Dr Ulf Sommer (u.sommer@bham.ac.uk).

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Left *500 MHz NMR spectrometer. The sample is loaded from the top into the large metallic container and the spin of nuclei, their interactions, and the resulting resonances in a magnetic field are used to determine the metabolites.* ***Right*** *FT-ICR mass spectrometer, which determines with high resolution and accuracy the mass of metabolites (or their fragments) by ionization, optional fragmentation, and separation and isolation by their mass-to-charge ratios in a cyclotron field.*

The Beauty of Science

Tom Anderson

The popular view of a scientist is one of a mad professor obsessively poring over potions in flasks and test tubes, or excitedly chalking up undecipherable equations on a blackboard. While these images are extreme, there is no doubt that many scientists go to great lengths in pursuit of knowledge, showing passion and devotion beyond the call of duty. Why is this so? The answer, I believe, is that science is beautiful, but not in the same way as early morning dew glistening in the sunlight or waves gently lapping on a remote sea shore. What, then, is it about science that makes it beautiful? Answering this question is important, for it is essential to ensure that our profession draws on this facet and is able to attract and retain the best young talent emerging from the education system. In this article, I will firstly describe the beauty I see in two of my favourite animals, the seahorse and the Galápagos tortoise. I will then proceed to discuss the beauty of science in more general terms, focussing on trends in contemporary research.

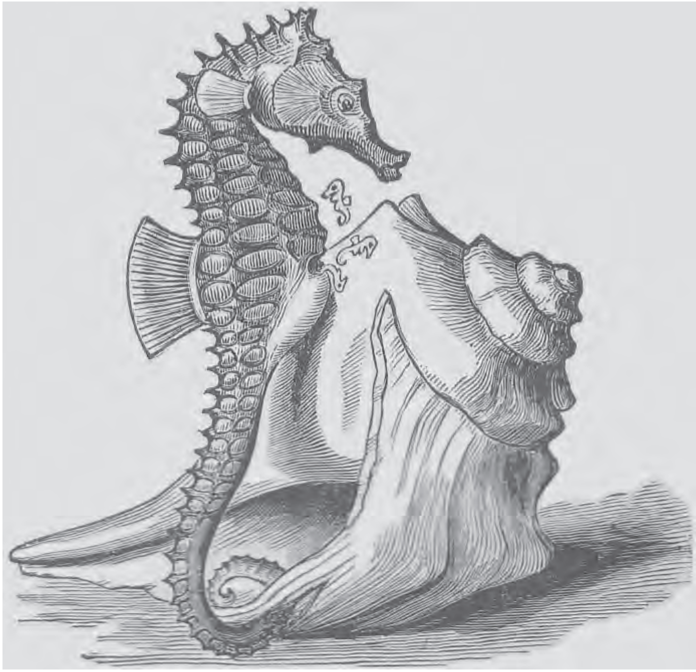

Figure 1
A male seahorse gives birth (Lockwood, 1867)

The seahorse (Figure 1), a well known lucky charm of sailors, was described by Samuel Lockwood as a creature of 'rich armature of daintily carved plates, like a coat of mail, its body always pertly erect, and, bent forward, it looks like the steed of a knight-errant in quest of adventure'. What wonderful writing, in itself radiating the joy and beauty of science. Given the quirky nature of this charismatic little animal, I michievously asked 50 of my non-science acquaintances the following 'Who Wants to be a Millionaire' multiple-choice question (Figure 2): 'What type of animal is a seahorse?' Amusingly, only 34% chose the correct answer, fish. Seahorses (genus *Hippocampus*) belong to the family Syngnathidae which also includes the pipefishes. The other three answers were chosen by 24% of respondents (crustacean), 32% (mammal) and 10% (reptile). Dentists seemed to fare worst, with the three that I asked choosing the three wrong answers between them! Mammal was a popular choice because it is well known that seahorses produce live young. Indeed, it is the sex life of the seahorse that is particularly unusual. Most species exhibit faithful monogamous relationships, returning to the same partner over and over in order to breed. And, curiously, it is the male who becomes pregnant after his spouse transfers her eggs to his brood pouch, and then he who has to suffer the pangs of childbirth.

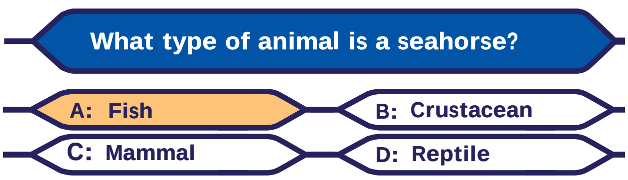

Figure 2
Only about a third of 'Who Wants to be a Millionnaire?' contestants would correctly classify a seahorse

With a life expectancy of supposedly 100 years or more, and body armour that has remained relatively unchanged since Triassic times, the Galápagos tortoise (Figure 3) is a masterpiece of evolution. A perhaps less well known, but no less remarkable, characteristic of this unmistakable animal is its ability to go without food or water for a year or more. During the rainy season, tortoises descend from the high ground down to near the coasts where they drink water, gallons of it, which is stored for future use in their oversized bladders. Sadly, this amazing adaptation, which allows them to survive periods of prolonged drought, proved to be their downfall. They were plundered by buccaneers and whalers during the 18th and 19th centuries, with many hundreds taken aboard ship during any one visit to the islands. Prior to the era of refrigeration, the unfortunate fate for most was to be piled away (alive) among the casks in the ship's hold as a source of fresh food, although animals were occasionally kept as pets above deck and fed the odd banana. Thankfully, although some subspecies were wiped out, the Galápagos tortoises were never driven to extinction and are today afforded protected status.

In what sense, then, do I see beauty in these animals? The answer lies not in visual appearance, but rather in the curiosity aroused by their unusual characteristics – the male pregnancy of the seahorse and the ability to go without food or water in the Galápagos tortoise. The beauty of science lies in marvelling at the diversity in structure, form and function of the natural world and in pondering and investigating the underlying causes and consequences. And it is not just the beauty associated with individual species, but also that of the way ecosystems function as a whole, namely the wonderful harmony of biological complexity and the physico-chemical environment. Keats voiced the complaint that science destroys the magical allure of phenomena such as the rainbow by reducing them to just one more entry into the 'dull catalogue of common things'. I could not disagree more. Rainbows remain as beautiful as ever to the eye but, from a scientific viewpoint, there is also an innate beauty in trying to understand the processes by which light is divided into its component colours to give rise to such an amazing phenomenon.

For some, beauty lies in simplicity, the aesthetic charm of simple theories appealing to truth. The theoretical physicist Paul Dirac, for example, once famously said that 'It is more important to have beauty in one's equations than to have them fit experiment'. But then, as Ian Stewart pointed out in his book *Does God Play Dice*?, beautiful romances can be founded upon a lie, and tend to become unstuck when confronted by the dreadful truth. In the same way, physics, and indeed all of the sciences, can be founded on erroneous assumptions, such as the myth of perfect circular motion of heavenly bodies.

***Figure 3** The Galápagos tortoise – an evolutionary marvel*

By courtesy of Rhett Butler www.mongabay.com

The beauty of science, at least for me, is that it is a voyage of discovery, with the unexpected and unexplained lying in wait at every turn. The great *Challenger* Expedition of 1872–76 springs to mind: the first major exploration of the deep sea which, amongst other things, provided unquestionable proof that life exists on the deep-sea bed. There have been many memorable discoveries since then, such as hydrothermal vents, the high biodiversity of the deep sea, the microbial character of the marine food web and the contribution of the mesoscale to variability in physical circulation. The key to discoveries such as these is, I believe, creativity, which lies at the heart of scientific progress. Thinking creatively allows us to see things in new ways, recognise patterns, and make connections between apparently unrelated facts. Fundamentally, creativity stems from seeing beauty in the world that surrounds us although, as in the painting of a masterpiece, training and experience are also important.

Discoveries should be in the making for all scientists, whether it be in the study of foodwebs, genomics, physical oceanography, chemistry, etc. If we are not careful, however, creativity, and indeed the very beauty of science, will become stifled within a culture that emphasises the timely execution of precisely worded deliverables and targets, in tandem with ever more proposal writing and bureaucracy. In the early 1990s, this issue was raised by Craig Loehle, who proposed that there is a general parabolic relationship between the difficulty of a problem and its payoff (Figure 4). The region of optimal benefit lies at an intermediate level of difficulty in what Loehle called the 'Medawar zone' in recognition of Sir Peter Medawar's (1967) characterisation of science as 'the art of the soluble'. Problems of intermediate difficulty have the highest benefit per unit effort because they are neither too simple to be useful nor too difficult to be solvable. The danger is that scientists may shy away to the left of the Medawar zone, rejecting the really interesting, beautiful problems in favour of easier ones. Science then becomes perspiration rather than inspiration.

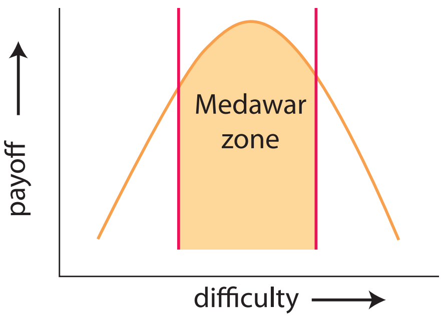

***Figure 4** Relationship between degree of difficulty and payoff from problem-solving. Beautiful problems are found within and to the right of the Medawar zone.*

Yet, despite the day-to-day pressures felt by scientists, as in many professions of contemporary society, scientific advance continues apace. In closing, it is therefore right and proper to acknowledge the very real successes being made, on the back of dedication and commitment, by scientists across many disciplines. In biological oceanography today, for example, exciting progress is being made in areas such as the impact of iron on production and export, controls on ecosystem structure and their response to changing climate, mixotrophy, the mesopelagic zone and the role of phytoplankton in biogas production and climate feedbacks. Science remains a beautiful, passionate affair for many (including myself) who follow in its path, offering a rich and rewarding career.

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Tom Anderson is a marine ecosystem modeller and co-leads the Ocean Modelling and Forecasting group at the National Oceanography Centre, Southampton, UK. His interests include marine biogeochemical cycles, stoichiometry, the microbial loop and dissolved organic matter, model complexity, and the methodology and philosophy of science.
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Figure 4 is from Craig Loehle, 'A Guide to Increased Creativity in Research: Inspiration or Perspiration?' in *BioScience* **40**, No. 2 (February 1990), pp.123–9 (1990) by the American Institute of Biological Sciences. Republished with the permission of the University of California Press.

Geoengineering the climate

science, governance and uncertainty

John Shepherd

Emissions of carbon dioxide are rising even faster than was expected, and if they continue to do so we are on track for global temperatures which are likely to be 4 °C higher, or even more, by 2100, with disastrous consequences. There is still no sign that we are even beginning to control emissions, let alone reduce them by the target of at least 50% by 2050, widely regarded as the minimum necessary to avoid dangerous climate change. It is to be hoped that new reduction targets for emissions post-2012 will stimulate greater action: however there is a serious risk that sufficient mitigation actions will not be introduced within the necessary time-frame. Some people are therefore now suggesting that we should seriously consider geoengineering: that is, intervening directly to engineer the climate system, so as to moderate the rise of temperature. Is this possible? How? At a reasonable cost? Without undesirable side-effects? Who could do it? Who should control it?

It is to answer just these questions that the Royal Society set up a study group on 'Geoengineering the climate: science, governance and uncertainty'. Without the answers there will be no way of making sensible decisions on this issue on the basis of evidence and facts rather than beliefs and suppositions (either for or against the idea). Our working group concluded that the safest and most predictable method of moderating climate change is to take early and effective action to reduce greenhouse gas emissions. No geoengineering method can provide an easy or readily acceptable alternative solution.

However, we also concluded that geoengineering methods could potentially be useful in future to augment continuing efforts to mitigate climate change by reducing emissions, and so should be subject to further more detailed research and analysis. Geoengineering is not an alternative to transforming our economies in order to achieve a low carbon energy future; we shall need that anyway, when the fossil fuels run out. But it is possible that it could at least make a contribution to reducing the damage which is otherwise expected to occur. We would in effect at least be treating the symptoms, to buy some time while we seek a cure. But this will only be an option when we have got the information to assess the credibility and potential of these ideas.

Geoengineering schemes for moderating climate change come in two main 'flavours'. First there are those that aim to increase the amount of sunlight that is reflected away from the Earth (currently about 30%) by a few percent more. Such 'Solar Radiation Management' techniques directly modify the Earth's radiation balance and, once they had been deployed, would take only a few years to have an effect on climate. They do not treat the root cause of climate change (increased levels of greenhouse gases in the atmosphere) but because they act quickly, they could be useful in an emergency, for example to avoid reaching a climate 'tipping point',

Solar Radiation Management methods include:

- Increasing the surface reflectivity of the planet, by brightening artificial structures (e.g. by painting them white), planting crops with a high reflectivity, or covering deserts with reflective material.
- Enhancement of marine cloud reflectivity (e.g. through the use of 'cloud generating ships').
- Mimicking the effects of volcanic eruptions by injecting sulphate aerosols into the lower stratosphere.
- Placing shields or deflectors in space to reduce the amount of solar energy reaching the Earth.

Secondly, there are some schemes that aim to increase the rate at which CO_2 is removed from the atmosphere, by enhancing the natural sinks for CO_2, and maybe even by scrubbing it out of the air. These Carbon Dioxide Removal methods include:

- Land-use management to protect or enhance land carbon sinks (e.g. regrowing forests).
- Growing biomass for carbon sequestration as well as to provide a carbon neutral energy source .
- Acceleration of natural weathering processes to remove CO_2 from the atmosphere.
- Direct engineered capture of CO_2 from ambient air.
- Enhancement of oceanic uptake of CO_2, for example by fertilisation of the oceans with naturally scarce nutrients such as iron, or by increasing rates of upwelling.

In most respects, Carbon Dioxide Removal methods would be preferable to Solar Radiation Management methods, because they effectively return the climate system to closer to its natural state, and so involve fewer uncertainties and risks. However, of the Carbon Dioxide Removal methods assessed, none has yet been demonstrated to be effective at an affordable cost, with acceptable side-effects. In addition, removal of CO_2 from the atmosphere only works very slowly to reduce global temperatures (over many decades). If safe and low-cost methods can be deployed at an appropriate scale they could make an important contribution to reducing CO_2 concentrations and could provide a useful complement to conventional emissions reductions. It is possible that they could even allow future reductions of atmospheric CO_2 concentrations (so-called 'negative emissions') and so address the ocean acidification problem.

Carbon Dioxide Removal methods that remove CO_2 from the atmosphere without perturbing natural systems, and without large-scale land-use change requirements, such as engineered CO_2 capture from air, and possibly also enhanced weathering, are likely to have fewer side-effects. Techniques that sequester carbon but do have land-use implications (such as biochar* and soil-based enhanced weathering†) may be useful contributors on a small scale although the circumstances under which they are economically viable and socially and ecologically sustainable remain to be determined. The extent to which methods involving large-scale manipulation of Earth ecosystems (such as ocean fertilisation) can sequester carbon affordably and reliably without unacceptable environmental side-effects, is not yet clear.

Compared to Carbon Dioxide Removal methods, Solar Radiation Management techniques are expected to be relatively cheap and, as mentioned above, would take only a few years to have an effect on the climate once deployed. However, there are considerable uncertainties about their consequences, and additional risks. It is possible that, in time – assuming that these

*Biochar is pyrolised biomass, i.e. charcoal (a stable form of carbon) that is used as a long-term store of carbon, rather than as a fuel.

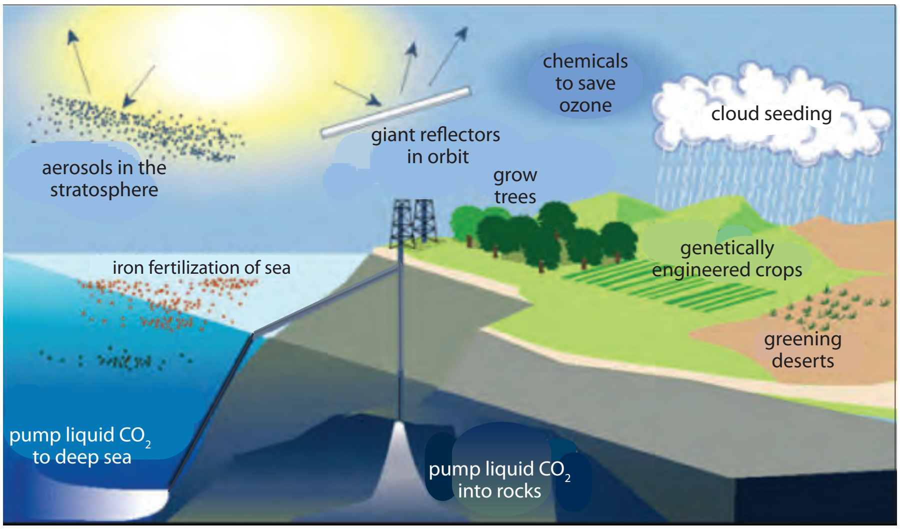
†An example would be grinding silicate minerals and adding the powder to fields, thus increasing reactions with atmospheric CO_2, and storing the carbon-rich by-products in the soil or run-off.

uncertainties and risks can be reduced – Solar Radiation Management methods could be used to augment conventional mitigation. However, the large-scale adoption of Solar Radiation Management methods would create an artificial, approximate, and potentially delicate balance between increased gas concentrations and reduced solar radiation, which would have to be maintained, potentially for many centuries. It is doubtful that such a balance would really be sustainable for such long periods of time, particularly if emissions of greenhouse gases were allowed to continue or even increase. The implementation of any large-scale Solar Radiation Management method would introduce additional risks and so should only be undertaken for a limited period and in parallel with conventional mitigation and/or Carbon Dioxide Removal methods.

Because Solar Radiation Management techniques offer the only option for limiting or reducing global temperatures rapidly they should be the subject of further scientific investigation to improve knowledge in the event that such interventions become urgent and necessary. Much more needs to be known about their climatic and environmental effects and social consequences (both intended and unintended) before they should be considered for large-scale experiments or deployment.

Of the Solar Radiation Management methods we looked at, stratospheric aerosols are currently the most promising because their effects would be relatively uniformly distributed, they could be much more readily implemented than space-based methods, and would take effect rapidly (within a decade or two). However, potentially significant uncertainties and risks are associated with this approach, and research into methods of delivery and deployment, effectiveness, impacts on stratospheric ozone and high-altitude tropospheric clouds, and detailed modelling of their impacts on all aspects of climate (including precipitation patterns and monsoons), are needed.

Various geoengineering options *This illustration, taken from the Royal Society Report, is a version of a graphic by Ben Matthews from a review paper published in 1996 just before Kyoto Conference, and available online at http://www.chooseclimate.org/cleng*



One factor that must not be forgotten amidst the science is that public attitudes towards geoengineering, and public engagement in the development of individual methods proposed, will have a critical bearing on its future. Perception of the risks involved, levels of trust in those undertaking research or implementation, and the transparency of actions, purposes and vested interests, will determine the political feasibility of geoengineering. If geoengineering is to play a role in reducing climate change, an active and international programme of public and civil society dialogue will be required to identify and address concerns about potential environmental, social and economic impacts and unintended consequences. This will also be crucial in determining the governance of any geoengineering projects, which will be another major hurdle.

If world leaders are unable to agree on effective action to deal with climate change, and fail to implement practical measures to reduce CO_2 emissions very soon, we may in future be glad that someone took these ideas seriously – seriously enough to separate the real science from the science fiction, anyway. Our study is a first significant contribution to doing just that.

John Shepherd is an Earth system scientist in the School of Ocean and Earth Science, University of Southampton. He chaired the Royal Society working group that produced the report *Geoengineering the Climate: Science, Governance and Uncertainty,* which can be downloaded from the Royal Society website at www.royalsociety.org

Editor's Note: The next issue will contain a special section on Ocean Acidifiication.

There's dosh in them thar diatoms!

Sediments laid down in the anoxic depths of the Black Sea are proving a boon to argriculture. Nanotechnology has begun to play a role in agriculture, and the Bulgarian Academy of Science has been investigating the possibilities offered by nano-sized Black Sea sediments. The sediments under investigation include a half-metre thick layer of layer of coccolithophore remains (*Emiliana huxleyi*), which overlie sapropels (organic-rich muds) and siliceous diatom ooze. Deep-water biogenic and inorganic sediments contain no bacteria that could harm crops or food, and do not need any special preliminary processing before use. Trials made over the course of many years have shown that they may be used in both organic and conventional agriculture, and may used in the raising of new plants, and in improving both the structure and the ferility of soil that has become eroded and nutrient-poor

Extracts from Black Sea sapropels are already successfully used in a wide range of agriculatural enterprises, incuding orchards, vineyards, and strawberry plantations. It has been found that seed germination is stimulated, and that there is accelerated growth in the early phases of the development, as sapropel-derived nutrients (applied during irrigation) are easily assimilable. Increased resistance of the plants to various kinds of stress and diseases is also observed, as is an increase in the soil microflora, which results in an increase in useful soil microorganisms, and a suppression of plant pathogens living in the soil.

Some readers may have come across 'diatomaceous earth', which consists of diatom remains from lake or marine deposits. This versatile material is used for filtration in swimming pools, as a growing medium in hydroponics, as a mild abrasive, as a mechanical insecticide, as an absorbent for liquids, as cat litter, as a thermal insulator and as a component of dynamite.

EPOCA

investigating the impacts of carbon dioxide on our oceans

Jean-Pierre Gattuso and Lina Hansson

Several recent policy briefs and information packs (e.g. the 'Monaco declaration', and a European Science Foundation policy briefing document) have drawn attention to the impacts of carbon dioxide on our oceans – a problem that is still largely unknown to policy-makers and the general public. Indeed, few people are aware of the potential consequences of the anthropogenic CO_2 currently entering the world ocean at a rate of 25 million tonnes of CO_2 per day (see Further Reading).

The acidity of the oceans has increased by 30% since the beginning of the industrial revolution and a three-fold increase is expected by the end of this century if emissions continue at current rates. The absorption of carbon dioxide by the oceans contributes to mitigation of global warming, but at a cost: when CO_2 dissolves in seawater, a series of chemical perturbations occur. Concentrations of inorganic carbon and bicarbonate ion increase, while pH and the concentration of carbonate ions decrease. These chemical changes may have biological consequences – in particular, but not exclusively, on organisms producing a calcium carbonate shell or skeleton.

The European Project on OCean Acidification (EPOCA) was launched in May 2008 as the first large-scale research project devoted to ocean acidification (http://epoca-project.eu). Funded within the EU Seventh Research Programme (FP7) for a four-year period, EPOCA combines European expertise within various fields of marine research, with the goal of elucidating the possible consequences of ocean acidification for organisms, ecosystems and biogeochemical cycling. With a consortium of over one hundred scientists from 27 institutes and 9 countries,* EPOCA is investigating all aspects of this young research area and includes important outreach and dissemination components.

*A complete list of EPOCA participants is available at www.epoca-project.eu

†A mesocosm is a large tank containing seawater and a community of organisms which is allowed to develop as naturally as possible.

The four themes around which EPOCA research is structured are as follows:

1: Changes in ocean chemistry and biogeography

How has the carbonate chemistry of the oceans fluctuated in the recent and distant past, and what have the effects been on the biogeography of key marine species? An important part of EPOCA focusses on such questions, considered across space and time. Past variability in ocean chemistry is studied via palaeoreconstruction methods on 'archives' such as cold-water corals and remains of foraminiferans in sea-bed sediments. The observational component of EPOCA consists of continuous sampling and measurements at time-series stations, along hydrographic transects, and along regular shipping routes, mostly in northern high-latitude areas such as the Arctic Ocean and the North Atlantic.

2: Biological and ecosystem responses

EPOCA's largest research theme is devoted to an area that is still poorly understood – the impacts of ocean acidification on marine organisms, from microbes to higher trophic levels. Laboratory and mesocosm† CO_2-enrichment experiments, combined with experimental approaches ranging from molecular to ecosystem scale, are used to study key organisms and physiological processes with the goal of quantifying biological response and assessing the potential for acclimation and adaptation.

3: Biogeochemical impacts and feedbacks

We need to determine the extent to which ocean acidification will alter ocean carbonate chemistry, biogeochemistry, and marine ecosystems over the next 200 years, and how these changes will feed back into climate change. With this in mind, results from themes 1 and 2 are being combined and fed into biogeochemical, sediment, and coupled ocean–climate models to project future biogeochemical changes in the Earth system and feedbacks affecting climate.

4: Synthesis, dissemination and outreach

This part of EPOCA will address the conclusions that can be drawn from combining the different findings of themes 1, 2 and 3. Uncertainties, risks and potential critical thresholds or tipping points** associated with ocean acidification are

**Critical points in an evolving situation that, if crossed, lead to a new and irreversible state.

Figure 1 *Divers collecting benthic organisms during the EPOCA Svalbard campaign in May 2009. After collection, the crustaceans, echinoderms and calcareous algae were transferred to laboratory mesocosms where they were maintained at different partial pressures of CO_2, corresponding to different atmospheric concentrations of CO_2.*
(By courtesy of Marie-Dominique Pizay, CNRS)

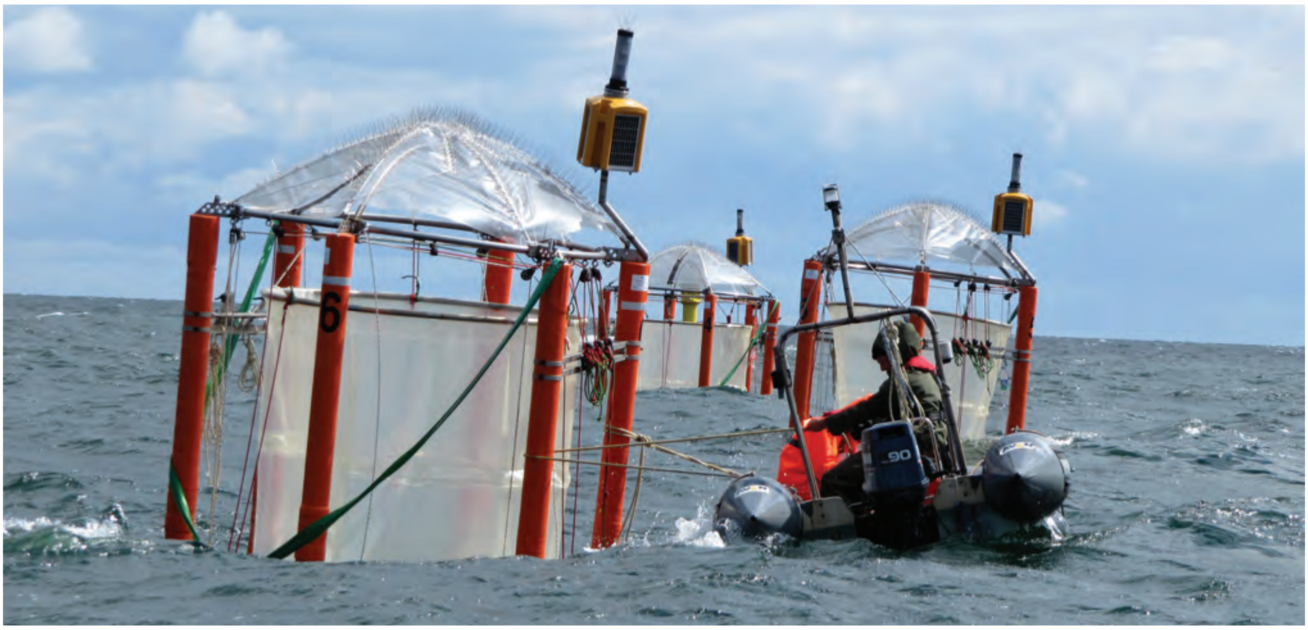


Figure 2 *The offshore mesocosm facilities that will be used off Ny-Ålesund, Svalbard, in the summer of 2010. The chemistry in the mesocosms will be manipulated to reflect past, current and future conditions. The set-up allows researchers to study the planktonic community under close to natural conditions.* *(By courtesy of Ulf Riebesell, IFM-GEOMAR)*

communicated to policymakers and the general public in a comprehensible format and accessible language. EPOCA aims to contribute high-quality scientific information directly to expert groups and committees through the EPOCA Reference User Group (RUG) of international stakeholders with representation from NGOs, governmental organisations, foundations and industry. The document *Ocean acidification – the facts* was launched at a press conference during the COP15 meeting in Copenhagen, December 2009. The brochure is available in five languages (downloadable from www.epoca-project.eu/index.php/Ocean-Acidification-the-facts.html).

Recent/upcoming EPOCA activities

EPOCA Svalbard experiments

EPOCA focusses on areas where it is believed that the effects of ocean acidification will strike first, such as the Arctic Ocean and the North Atlantic, where water temperatures are low, promoting CO_2 uptake. In May 2009, fifteen EPOCA scientists took off for Ny-Ålesund, Svalbard, for the first large-scale experiment of the project: a five-week campaign aimed at investigating the impact of ocean acidification on Arctic benthic organisms such as echinoderms, molluscs, crustaceans and calcareous algae (Figure 1). The organisms were exposed to different levels of pCO_2 using indoor mesocosms. In the summer of 2010, 35 scientists will return to Svalbard, this time to investigate the response of pelagic communities using offshore mesocosm facilities (Figure 2).

Guide to best practices for ocean acidification research and data-reporting

In November 2008, EPOCA, together with the International Oceanographic Commission (IOC) of UNESCO, organised an international workshop on best practices in ocean acidification research, in Kiel, Germany. The meeting was supported by funding from the Scientific Council on Oceanic Research (SCOR), the US Ocean Carbon Biogeochemistry program (OCB) and the Kiel Excellence Cluster, 'The Future Ocean', and brought together around 40 scientists from the EU, US, Japan, Korea, China and Australia. The workshop participants reviewed the best practices in this field of research and prepared the outline of a guide that served as a basis for a series of manuscripts providing a comprehensive set of guidelines on ocean acidification research.

After a first round of expert reviews, revised sections were made available on-line for an open access community review starting in May 2009. On the basis of the comments, and with input from the international community and the assigned chapter editors, the sections were further revised; drafts are available at www.epoca-project.eu/index.php/Best-Practices-Guide/. *The Guide to Best Practices in Ocean Acidification Research and Data Reporting* will be published as an EU report and will be available at the web address above.

EPOCA training courses

EPOCA has organised several training workshops on different aspects of ocean acidification research, including a recent course on paleo-reconstruction methods (Cambridge, September 2009), and a course on carbonate chemistry and perturbation experiments, held in Kiel in March 2010, and run jointly by EPOCA and the recently launched programmes BIOACID and CalMarO. EPOCA has also co-sponsored a ten-day Ocean Carbon and Biogeochemistry (OCB) short course (Woods Hole, November 2009). The courses are open to non-EPOCA members whenever possible (see www.epoca-project.eu/index.php/What-do-we-do/Training/).

EPOCA Project Office

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Website: epoca-project.eu

Further Reading

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SECOND EFMS CONFERENCE

First announcement and call for papers

EFMS

The Significance of Marine Science and the Role of Marine Scientists in Present-day Europe

University of Athens
Athens, Greece

15–16 October 2010

organized by
the Hellenic Oceanographers' Association

HOA

PRELIMINARY PROGRAMME

Session 1: Linking European Marine Research to Education and Employment

Session 2: Climate Change and the Marine Environment: Priorities for European Seas

Session 3: Operational Oceanography and Sustainability in Europe

Session 4: The EU Marine Strategy Directive and the European Marine Community

Every session will include an invited keynote speaker followed by a speaker from an EFMS member society.

Submissions from students will be especially welcome.

Abstracts of one page (up to 500 words) can be submitted by email, fax or post up until 10/9/2010. After the meeting extended abstracts may be submitted for publication in a special issue of *Advances of Oceanography and Limnology.*

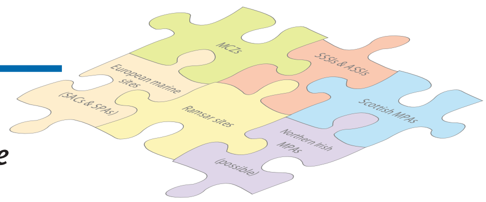
The annual EFMS General Assembly will take place after the conference

Social activities will include an evening at the Temple of Poseidon at Cape Sounion, with dinner at a local taverna.

For more information and a registration form
email: edasenak@chem.uoa.gr or fax: 0030-210-727-4945.

The MPA jigsaw

engaging stakeholders in the Irish Sea



Matthew Sutcliffe

Marine protection in the UK is undergoing a transformation that is little short of revolutionary. For the first time in our history we are creating a network of marine protection worthy of the richness of our marine environment and its wildlife. The final elements in the network in England and Wales, Marine Conservation Zones, are now being created under last year's landmark legislation, the *Marine and Coastal Access Act.*

In the long term this should be excellent news not just for our marine environment, but also for the people who value it and make their living from it. In the short term, however, completing the network of Marine Protected Areas is not without challenges. For the network to be most effective, it is vital that sea-users understand and support it.

For those of us working for the Marine Conservation Zone Project, the first major challenge was to identify and engage the many diverse stakeholders who are at the heart of what we are doing. A second major challenge is that many of our stakeholders are confused about Marine Protected Areas – the process for setting up the network is so complex that even people well versed in marine issues were often unclear about it. Let's start then, with an overview of how Marine Protected Areas are being identified.

Different kinds of protected areas

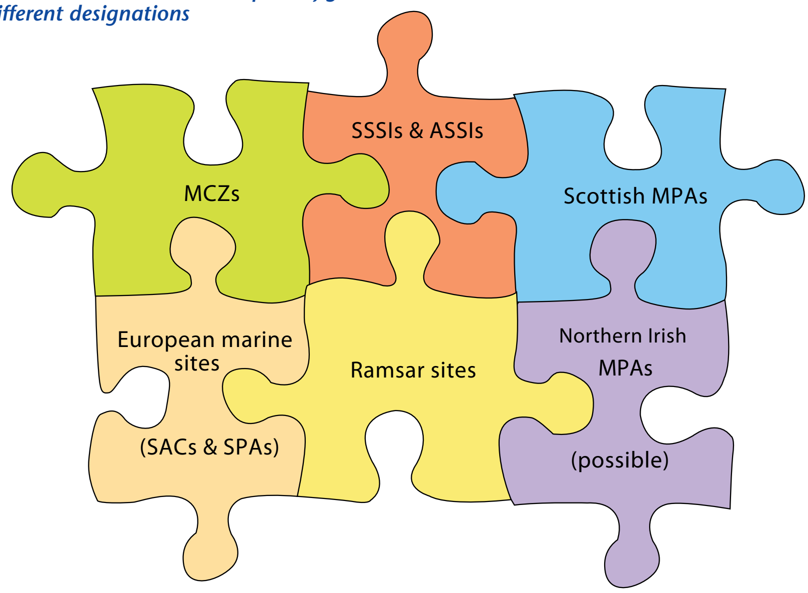
The network of Marine Protected Areas around England and Wales can be thought of as a jigsaw made up of five different designations – Special Areas of Conservation (SACs), Special Protection Areas (SPAs), Sites of Special Scientific Interest (SSSIs), Areas of Special Scientific Interest (ASSIs, in Northern Ireland), Ramsar Sites and Marine Conservation Zones (MCZs) (cf. Figure 1). New MPAs in Scotland and Northern Ireland will also fit into this jigsaw but different processes and time-scales are in operation for these.

Each of the five different designations that make up the Marine Protected Area network in England and Wales has its own origins and processes. Two of the designations, SACs and SPAs, are usually bracketed together because both originate with EU Directives and form parts of the Natura 2000 process. The first, SACs, are required under the Habitats Directive and aim to protect marine habitats and species threatened at a European scale, such as sandbanks, sea-caves and reefs, and grey seals. There are currently 81 SACs with marine components around the UK.

The second designation, SPAs, are required under the Birds Directive and seek to protect threatened seabird aggregations. Both SACs and SPAs are identified by the statutory conservation agencies – the Joint Nature Conservation Committee, Natural England, the Countryside Council for Wales, Scottish Natural Heritage and the Northern Ireland Environment Agency – and their selection must be based completely on scientific evidence, without taking socio-economic factors into consideration. However, formal consultation on the proposed sites was held between November 2009 and February 2010, with the final site recommendations due to be submitted to Defra in June 2010. The government plans to submit the list of designated sites to the EU in October 2010.

This package should complete the network of SACs in English waters, but more are required offshore (i.e. beyond the 12-nautical-mile territorial sea, within in the UK's exclusive economic zone) to ensure that the UK meets its commitments. These should be completed by October 2012.

Figure 1 *The UK's network of Marine Protected Areas will be made up of a jigsaw of different designations*



In contrast to SACs and SPAs, Sites of Special Scientific Interest are set up under UK national legislation. They protect the best examples of the country's plants, animals and geological features. Most are land-based but some sites extend below the low-water mark.

Ramsar sites are designated under the 1971 *Convention on Wetlands of International Importance*, which was agreed in the town of Ramsar in Iran. They are designed to protect 'areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres'. The Irish Sea Conservation Zones project area covers several Ramsar sites, most notably on the estuaries of the Rivers Mersey and Ribble (Figure 2, overleaf).

But before we look at the final element in the English network of MPAs, it is worth pausing to clarify a point of detail. A conservation initiative that does not directly contribute to the jigsaw of Marine Protected Areas is the Your Seas Your Voice campaign run by the Marine Conservation Society. The campaign asks members of the public to vote on the importance of 73 marine sites around the UK or to nominate their own site. While the campaign is expected to make a welcome contribution to the process of recommending MCZs, some people have mistakenly concluded that its 73 sites are in fact proposed MCZs. This is not the case.

Marine Conservation Zones

The final piece of the jigsaw in England and Wales – Marine Conservation Zones – are a new form of marine protection that will be designated under the recently enacted *Marine and Coastal Access* Act. They will protect nationally important marine wildlife, habitats, geology and geomorphology, with sites selected to encompass a range of marine wildlife, not just the rare or threatened. The list of species and habitats to be protected by MCZs (known as the 'ecological guidance') has recently been issued by Natural England (see Post Script). These species and habitats can be designated anywhere in English and Welsh inshore or offshore waters, and the recommended sites are due to go to the government in June 2011. Marine Conservation Zones should complement, not duplicate, existing Marine Protected Areas or areas proposed as SACs or SPAs. Only in exceptional circumstances should they be proposed for habitats and species that are protected under EU Directives, in order to meet the objectives of the wider MPA network. However, there are likely to be circumstances where MCZs and European sites fully or partially overlap to protect different features.

Two key elements set MCZs apart from other forms of marine protection and identify them as something new and ambitious. The first is that the designation of MCZs may take socio-economic factors into account, as long as these factors do not undermine the creation of the network. This ensures a network of sites can be achieved in a way that minimises adverse impacts on sea-users and maximises nature conservation benefits.

The second key element is the way in which MCZs will be recommended. At the heart of the process are the stakeholders – the people who use, value or make their living from the sea. It is these stakeholders who will identify and recommend sites for MCZs to the government: the first time such a stakeholder-led process has been used in this way in the UK. However, the people with a stake in our seas are many and diverse, so how has the challenge of identifying and engaging them been addressed?

The overall Marine Conservation Zone Project was set up by Defra, Natural England and the Joint Nature Conservation Committee. It is being delivered through four regional projects covering the south-west (Finding Sanctuary), Irish Sea (Irish Sea Conservation Zones), North Sea (Net Gain) and south-east (Balanced Seas) (Figure 2). Although they work alongside Natural England and the Joint Nature Conservation Committee, the four regional projects also enjoy significant autonomy while working closely together.

Irish Sea Conservation Zones

The team working on the Irish Sea Conservation Zones project have now met face to face with over 1200 people, at more than 80 events, in almost 40 different locations around the Irish Sea. From the outset, the situation was complicated. The Irish Sea is used by people from England, Wales, Northern Ireland, Scotland, the Republic of Ireland and the Isle of Man. It is also important for commercial fishing, shipping, aggregates, oil and gas, offshore wind energy and recreation. Stakeholders in all these places and across all sectors needed to be identified and engaged.

The team's liaison officers began by identifying over 300 individuals, organisations and associations within its project area. An internet search by industry and sector yielded organisations as diverse as the Whitehaven Fishermen's Association, Chester Dive Club and the Environment Centre at Lancaster University, amongst many others. At the same time, liaison officers began talking to relevant contacts on the database of our host organisation, Envirolink North West. These contacts were able to recommend further people to speak to. A contact within the seafood industry, for example, was a font of knowledge on commercial fishermen in the Fleetwood area of Lancashire.

The next step was to identify the people who would be critical to the success of the project, so that the team could be sure that they were contacted. Meanwhile, an independent facilitator was selected who is responsible for designing the engagement strategy and facilitating key stakeholder meetings. The team could now begin contacting its stakeholders.

Every contact was invited to one of four local meetings held around the north-west of England in October 2009, with special effort given to making sure the stakeholders of high importance and high influence attended. Organised by the independent facilitator, these workshops were the first step in stakeholders finding out more about the project and raising issues for the team to consider.

Next the team renewed its efforts to contact stakeholders who are hard to reach – people who are not represented by professional bodies or members of clubs, such as sea anglers, windsurfers and, in some cases, commercial fishermen. Here the liaison officers set up meetings and presentations that were advertised by word of mouth, starting with a few key contacts – often a very effective approach, leading to a good turnout. At the same time, staff and liaison officers continued to meet members of clubs and organisations, such as sailing clubs and diving clubs. These meetings with local groups allow people to find out more about the project and to raise their concerns – which they very often do. They also allow the liaison officers to present accurate information on

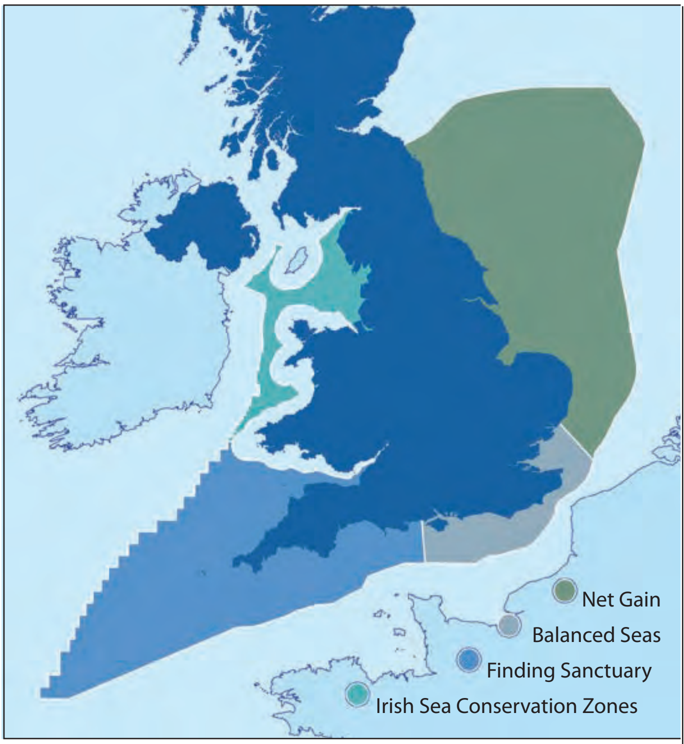
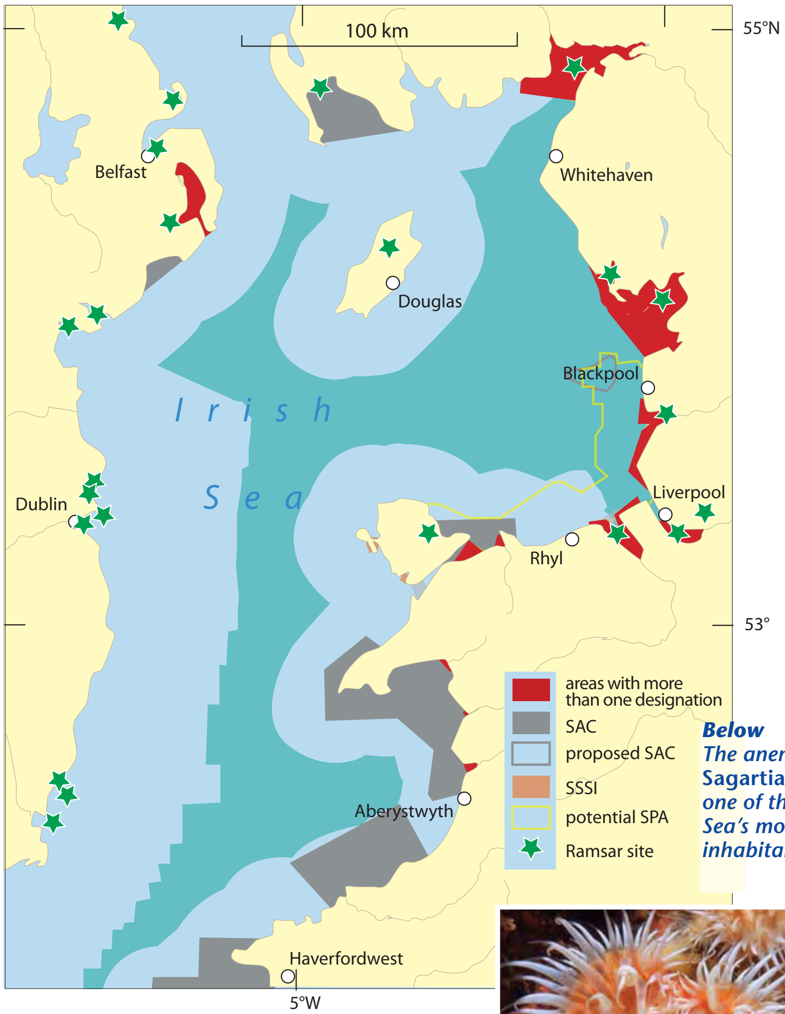


***Figure 2** Four different projects will determine the locations of Marine Conservation Zones around England and Wales (The Irish Sea project area does not include the inshore waters of Wales, the Isle of Man and Northern Ireland)*

Figure 3 *The Irish Sea Conservation Zones project area (dark turquoise) encompasses SACs, SPAs, SSS1s (mostly within the red areas) and coastal Ramsar sites (stars), and abuts various marine conservation areas in the adjacent territorial seas of Wales, Northern Ireland and the Isle of Man.*



the project, because stakeholders have often already become confused.

The team is now in the process of setting up its stakeholder group, a group of around 40 individuals who have agreed to be the voices of the various sectors with an interest in the Irish Sea. It is this stakeholder group, rather than a team of scientists, who will recommend the size, location and conservation objectives for Marine Conservation Zones to the government. Its recommendations must meet national ecological guidance prepared by Natural England and the Joint Nature Conservation Committee, and it will be able to draw on the advice of an independent scientific advisory panel. The group will meet five times between March and October 2010, and must make its final recommendations to the government by June 2011.

So the challenges for the Irish Sea Conservation Zones project team have moved on. We must continue to find our stakeholders and explain Marine Conservation Zones and other kinds of Marine Protected Areas to them. We must encourage them to be part of the project to recommend Marine Conservation Zones in the Irish Sea in whatever way they can. We must keep them informed and engaged as the stakeholder group moves towards its final recommendations. And we must support the vital work of the stakeholder group, ensuring that it runs smoothly, possesses and understands the best available science, and considers the comments and opinions of sea-users. If we can do this, we can deliver the government's vision of a 'strong, ecologically coherent and well-managed network of marine protected areas … that is well understood and supported by all sea-users'.

Below *The anemone* ***Sagartia elegans****, one of the Irish Sea's most colourful inhabitants*

Figure 4 *Commercial fishermen are important stakeholders in all four Project Areas*
(By courtesy of Rowan Byrne)

Post Script

The document *Marine Conservation Zone Project: Ecological Network Guidance* may be found at www.naturalengland.org.uk/Images/100608_ENG_v10_tcm6-17607.pdf

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From wooden hut to Ocean Institute

A history of the Gatty Marine Laboratory, St Andrews

Ian A. Johnston and Emma Defew

The Gatty Marine Laboratory has its origins in the government-funded St Andrews Fisheries Laboratory. In 1884, the Fisheries Board provided a sum of money to lease a wooden building between the harbour and the beach, which had previously been utilized as a fever hospital. This building was named the St Andrews Fishery Laboratory. It had two main rooms, one of which had sea-water pumped into it so it could serve as an aquarium. This old wooden laboratory was abandoned in 1896, when the Gatty Marine Laboratory, a purpose-built stone building with much improved facilities, was opened on the East Sands.

***Figure 1** William McIntosh, the Gatty's first Director, photographed c.1865. Amongst a wide range of academic pursuits, McIntosh studied specimens collected on the* Porcupine *and* Challenger *Expeditions, and contributed to the* Challenger *Reports.*

By courtesy of the University of St Andrews Library.

The creation of a permanent marine laboratory was the fulfilment of the dream of local teenager William McIntosh, who went on to become one of the leading zoologists of his generation. It was McIntosh himself who had prompted a magistrate and councillor from East Grinstead, Sussex, Charles Henry Gatty, to donate a sum of £2500 towards building the laboratory. Planning for the new building began in 1894, and Lord Reay opened it on 30 October 1896 in the presence of over 700 guests. This new building contained a Director's room, a library, a specimen room, a research laboratory with compartments for six workers, a small chemical room and an aquarium. The aquarium was 30.5 feet by 30 feet, with four large tanks of concrete and glass, supported by massive walls of concrete and special three-feet thick concrete foundations. Professor William MacIntosh became the Laboratory's first Director, and conducted pioneering work on the taxonomy of annelids and the early life histories of marine fish.

The work of the Laboratory and its reputation continued to expand as the first decade of the new millennium passed. However, tragedy almost struck at 2 a.m. on 23 June 1913: fisherman David Cunningham observed smoke and flames rising from the vicinity of the Gatty above a thick sea mist, and on return to the harbour he alerted the coastguard who verified that the Gatty was indeed on fire. It then took David half an hour to walk to the gas works where he could use a telephone to call the fire brigade. The fire brigade arrived at 5 a.m. and by 6.30 a.m. the fire had been put out. Damage was not as great as it might have been due to the heat of the fire melting some of the seawater pipes, which led to a burst tap localizing the fire. The repairs to the Gatty were estimated at a cost of £500, and luckily McIntosh's experimental notes, and zoological drawings by both MacIntosh and his sister, Roberta, escaped unharmed (cf. Figure 3).

***Figure 2** A fire which damaged the Gatty in 1913 may have been the work of suffragettes*
(By courtesy of the University of St Andrews Library)

The Gatty had had a lucky escape, because in the aftermath of the fire it was discovered that a window had been broken and that the fire had been started deliberately! Two notices found at the door indicated that the arson was the work of suffragettes, perhaps because of McIntosh's perceived indifference to women. However, the St Andrews Branch of the National Suffragette Society issued a vigorous denial and condemnation of the act. The case was never solved and the charred timbers from the fire are still visible in the attic to this day.

At the outbreak of the Great War in 1914, McIntosh was already 76 years old. Personnel at the Gatty gradually diminished until by 1917 only the Professor and his servant, Wallace Brown, were left. Although McIntosh retired that year, he continued to work at the Gatty (without any facilities or heating) until his death in 1931.

At the end of the Second World War the Gatty was largely abandoned except for an occasional visit from the janitor and cleaner. In 1946, the continued existence of the Laboratory was threatened by a severe storm that damaged the building itself and the sand dunes upon which it sat. An emergency committee was established and in April that year a scheme was adopted to reconstruct the embankment in front of the Laboratory with funds in equal measure from the Town Council and the University. The work was completed in the summer of 1949, and those sea defences still protect the Laboratory from North Sea storms today (Figure 4).

In 1945–46 the Gatty received an operating budget of £50 and was used as a field station by zoologists and botanists based in the Bute Medical Building in the town centre. In 1947, Helen Blackler was appointed to a lectureship (working on marine algae) and became the first resident of the Gatty since McIntosh's death 16 years previously. In that same year, Jimmy Dodd was also appointed as a zoology lecturer and, helped by a small but dedicated staff, Jimmy began to develop the modern Laboratory.

The Gatty was in a sorry state after being abandoned for so long, and the only remaining equipment consisted of a large number of one-gallon collecting jars and baskets. The University Court released funds for the installation of a heating system and new seawater pumps in 1947, and in 1948 the first telephone was installed. In 1947 an Easter course in marine biology was started, and this was opened to students from other Scottish universities in 1949. In the same year, the (not very seaworthy) *Argonaut* was obtained for trawling and collecting plankton.

Building on the success of the Easter course and the growing activities within the laboratory, the University Court approved an extension to the original Laboratory in 1949 to provide additional teaching space. The new extension on the south side, which was clad in stone to match the original building, was started in 1950 and finished in August 1951. In addition to the single large teaching laboratory, there was a dark room, an histology room and an underfloor equipment store.

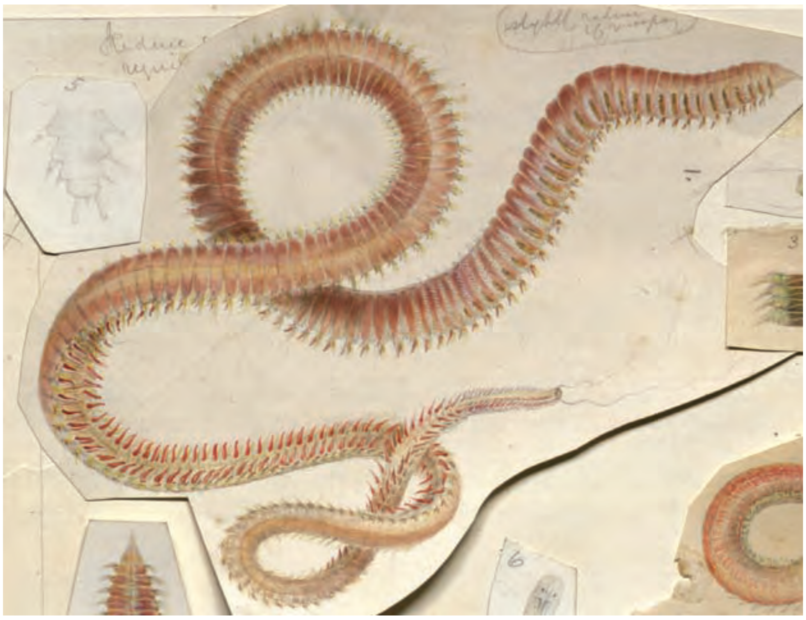


Figure 3 ***Drawings of marine annelids by William McIntosh's sister, Roberta, whose artistic talents greatly enhanced McIntosh's publications and displays. Roberta was later to assist him in many of his most important projects.***
(By courtesy of the University of St Andrews Library)

In 1951 Jimmy Dodd was joined at the Gatty by his wife Margaret (a fellow endocrinologist). Over the next few years they helped to lay the foundations of modern comparative endocrinology, in particular carrying out experiments on the thyroid and pituitary glands of frogs and dogfish, and the mechanisms that enable brown trout to transfer between freshwater and seawater. Dodd was also successful in attracting outside funds, and during the 1950s he built up an enthusiastic team of researchers. The atmosphere was informal and friendly, and long hours and weekend work the norm.

In 1956 Adrian Horridge was appointed to a lectureship in zoology, working on simple nervous systems. Horridge took 15 months unpaid leave in 1958–59 in order to work with Ted Bullock (University of California) on a two-volume book entitled *The Structure and Function in the Nervous Systems of Invertebrates*. This book was to become one of the classics of neurobiology and Horridge made numerous contacts in the USA, many of whom came to work in the Gatty in the 1960s. Meanwhile, Jimmy Dodd had been working on isolated hearts of a marine mollusc, and together with Professor Hunter and an eminent pharmacologist, Gaddum, they developed the first bioassay for the important transmitter substance, 5-hydroxytrypramine (5HT). It was this research that attracted the attention of Sir Henry Dale, a member of the advisory committee for the Wellcome Foundation. Sir Henry persuaded the trustees of the Foundation to provide a large grant to build an extension for comparative endocrinology and pharmacology. These plans were expanded to include a new floor for Botany, financed by the University Court and the Carnegie Trust of Scotland.

In February 1959, the University Court formally appointed Jimmy Dodd as Director of the Gatty, but in that same year he accepted a Chair at the University of Leeds. In 1960, Adrian Horridge was appointed as Director and Michael Laverack filled Dodd's position as lecturer. Under Horridge's leadership, the Gatty became a University department with six or seven members of teaching staff, and its faciities were augmented by a workshop, animal house, electronics workshop, histology unit, photography

Figure 4 ***The Gatty Marine Laboratory – now part of the Scottish Oceans Institute – as it is today. The modern buildings on the left are student accommodation blocks. The embankment mentioned in the article can be clearly seen at the back of the beach.***

Figure 5 *SMRU scientists returning from fieldwork*

unit and improved seawater circulation system. This major burst of activity allowed the Gatty to rival many much larger research institutes of international reputation.

The Gatty was filled with students and visitors and the pressure for space led to further extensions of the building in 1962 and 1966, and the provision of new equipment including an electron microscope. Horridge and coworkers exploited the new technology, exploring the brain and sensory systems of a whole range of marine invertebrates including insects, crustaceans and jellyfish. There were several additions to staff and changes in personnel during the 1960s, including the arrival of Glen Cottrell, fresh from a postdoctoral position at Harvard.

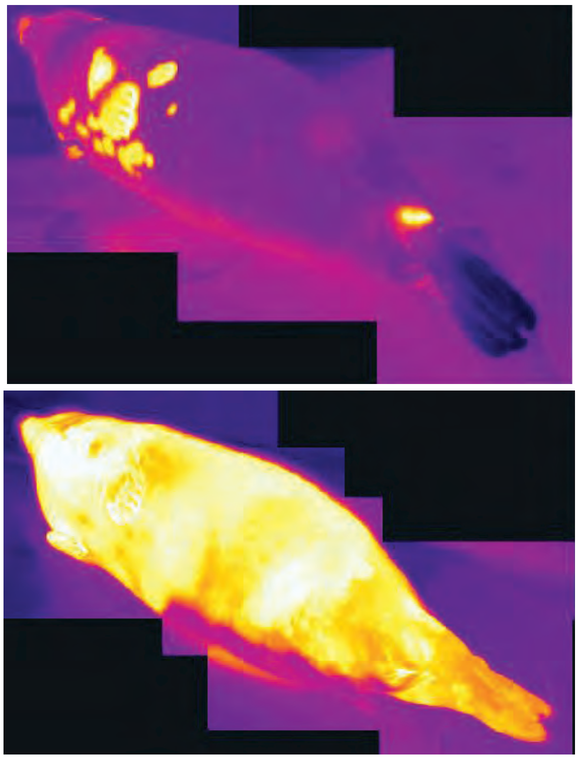
In February 1969, fter 13 years as Director, Horrdige resigned to take up a Chair at the Australian National University in Canberra, and another important chapter in the history of the Gatty Marine Laboratory drew to a close. Mike Laverack was appointed to a Chair in Marine Biology in 1969, and Mike was persuaded to allow Professor of Psychology, Malcolm Jeeves, to reside in the Gatty, where he carried out experimental work and converted the basement into an animal house. Malcolm went on to build one of the leading Psychology Departments in the UK.

In 1979, the department of Marine Biology was formed and Christopher Todd was appointed as the first lecturer. Together, with help from external lecturers and a new research vessel called *Homarus,* Laverack and Todd built up a thriving course in marine biology. However, in the early 1980s, this department was merged with Zoology and various staff members left for other buildings within the University. With just four zoologists remaining, and with a considerable sum being required for maintenance and modernization of the building, the University seriously considered closing the Gatty and selling the valuable waterside site.

In 1985, Principal Steven Watson decided that the Gatty should be redeveloped as an inter-departmental research institute, and Professor Ian Alistair Johnston of the Department of Physiology was appointed Director. Investment was found from internal and external sources to recruit new staff and refurbish the aquarium and laboratories, and another period of expansion began. The Gatty served as a model for the integration of biological sciences, and it became a component institute of the School of Biology in 1987 (although the name and composition of the School has changed several times since). The Laboratory built up strong research groupings in marine physiology and ecology and by the early 1990s was amongst the best funded in the UK. In 1997, a major £4.3 million extension to the building was financed by the University Court. The new building provided a modern lecture theatre and teaching laboratory, and research laboratories for immunological and muscle research. The major part of the new build was occupied by the NERC-sponsored Sea Mammal Research Unit (SMRU: http://www.smru.st-andrews.ac.uk/default.aspx), which transferred from Cambridge in 1996. The Gatty site gave SMRU boat access to the sea (Figure 5) and to the local seal populations, which are studied under a variety of research themes including estimates of abundance and distribution, reproduction and diet. SMRU's world-class experimental facilities include a 40 m pool for investigating diving and foraging behaviour (cf. Figure 6). Over the period 2005–2008 there was a major refurbishment of research laboratories with £2.4 million invested in improvements to the seal pool and facilities for algal and tissue culture, confocal microscopy and marine genomics.

The Gatty Marine Laboratory passed into the history books at the end of 2008 with the creation of the Scottish Oceans Institute (SOI) under the Directorship of Professor Ian L. Boyd. SOI brings together the Gatty, SMRU and marine interests in the Schools of Mathematics and Statistics, and Geography and Geosciences, to form a new interdisciplinary research institute studying the marine environment. Research within SOI now ranges from

Figure 6 *Themal images showing how a seal's body surface warms as it dries out: 5 mins (upper) and 40 mins (lower) after leaving the SMRU pool; dark purple/black: coldest (< 15 °C) pale yellow/white: warmest (32–34 °C).*



the deep oceans to the coasts, and from people who use and interact with the sea, to the biological and physical processes that make the oceans function.

Ian Johnston is a Chandos Professor of Physiology and was Director of the Gatty Marine Laboratory from 1985 to 2008. http://portal.st-andrews.ac.uk/research-expertise/researcher/iaj/

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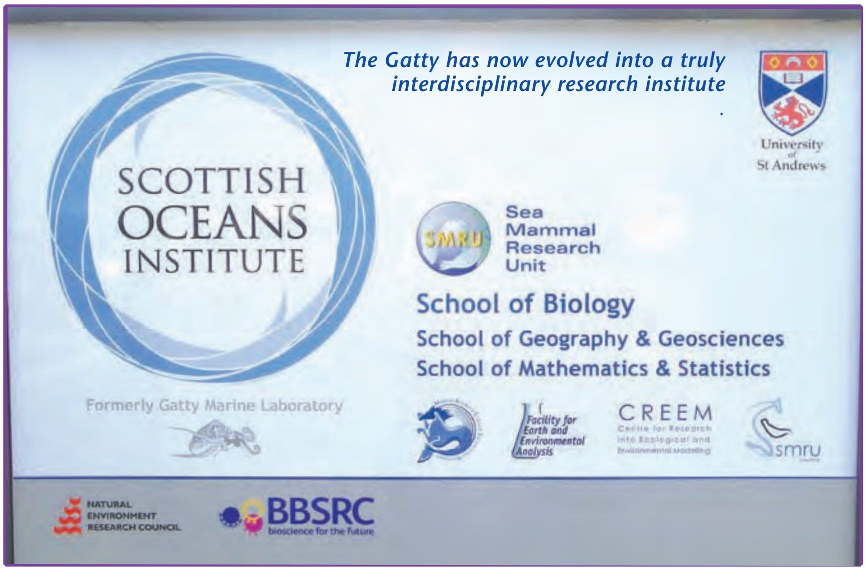

The Porcupine Marine Natural History Society

Paul Brazier and Frank Evans

The Porcupine Marine Natural History Society (PMNHS) is an informal society interested in marine natural history and in the recording of marine organisms, particularly in the north-east Atlantic region and the Mediterranean Sea. Members range from interested amateurs and hobby rock-poolers, to specialists and professional marine biologists. Membership entitles individuals to receive the Society Newsletter and to attend Porcupine scientific meetings.

Our aims as a Society are:

- to promote a wider understanding of the biology, ecology and distribution of marine organisms;
- to stimulate interest in marine biodiversity, especially in young people;
- to encourage interaction and exchange of information between people interested in different aspects of marine biology, amateur and professional alike.

Our scientific conference is held in a different part of the British Isles each year. This provides members with the opportunity to have the conference in their neck of the woods and also provides an infinitely variable backdrop to the conference and associated field trip. In addition to the conference field trip to a nearby shoreline or dive site, we organise one or more trips in the summer and/or autumn. These are normally more extensive trips over long weekends, and can be very popular. Last autumn, we visited two contrasting sites in Pembrokeshite: the sheltered waters of Milford Haven and the exposed rocky shores of St Govan's Head.

The history of the Society

The name 'Porcupine' is taken from the naval survey vessel HMS *Porcupine*, which was engaged on scientific expeditions in the norh-east Atlantic and Mediterranean in 1869 and 1870. This modest two-masted 141 ft wooden gunboat of 490 tons, propelled by wind and paddle-wheel, spent much of her life in hydrographic survey work. She gave her name to the extensive Porcupine Bank west of Ireland, discovered during the first ever attempt to dredge the deep ocean for living creatures. In May 1869, at the request of the Royal Society (following lobbying by Charles Wyville Thomson and William B. Carpenter), HMS *Porcupine* set off to dredge the deep waters to the west of the English Channel. The Royal Society hoped to discover whether life existed at the deep ocean floor and this was confirmed when the onboard naturalist John Gwyn Jeffreys dredged animals from depths reaching 1476 fathoms (2700 m). The finding prompted the excited Wyville Thomson to re-direct the second leg of the cruise south into deeper water and, on 22 July, mud and animals were successfully brought up from 2453 fathoms (4289 m). These pioneering discoveries helped disprove the deep-sea azoic hypothesis (1843) of Edward Forbes.

As a direct result of *Porcupine*'s work, the *Challenger* expedition was rapidly organised. Lasting from 1872 to 1876, it was the greatest oceanographic expedition that there had ever been or ever will be. Further information about the early history of deep-sea exploration and the involvement of HMS *Porcupine* can be found at www.deepseascape.org (see also Further Reading). A model of HMS *Porcupine* stands in Whitby museum.

The Porcupine Society was inaugurated in 1977. Its founders were the conchologists Shelagh Smith, David Heppell, Fred Woodward and David McKay. The interests of the Society were accepted at the February 1977 meeting as embracing the ecology and distribution of the generality of marine fauna and flora in the north-east Atlantic and the Mediterranean, reflecting the Society's attachment to HMS *Porcupine*. Biological recording was to form an important feature of the Society's objectives, and the extensive lists in the Society's Newsletter demonstrate the success of this aim.

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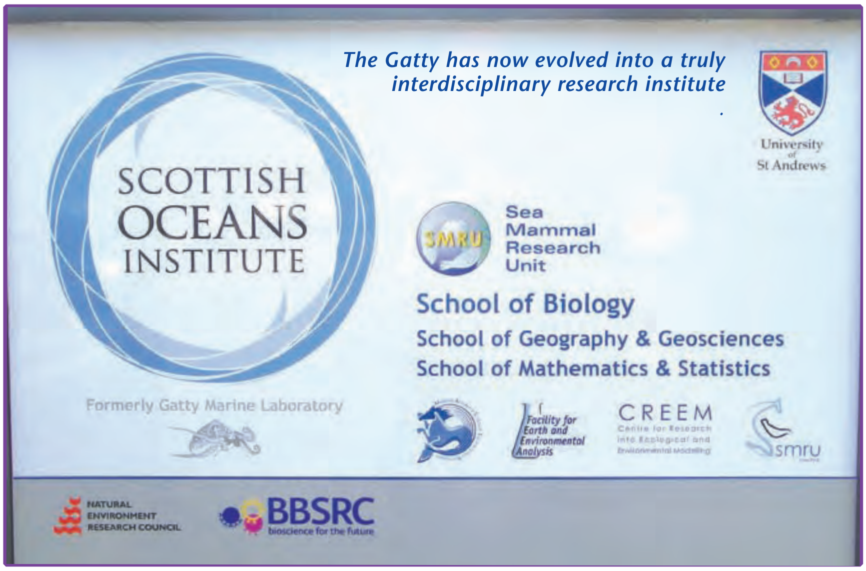

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The name 'Porcupine' is taken from the naval survey vessel HMS *Porcupine*, which was engaged on scientific expeditions in the norh-east Atlantic and Mediterranean in 1869 and 1870. This modest two-masted 141 ft wooden gunboat of 490 tons, propelled by wind and paddle-wheel, spent much of her life in hydrographic survey work. She gave her name to the extensive Porcupine Bank west of Ireland, discovered during the first ever attempt to dredge the deep ocean for living creatures. In May 1869, at the request of the Royal Society (following lobbying by Charles Wyville Thomson and William B. Carpenter), HMS *Porcupine* set off to dredge the deep waters to the west of the English Channel. The Royal Society hoped to discover whether life existed at the deep ocean floor and this was confirmed when the onboard naturalist John Gwyn Jeffreys dredged animals from depths reaching 1476 fathoms (2700 m). The finding prompted the excited Wyville Thomson to re-direct the second leg of the cruise south into deeper water and, on 22 July, mud and animals were successfully brought up from 2453 fathoms (4289 m). These pioneering discoveries helped disprove the deep-sea azoic hypothesis (1843) of Edward Forbes.

As a direct result of *Porcupine*'s work, the *Challenger* expedition was rapidly organised. Lasting from 1872 to 1876, it was the greatest oceanographic expedition that there had ever been or ever will be. Further information about the early history of deep-sea exploration and the involvement of HMS *Porcupine* can be found at www.deepseascape.org (see also Further Reading). A model of HMS *Porcupine* stands in Whitby museum.

The Porcupine Society was inaugurated in 1977. Its founders were the conchologists Shelagh Smith, David Heppell, Fred Woodward and David McKay. The interests of the Society were accepted at the February 1977 meeting as embracing the ecology and distribution of the generality of marine fauna and flora in the north-east Atlantic and the Mediterranean, reflecting the Society's attachment to HMS *Porcupine*. Biological recording was to form an important feature of the Society's objectives, and the extensive lists in the Society's Newsletter demonstrate the success of this aim.

The beautiful blue-rayed limpet, **Helcion pellucidum,** *subject of a review in a recent Porcupine Newsletter*

PMNHS activities

The Porcupine Society has continued to flourish and has held indoor meetings in most of the British and some Irish marine laboratories as well as in many universities and museums. Additionally there have been memorable field meetings at places including Sherkin Island on the coast of south-west Ireland, Guernsey, the Fleet lagoon behind Chesil Beach, the Isle of Wight, and at sea off the Northumberland coast.

Our Newsletter has appeared steadily since the Society's inception. Featuring largely scientific papers and other communications, it also contains oceanographic and marine biological notes, information about meetings and field excursions, book reviews, correspondence, and related matters. Additional items of interest can be found on the website www.pmnhs.co.uk, which also provides valuable updates to Society members. Keeping up with the times means that the Society also has a presence on Facebook – look us up!

We operate a recording scheme for *ad hoc* records of species, as well as for observations that are of interest to the wider marine biological community. In the past, such observations have been of unusual species (visitors from the south!), unusual aggregations of species, and strandings. Species records from field trips, as well as one-off casual records, are added to the Marine Recorder, and ultimately feed into the wider National Biodiversity Network (www.nbn.org.uk).

The PMNHS Grant Scheme

The PMNHS Grant Scheme, now in its third year, provides an opportunity for reseracher to apply for funding for small projects. Funding is considered for any small project that falls within the objectives of the Society. Projects may be field-based or pursued in a laboratory or museum, and might vary from basic sorting and identification, to specialist identification/study of a particular taxon of interest.

The Society Council particularly encourages applications to study the Discovery Collections at the National Oceanography Centre in Southampton (www.noc.soton.ac.uk). The collections consist of a great variety of both sorted and unsorted samples from the Porcupine Seabight and Porcupine Abyssal Plain, and provide an exciting research opportunity that could lead to the discovery of species new to science.

The Discovery Collections differ from other collections in that they are dedicated solely to samples from the open ocean and the deep sea, and they contain many unique and exotic animals. They are used primarily for ecological research, and, rather than being ordered by taxon, as in most museums, the collections are arranged so that whole samples, and hence communities, may be examined. The collections provide important baseline data on the deep-sea environment for measuring ecosystem change and for studying local and regional biodiversity.

Applications for grants are accepted from students and researchers, as well as anyone willing and able to carry out research, under appropriate supervision if necessary. The grants are open to all, irrespective of status, whether professional or amateur marine biologist or environmentalist. Applicants are expected to be members of the Porcupine Society (you do not have to be a current member, but must join the Society to be eligible). Projects will be excluded if they are part of the professional work of the applicant or are part of an undergraduate or postgraduate degree programme. If you would like to submit a proposal, further details can be found on the Porcupine website. A panel from the PMNHS Council will assess applications. See the website for the deadline each year (early summer).

Recent events

Our recent conference in St Andrews, assisted by the University of St Andrews, proved a great success. There were presentations covering topics such as Scottish fisheries, ocean acidification, scientific diving as a scientific tool, foraminiferan genetics, and predicting impacts of climate change on species distribution. Members were able to view specimens from the original *Porcupine* survey displayed in the fascinating Bell Pettigrew Museum. Excellent weather saw over a dozen members sail off to the Isle of May, where the seabirds were establishing mating pairs and nests, and the good underwater visibility was crying out to be SCUBA-dived in! In 2011 we intend to hold our conference in the south-east of England, where new members will be made welcome.

Further Reading

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Paul Brazier and **Frank Evans** are both enthusiastic members of the Porcupine Marine Natural History Society and have both served on the Society's Council.

St Govan's Head on the Pembrokeshire coast – a wonderful field-trip location

From Physics to Fish
at the Shelf Edge

During a research cruise aboard the RRS *Charles Darwin* to the shelf edge of the Celtic Sea in 2005, we stumbled upon a new explanation of why large numbers of fishing vessels are attracted to the region. Our original project was aimed at understanding how a breaking internal tide affects phytoplankton growth, but while at sea it became clear to us that the area was also very heavily fished. Was there a connection between the results we were seeing in the physics and biochemistry of the shelf edge and the presence of important commercial fish stocks?

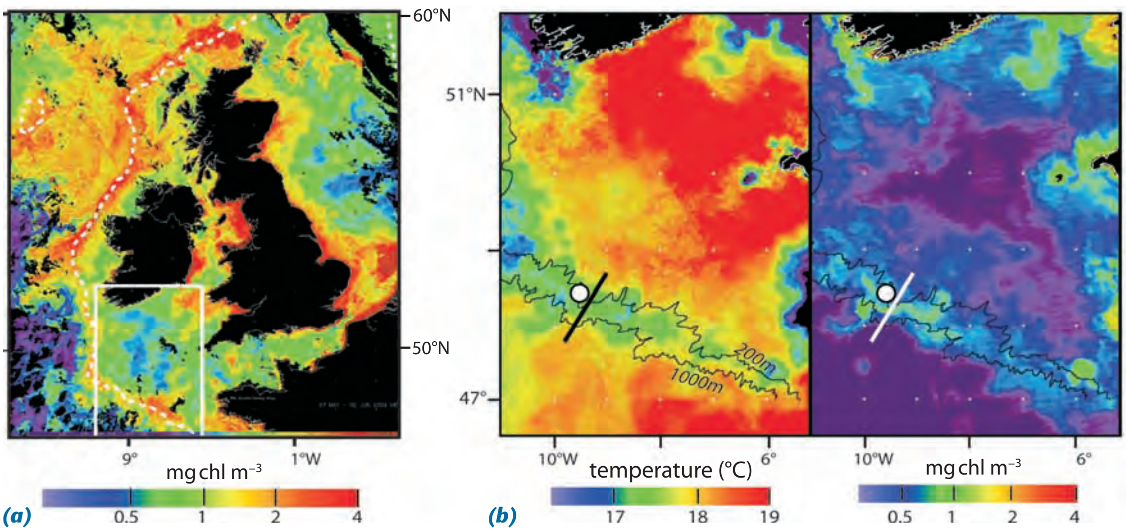
The edges of many of the world's continental shelves are important sites for fishing. The general explanation for higher fish concentrations at shelf edges usually involves some upwelling of nutrients fuelling the primary producers, so providing more food to support zooplankton, and so on up through the food chain to the fish.

Off the north-west European shelf edge, from the south of the Bay of Biscay through to the north of Scotland, there is intense fishing activity targeting spawning stocks of mackerel, hake, and sardines. Analysis of samples from the International Mackerel and Horse Mackerel Egg Survey (e.g. by Ibaibarriaga and colleagues) shows that the distribution of the eggs and larvae produced by the spawning fish are most closely correlated with the 200 m isobath, i.e. the shelf break. Certainly the shelf break is well recognised as a site of vigorous mixing generated by internal tides (e.g. the work by Robin Pingree, Adrian New and others in the 1980s), driving cool, nutrient-rich water towards the sea surface. The impact is clearly seen in the satellite imagery of Figure 1, with a band of cooler water and a band of elevated surface chlorophyll both coincident with the 200 m isobath. The simple nutrients-to-fish paradigm seems to be very evident. However, our results suggest that the simple picture misses some very important aspects of the shelf-edge physics and how the biology responds to it.

Figure 1 ***(a)*** *A typical June image of sea-surface chlorophyll over the north-west European continental shelf. Note the band of elevated chlorophyll concentration (yellow/red) aligned with the shelf edge, marked by the 200 m isobath (dashed white line).*

(b) *Detailed images of the area within the white box in (a) of sea-surface temperature (left) and sea-surface chlorophyll (right), taken during the research cruise in July 2005. In each image, the white line across the shelf edge marks the CTD transect carried out during the cruise (to determine the variation of salinity and temperature with depth), and the white circle is the position of the mooring and the turbulence measurements.*

(Satellite images all courtesy of NEODAAS, Plymouth Marine Laboratory)



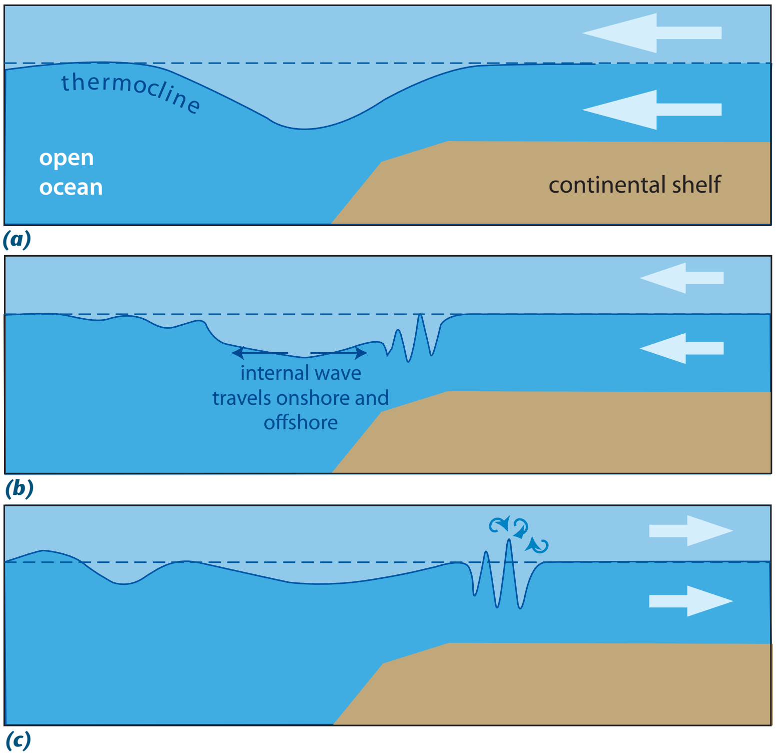
Satellite images show that shelf-edge waters are cooler and richer in chlorophyll than adjacent waters

Internal tides and nutrient fluxes

To generate an internal tide – i.e. a tidally generated internal wave – you need tidal currents, stratified water, and some sharp changes in topography (Figure 2). The shelf edge in spring/summer is an ideal site. As the tidal currents flow off the shelf, the thermocline is pulled downward. As the tidal currents decrease, the thermocline can no longer remain bowed downward, and it bounces back. This bounce-back sets up the oscillation of the thermocline (an internal tidal wave), which moves as a wave both off-shelf and on-shelf. It's the on-shelf part that we were interested in. As the internal wave moves over the shelf edge into the shallower water it behaves in much the same way as swell waves approaching a beach: it breaks. For the internal tidal wave, this breaking manifests itself as the generation of much smaller (1–2 km wavelength, 10–20 minute period) internal waves which travel in groups along the thermocline. These smaller internal waves dissipate rapidly, producing turbulence and leading to vertical turbulent mixing localised around the shelf edge (Figure 2(c)).

Interaction of tidal currents with shelf-edge topography results in internal waves and mixing

Figure 2 *Schematic illustration of how the internal tidal wave is set up at the edge of the continental shelf.* ***(a)*** *Tidal currents flowing off the shelf drag the thermocline down.* ***(b)*** *As the tidal flow decreases, the thermocline is released and bounces back, propagating an internal wave both offshore and onto the shelf. The internal wave moving into shallower water breaks up into smaller-scale internal waves (analogous to swell waves breaking as they approach a beach).*
(c) *As the tidal flow turns, the internal waves move onto the shelf and dissipate rapidly, generating turbulence and mixing locally at the shelf break.*



Our sampling at the shelf edge was designed to allow us to measure the turbulent mixing generated by the breaking internal tidal wave, and so calculate the vertical fluxes of nitrate driven by the mixing at the shelf edge. We kept the *Charles Darwin* approximately on station in a depth of 200 m, for 25 hours at a neap tide and for 25 hours at the folowing spring tide. Over the entire period we kept a mooring in place, with a string of individual temperature loggers sampling the vertical temperature structure every minute. Over the stern of the ship the Turbulence Group from Bangor University deployed their 'FLY' free-fall turbulent microstructure profiler to collect data on the structure of turbulence through the water column. At the same time, the biochemists from the University of Southampton used the CTD to obtain vertical profiles of nitrate concentration, and to collect water samples for analyses of primary production rates.

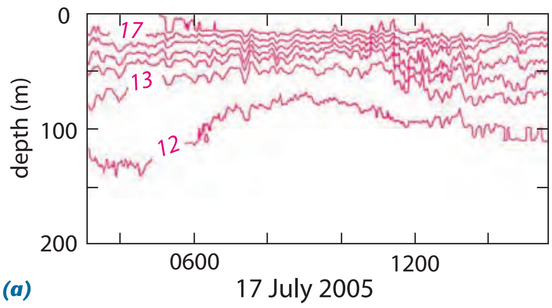
Combining the nitrate profiles with the turbulence measurements allowed us to calculate daily-averaged fluxes of nitrate from the bottom water up into the thermocline and surface layer. We found a very strong contrast in the rate of nitrate supply between neap and spring tides. The neap-tide flux was about 2 mmol m^{-2} day^{-1}. At spring tide, the nitrate flux reached 9 mmol m^{-2} day^{-1}. This flux was so strong that we were able to measure nitrate in the surface layer at concentrations of >0.5 mmol m^{-3}; normally in summer stratified shelf seas nitrate does not reach the surface as the phytoplankton in the thermocline are well capable of intercepting all of the weak turbulent fluxes from the bottom water. This spring-tide flux of nitrate was driven by strong mixing triggered by the small scale internal waves (Figure 3(b)). By contrast, there was very little activity of the small-scale internal waves at neap tides (Figure 3(a)).

We can compare these nitrate flux measurements with fluxes found on the shelf and in the open ocean. Using similar techniques on the shelf in stratified regions of the Celtic Sea and western English Channel we typically find nitrate fluxes of about 2 mmol m^{-2} day^{-1} into the base of the surface layer. Others have found nitrate fluxes into the thermocline of the adjacent open north-east Atlantic of typically 0.1 mmol m^{-2} day^{-1}. Clearly, the shelf edge, particularly at spring tides, is a localised site of strong nitrate supply.

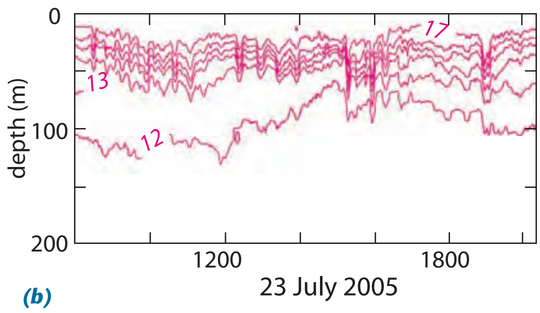
The phytoplankton response

The strong vertical supply of nitrate to surface waters above the shelf edge would seem to be consistent with the accepted view of a physically driven nutrient flux supporting the shelf-edge food chain, including the fish. What response did we see in the phytoplankton?

We collected samples of phytoplankton, and measured rates of primary production, along a transect line of CTD stations from the shelf out

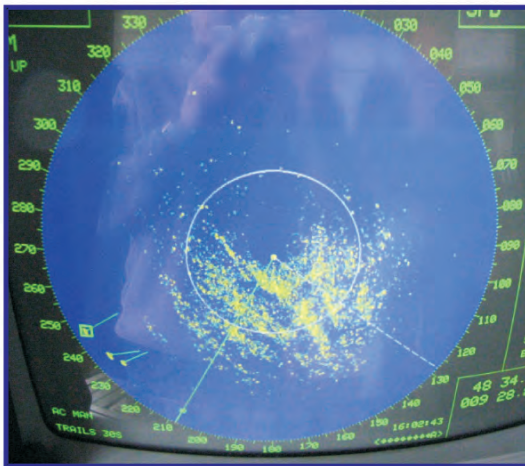


(a)



(b)

The temperature structure shows that internal waves are generated, and break over the shelf edge during spring tides



(c)

Figure 3 ***(a)*** *The change in the temperature structure of the water column over the course of one tidal cycle, close to neap tides, recorded by the mooring at the shelf edge.* ***(b)*** *As (a), but approaching spring tides.*
The rising and falling of the 12 °C isotherm shows the passage of the internal tidal wave. Notice that in (b) there is much more high-frequency variability, for instance between 15.00 and 16.00. This variability is caused by the passage of packets of internal waves, formed as the internal tidal wave breaks (cf. Fig. 2(c)).

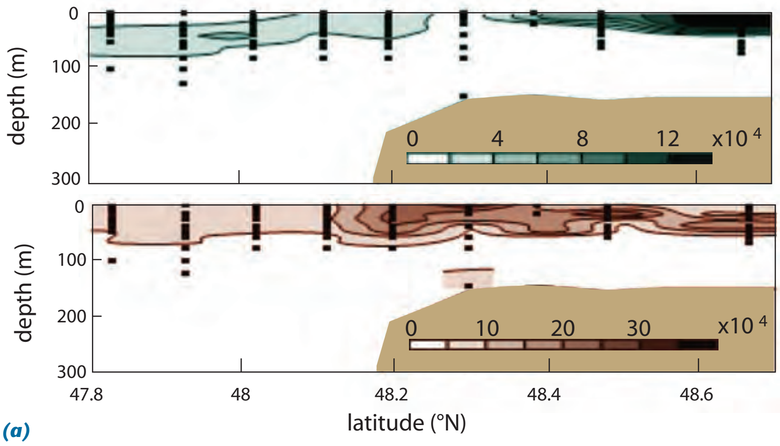
(c) *This image, taken from the ship's radar, shows bands in the radar noise as the packet of internal waves seen in the mooring at 15.00–16.00 on 23 July passes the ship. The three targets in the lower left of the radar image (near the edge) are fishing vessels.*

to the deep ocean, passing through the shelf-edge sampling station (see Figure 1(b)). While the satellite imagery may give the impression of greater chlorophyll concentrations at the shelf edge, integrating the chlorophyll within the upper 100 m of the water column showed that there was little difference in the standing stock of phytoplankton biomass along the transect. However, rates of primary production at the shelf edge (400–800 mgC m^{-2} day^{-1}) were about twice those found either in the open north-east Atlantic or in the Celtic Sea. So, shelf-edge phytoplankton are more productive, but is the factor of 2 increase in carbon fixation rates sufficient to explain the strong correlation between the spawning fish and the site of internal mixing?

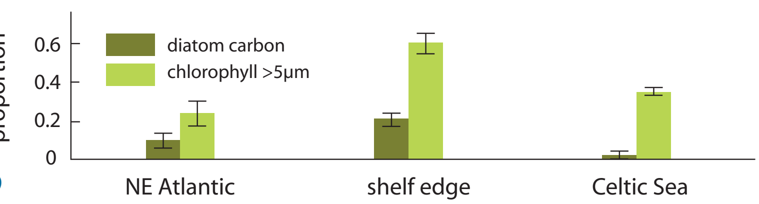
Figure 4 shows a perhaps more dramatic phytoplankton contrast associated with the shelf edge. The band of high sea-surface chlorophyll along the 200 m isobath may not reflect a biomass maximum, but it does indicate a region where the phytoplankton population changes quite remarkably. Phytoplankton samples run through a flow cytometer show the thermocline in the open ocean and the surface layer in the Celtic Sea to contain significant concentrations of cyanobacteria (mainly *Prochlorococcus* in the Atlantic, and *Synechococcus* in the Celtic Sea; see Figure 4(a)). At the shelf edge there was an almost complete lack of cyanobacteria, with the flow cytometer showing larger numbers of pico-eukaryotes,* such as small flagellates. Size-fractionated chlorophyll filtering showed the shelf edge to be dominated by phytoplankton cells > 5 μm, in contrast to much smaller cells

*Eukaryotes are organisms whose cells contain a nucleus, in contrast to prokaryotes, such as bacteria and cyanobacteria, which have no nuclei. Those observed were typically 2–5 μm in size.

Shelf-edge waters are characterised by more large phytoplankton and fewer cyanobacteria



(a)



(b)

Figure 4 ***(a)*** ***Upper*** *Cross-shelf-edge distribution of the cyanobacterium* Synechococcus *(cells ml^{-1}).* ***Lower*** *Distribution of small (~2–5 μm) eukaryotes.*

(b) *Proportions of phytoplankton chlorophyll in cells >5 μm diameter, and the proportion of total cell carbon attributable to diatoms, in the open north-east Atlantic, at the shelf edge, and in the Celtic Sea.*

The data in (a) and (b) were obtained using a flow cytometer (which counts cells optically), with the dots showing the positions of the water samples used in the analyses. Data in (c) were obtained by size-fractionated filtering and by light microscopy.

away from the shelf edge. Microscope analysis of samples identified more diatoms at the shelf edge, accounting for over 20% of the cell carbon compared to 10% and <3% in the Atlantic and in the Celtic Sea respectively (Figure 4(c)). All of this evidence suggests that the shelf edge, rather than simply a site of elevated primary production in response to nutrient supply, is a site notable for having a phytoplankton population that is very distinct from that in either the open north-east Atlantic or the Celtic Sea: the shelf edge supports phytoplankton groups and species with larger cell sizes than elsewhere.

Why should we find larger phytoplankton just at the shelf edge? The molecular diffusive flux of nutrients to a phytoplankton cell wall is inversely proportional to the cell diameter; i.e. small cells (with a relatively large surface area/volume ratio) are far better adapted to survival in nutrient-poor environments. In summer, in the oligotrophic surface waters of the open ocean or the Celtic Sea, nitrate concentrations are extremely low, and as a result the small cyanobacteria are able to outcompete larger phytoplankton cells. If that nutrient stress is removed, e.g. by upwelling or mixing of deep nutrients towards the surface, then the small cells lose their competitive advantage. The larger cells can then dominate, because they often have higher growth rates, and in some cases may have the ability to divert resources into defences against grazing (e.g. silica shells for the diatoms). Thus the mixing by the internal tide, localised at the shelf edge where the internal tidal wave breaks, provides the underlying mechanism that alters the size structure of the phytoplankton community.

More speculatively, we think that the effect of the spring–neap cycle on the rate of vertical mixing of nitrate could be playing an important role. Increased vertical mixing may be good for phytoplankton growth by supplying nitrate from deeper waters, but mixing can also prevent the phytoplankton from responding to the nutrient supply if it is strong enough to disrupt the light environment experienced by phytoplankton cells. Mixing by the internal tide at spring tides is very strong at the Celtic Sea shelf edge; our measurement of surface-water nitrate at spring tides suggests that the nitrate supply overwhelms the phytoplankton population's capacity for nitrate uptake. Perhaps the subsequent reduced mixing at neap tides, back down to levels more like those seen in the summer thermocline of the Celtic Sea, is important as it provides phytoplankton with the chance to acclimate to a more stable light environment and so be able to utilise the nitrate. The mixing would have to be reduced for sufficient time for phytoplankton to be able to respond, before the disruption of the next strong mixing episode. The 14-day periodic nature of the spring–neap cycle could be ideal for this.

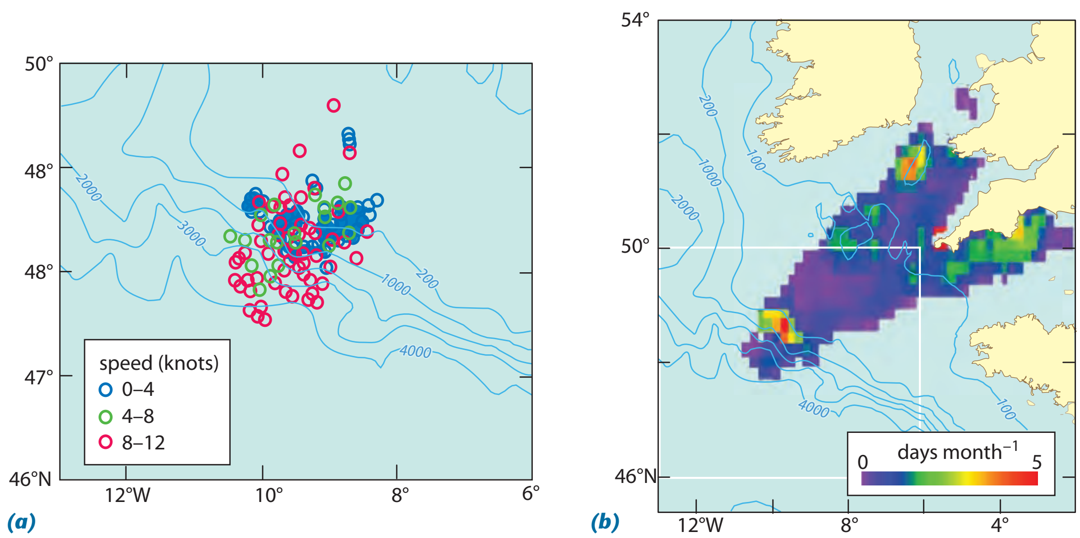
The link to the fish

That is about as far as our original project planned to go. We had aimed to measure the vertical supply of nitrate to shelf-edge waters in response to the spring–neap modulation of the internal tidal mixing, and we wanted to see what implications there were for the growth and characteristics of the phytoplankton community at the shelf edge. While we were at sea making these measurements it quickly became clear that there were a large number of Spanish fishing vessels in the area. Much of the physical information we

Figure 5 ***(a)*** *Positions of an individual fishing vessel near the shelf edge, colour-coded by vessel speed. Depths on isobaths are in metres. Assuming that speeds <4 knots (red and green circles) suggest fishing activity, the shelf edge (200 m isobath) is clearly a focus for fishing effort for this vessel.*

(b) *Fishing activity within the UK sector of the Celtic Sea (calculated assuming speeds <4 knots imply a vessel engaged in fishing), and a summation of all of the data for individual vessels between March and October 2005. The area within the white box corresonds to that in (a), and shows the high fishing activity at the shelf edge.*

(Fishing vessel positions are from the VMS, provided by the UK Department for Environment Food and Rural Affairs)



VMS data confirm that fishing activity is concentrated at the shelf edge

collected during the cruise (e.g. the data shown in Figure 3) was based on a mooring deployed for about 8 days at the 200 m isobath. The ship's radar image in Figure 3 shows three fishing vessels on course towards the *Charles Darwin* and the shelf edge mooring. The survival of the mooring, and the success of the project, were entirely down to the tireless efforts of the *Darwin's* bridge officers in keeping regular contact with the fishing vessels. Having a third mate on the *Charles Darwin* who was fluent in Spanish was a particular bonus.

On our return from the cruise I thought I would try to quantify our anecdotal experience of high fishing activity focussed on the shelf edge. From the UK's Department for Environment, Food and Rural Affairs (Defra) we were able to acquire data from the Vessel Monitoring System (VMS) for the UK sector of the Celtic Sea out to beyond the shelf edge. This VMS data provided hourly positions of all EU fishing vessels in the area, from which individual vessel tracks and speeds could be calculated. If a vessel speed drops below, say, 4 knots then it is assumed to be fishing. Collating the data for all vessels allows a map of fishing activity to be produced (e.g. Figure 5). This map clearly shows that the edge of the continental shelf is a site of some of the most intense fishing activity in the Celtic Sea.

The fishing vessels are hunting for the fish that are using the shelf edge as a spawning site, and both the VMS data and the fish egg and larvae distributions indicate that the fish and the fishers are very tightly associated with the 200 m isobath. What is it about this site of increased internal mixing by the internal tide that leads to this association? Is it simply that the increased primary production rates driven by the nitrate flux leads to better conditions for the fish, or is there something more subtle involving the characteristics of the phytoplankton community?

Work by Dave Conway and Steve Coombs (both now at the Marine Biological Association) and colleagues provides the possible link between the internal tide and the spawning fish. Analysis of the diet of first-feeding mackerel larvae shows them to be dependent on copepod eggs and nauplii and, most interestingly, that the smallest larvae ingest phytoplankton. Fish larvae are known to target particles > 5 μm in size, so there is a strong implication that the shift of the phytoplankton community from small cyanobacteria to larger eukaryotes at the shelf edge (cf. Figure 4(a)) is fundamental to the survival of the first-feeding mackerel larvae. So, the breaking internal tide mixing nutrients towards the sea surface and fuelling more primary production is only part of the explanation for the shelf-edge fishery. More importantly, the nutrient flux allows the phytoplankton community to shift to larger cells, which provide better food for the fish larvae and ultimately support the fish stocks that have adapted to spawn at the shelf edge (see Further Reading).

Unanswered questions

The link between the internal tide and the shelf-edge fish, via the response of the phytoplankton community to a periodic supply of nitrate, is novel but we have only scratched the surface of the problem. There are several avenues for future research.

The spatial extent of this link is certainly implied by a larger-scale correspondence between the shelf-edge chlorophyll and the distributions of mackerel eggs and larvae. Satellite images (Figure 1) show the surface chlorophyll band along the shelf edge to be a consistent feature from the northern part of the Bay of Biscay, round the west of Ireland, and to the north of Scotland. Our observations were focussed on a very small section of the shelf edge. Other work has shown that the internal tide is a feature of the Malin Shelf west of Scotland (e.g. the SES study in the early 1990s). We can hypothesise that the internal mixing is a consistent feature along the entire shelf edge, and that the chlorophyll pattern seen in the satellite imagery indicates a region where not only primary production, but also the species structure of the phytoplankton, respond to the internal mixing.

The periodic nature of the mixing, and the necessity for regular low mixing periods to allow the phytoplankton community to respond to the nutrient supply, requires investigation. The idea is analogous to findings off the California shelf in the late 1960s, where Ruben Lasker suggested that episodic wind mixing, with sufficient gaps between wind events, was required to produce a phytoplankton community suited to feeding anchovy larvae (see Further Reading). In particular, direct observation of the relative growth rates of different groups of phytoplankton at the shelf edge, and on-shelf and in the adjacent open ocean, are needed to test the concepts underlying our ideas about the success of different species in different mixing environments.

Linking the phytoplankton community through to zooplankton, and the success of fish larvae, is the most challenging area that we have not yet addressed. Can we confirm which phytoplankton groups the first-feeding larvae are eating? Do other zooplankton benefit from the changes in the phytoplankton community, and do they then provide better food for the larger fish larvae? Can we track measures of the 'quality' of organic material (e.g. nitrogen content, fatty acids) through to patterns in successful fish larvae? We must also not lose sight of other physical impacts at the shelf edge, for instance the slope current (which flows parallel to the shelf-edge) as a conveyor of eggs and larvae back towards the adult fish feeding grounds, or the potential for increased predator–prey encounters in regions of elevated turbulent mixing.

Our original project had a relatively narrow focus on the impact of a breaking internal tide on primary production at the shelf edge. The link from the internal tide to the presence of commercial fish stocks along the shelf edge was triggered by anecdotal experience of carrying out our observational work amongst fishing vessels. We have found a very novel link between a physical process (one that is ubiquitous at shelf edges around the world) and the structure of shelf-edge ecosystems. We have certainly triggered far more new questions and ideas for areas for research than we expected.

Acknowledgements

Our work was supported by NERC responsive mode grants to the University of Southampton and Bangor University, and by NERC core funding at the Proudman Oceanographic Laboratory. The success of the work at sea owed much to the crew of the RRS *Charles Darwin* (CD173) and the support of the UK National Marine Facilities.

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Jonathan Sharples* is an oceanographer with research interests on the boundaries between the physics, biochemistry and ecology of the oceans. His main interest is in finding out how physical processes determine the structure and functioning of marine ecosystems, mainly on the shelf and at the shelf edge.

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Dr Darius Campbell : Safe Seas for the Coming Century
Dr Vicky Pope : Dealing with Uncertainty in Models and Observations

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Book Reviews

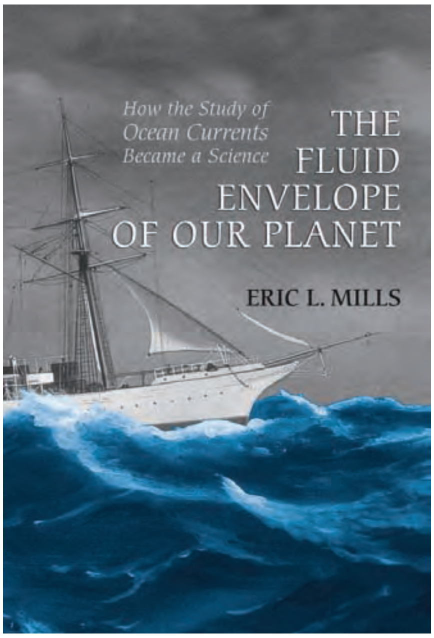
A page-turning history of physical oceanography

The Fluid Envelope of our Planet: How the study of ocean currents became a science by Eric L. Mills (2009) University of Toronto Press, 434pp. £48 (hard cover, ISBN-13: 978-080-2096975).

On the front cover, the subtitle – How the study of ocean currents became a science – tells you what this splendid and scholarly book is all about. Mills articulates the development of ideas, but he also delves into the background, motivation and character of the leading actors in what is a compelling story that unfolds page by page. He writes of opportunities seized, and opportunities missed. We marine scientists do need to be reminded every now and then that bringing ideas from other disciplines into oceanography is not a new phenomenon. Mills argues convincingly that the foundation of dynamical oceanography owed a great deal to mechanics and the quest in the 19th century to understand electromagnetism

Chapter 1 sets out to summarise knowledge of ocean circulation before the 19th century. This may seem an impossible task, but by concentrating on the ideas relevant to an emerging scientific approach, and maintaining a cracking narrative pace, Mills succeeds. The work and influence of Hadley, Rennell and Humboldt feature prominently. Mills also draws our attention to the geophysical insights of others whose work was long neglected, for example, the Scottish mathematician Colin Maclaurin, who proposed in the early 18th century that the rotating Earth would have an effect on meridionally directed ocean currents.

The cover shows the yacht Princesse-Alice II, in which Prince Albert Ist of Monaco undertook some of his most important work (Artist: De Simone, 1909)



Groping through Darkness, the title of Chapter 2, describes an era in the 19th century when 'Physical scientists resolutely stayed at their benches and ignored the sea, while a variety of others … did not hesitate to pronounce on the causes of ocean currents.' The 'variety of others' included the hydrographer Mathew Fontaine Maury, the naval officer Jules Dumont d'Urville, zoologist Charles Wyville Thomson, physiologist W.B. Carpenter, and clerk to the Geological Survey of Scotland, James Croll. Mills is forthright in his descriptions of the work of this period, from the 'misguided hypothetical schemes' of Carpenter's general oceanic circulation, to the 'mind-numbing sameness' of the Carpenter–Croll controversy over the cause of ocean currents. Why the sophisticated mathematics, physics and fluid dynamics current in England at that time were not brought to bear on ocean circulation is a question Mills attempts to answer, but a more detailed study is really called for.

The mathematical approach, and hence dynamical physical oceanography, emerges in the late 19th century in Scandinavia. Henrik Mohn began applying the quantitative methods that were then transforming meteorology to the analysis of the results of the Norwegian North Atlantic Expeditions of 1876–78. The originality, and significance, of Mohn's work, the central role of Vilhelm Bjerknes, the inspiration from theories on ether-based physics, and the foundation of the Bergen School, make for a dramatic and inspiring Chapter 3. Bjørn Helland-Hansen and Johan Sandström's creation of useable mathematical tools to implement the theories of Bjerknes is critically assessed.

Mills surprises the reader in Chapter 4 by describing how Canada provided the datasets and motivation for the 'first full-scale' application of dynamical physical oceanography. Johan Hjort of Bergen was the intermediary between the data-collection on the Canadian Fisheries Expedition of 1915 and Johan Sandström, who carried out the analysis. There is a pace and excitement to this chapter, as the scientists attempt to solve 'the biological–hydrographical problem', while bureaucrats try to understand the resulting report of 'a most abstruse and technical character'.

The interplay between adherents in Germany of the new mathematical techniques, mainly at the Institut für Meereskunde, Berlin, and the essentially descriptive physical oceanography practiced at the Deutsche Seewatre in Hamburg is the subject of Chapter 5. It is an insightful study into the importance of scientific training, the influence of motivation and character, and the role of debate among opponents. At a time when groups in Germany led on the development and application of dynamical oceanography, there was 'virtual invisibility' in France. Mills considers this a paradox, given France's breadth and depth of science. Although he credits Prince Albert 1st of Monaco with advancing several areas of oceanography, the heading 'Découverte de l'océan: Monaco and the Failure of French Oceanography' sets the tone for Chapter 6.

How dynamical physical oceanography took root in the Unites States is the theme of Chapter 7. Mills contrasts the research directions and motivation on the west coast, centred at Scripps, with those at Woods Hole. He clearly considers the work at Scripps would have benefited from a less isolationist culture. While the epigraph to this chapter, from Columbus Iselin to Henry Bigelow, credits Carl-Gustaf Rossby with training a hydrologist, 'beginning the fall of Bergen'. Oddly, Rossby himself does not feature in the narrative, which is one of Bergen being 'overtaken by the success of their own methods'. The chapter closes with a salutary reminder of how those that create new directions in science can be overtaken during the course of a working life.

Returning to Canada, Chapter 8 has a broader theme, the development of physical oceanography between 1930 and 1950. It portrays the expansion of a branch of science, spurred on by the needs of navies during World War II, and the energy of scientists themselves. Harry Hachey and Jack Tully, in 1939 'the only two physical oceanographers in Canada', were leaders of this change.

This broader theme continues in Chapter 9, beginning with a discourse on the background and content of Sverdrup, Johnson and Fleming's 'magisterial and definitive treatise' *The Oceans*. Post-war, Harald Sverdrup provided suggestions to his student Walter Munk, who, for the first time, formulated a scheme for the quantitative assessment of gyral circulation. Munk was also influenced by the ideas of Henry Stommel on the westward intensification of wind-driven ocean currents. And, with a critical review of the work of Stommel, who Carl Wunsch described as the 'most original and important physical oceanographer of all time', Mills ends his excellent book. To all of you interested in the development of ideas in oceanography: please read this book, you will learn, as I did, and in many places you will turn the pages as if it were a thriller.

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Centuries of exploration at the top of the world

A History of Arctic Exploration: Discovery, adventure and endurance at the top of the world by Matti Lainema, and Juha Nurminen (2009) 349pp., London: Conway Press, £40 (hard cover, ISBN-13: 978-1-84486-069-2).

This excellent, very well illustrated history of the Arctic first appeared in 2001, published in Helsinki. It is one of several polar works published by the John Nurminen Foundation which have been researched and illustrated to a uniformly high quality. Its copious illustrations are carefully selected; 40% of them are of contemporary maps, while others show persons, vessels, instruments, and various other subjects. This recalls much of the very comprehensive material held in Helsinki by the earlier Nordenskiöld Foundation.

After an introduction by Lennert Meri, former President of Estonia, Juha Nurminen explains the development of the book and indicates that much is derived from personal knowledge and travels of both authors in Arctic regions – a rare advantage in historical writings of polar regions. The boundary of 'the Arctic' is debatable. In this book, as wilder places become known the geographical boundary recedes farther north, a logical progression as history develops. In summary, the region covered is well north of the Arctic Circle and the period is expressed as 'from Pytheas to Peary'. Thus it begins with the identification of the land known as 'Ultima Thule' from the voyage of Pytheas (c. 325 BC), and draws to an end in the central Arctic Ocean.

The corvette *La Recherche****, near Beeren Island in 1838, by Auguste Mayer (1852).***
(By courtesy of The Nurminen Foundation)

The treatment of the subjects is organized into a series of 13 thematic chapters which facilitate understanding of the general progress of Arctic exploration. In the historical continuum there are no 'watertight compartments' and these chapters indicate the relationships between many discoveries. It is good to see that the whalers and sealers, hunters and trappers are described, as their industries made major contributions to exploration, which are sometimes neglected. Sections in the chapters discuss tangential subjects where these are appropriate, including: navigation, Eskimo survival, Arctic fauna, scurvy, ice, and similar relevant topics.

Many works on this subject tend to be biassed by language or other sources of information and, when in English, tend to neglect the very extensive Russian parts of the Arctic. This book does not; the text, maps, and illustrations have an effective distribution covering all Arctic regions – this is undoubtedly a consequence of its Finnish origin.

I have one reservation in my praise of the research; the attribution of attainment of the North Pole by Robert Peary in April 1909 is not assessed fully. There has been much doubt about this claim and, following release of documents after many years of closure, support is no longer strong. Indeed a discussion, or even a tabulation such as appears on page 332, would have been desirable. Another difficulty I note involves the vexatious problem of rendering the Cyrillic alphabet into the Latinised one. This sometimes follows systems applicable for languages other than English, but causes no major problems.

The historical account concludes at about the time of the first World War, when exploratory activities throughout the world went into abeyance. An Epilogue, however, brings things closer to the present where the main events of the 1900s are described very concisely. Knowledge of the Arctic developed rapidly after the war, particularly after aircraft became practical for exploration; perhaps this might be a welcome subject for a future work.

The book is large (35 × 25 cm) which allows the maps and other illustrations to be printed clearly (although many cross two pages). The 108 maps are listed with detailed specifications, and a list of sources for the 158 illustrations is comprehensive. As well as belonging to the John Nurminen Foundation many are from the personal collection of Juha Nurminen. The well organized bibliography includes approximately 450 references ranging over more than two-and-a-half centuries. The index is of personal names only; while this may cause difficulties with investigating particular geographical regions, it provides a compendious indication of history. The new edition of the work clearly demonstrates the success of the original volume, and it is, bearing in mind its quality, a very reasonably priced work. Conway Press, which has published similar volumes, is to be congratulated on this new edition.

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Paradise for mermaids

Cold-water Corals: The biology and geology of deep-sea coral habitats by J. Murray Roberts, Andrew J. Wheeler, André Friewald and Steven Cairns (2009) 352pp, Cambridge University Press, £65 (hard cover, ISBN-13: 978-0-521-88485-3).

If only I were a mermaid! That was my first thought on reading this exemplary book on cold-water corals – how wonderful to be able to drift over the pale tentacles of a *Lophelia pertusa* reef, swim through a forest of rosy *Paragorgia arborea*, or wander through the Aleutian Island coral gardens. Sheer pleasure. But this publication is primarily a very important contribution to coral and deep-sea research.

Cold-water corals belong to the same cnidarian taxa as shallow tropical reef corals; thus they share so many similarities that any attempt at placing them into a separate category tends to fail. For example, while it is true that the symbiotic relationship between coral host and zooxanthellae is a characteristic found most commonly in shallow tropical species, it also occurs in some cold-water species; conversely, non-symbiotic species representing most cold-water corals are also found in shallow tropical waters.

Sebastes viviparous *among the tentacles of a* **Lophelia pertusa** *reef in Trondheimfjord.*
(By courtesy of R. Holt)

Nonetheless, there is one fact that distinguishes them: cold-water corals have received none of the attention of their tropical counterparts, in neither the public nor the scientific domain. This book is a very welcome step towards adjusting the balance; and this is indeed necessary when over half of all coral species are in cold waters.

The authors' focus is on habitat-forming species, i.e. those species instrumental in either constructing a reef framework or in providing other structural habitat and refuge for many more associated species. They include scleractinians (stony corals), with their calcium carbonate hard skeleton, which form reefs comparable to their tropical counterparts. However, in cold water Scleractinia are not the only taxon of interest; habitat-forming species are also found among Antiphatharians (black corals), Octocorals (soft corals, precious corals), Stylasterids, and even among Zoanthids which, with the remarkable exception of three cold-water species (out of total >200 species), are known as soft-bodied creatures.

The book starts by presenting a history of the discovery of cold-water corals and a review of the recent technological developments that have allowed research in this field to bloom, and it ends with a poignant discussion of why conservation measures are needed now. In between, the reader learns an enormous amount about these wonderful creatures and the astonishing environments they generate and inhabit; also information about taxonomy, molecular phylogeny, biology, physiology, ecology, biodiversity, geology and palaeontology. In addition, the book documents the ways in which coral reefs and mounds are providing scientists with biological, chemical and geological archives of tremendous contemporary relevance.

Overall this is a specialized text likely to be best appreciated in its entirety by students at post-graduate level and researchers with a background in the field. All the same, the four writers adapt style to content with flair, and the range of subject matter presented will keep readers on their toes and turning the richly illustrated pages with anticipation and satisfaction. It is a real gift of this volume to bring together what too often is dealt with separately; thus organismal level biology is side-by-side with habitat ecology, the present is next to the evolutionary past, highly academic discourse is flanked by descriptions which convey a very palpable excitement and awe regarding the challenges faced by deep-sea researchers.

The authors do not shy away from complex issues or the analysis of developing trends and this is particularly valuable in a text where scientific rigour is paramount. For example in the biomineralisation section, two current and contrasting theories of coral calcification are both discussed, and in the section on phylogeny, we learn how new molecular techniques are continuing to challenge the classical phylogenies based on morphological data. The authors are conscious that theirs is a subject still in its infancy. Thus we read about the different schools of thought and the need to see and consider both sides of the coin – as well as the spinning rim!

Of course, with so many new lines of research being discussed, one is left wondering how long this volume will remain up-to-date. Indeed, the authors must be aware that the speed with which this volume will have to be followed by a revised edition will be one measure of its success. But for now they give us sound facts, current knowledge, and inspiration for the future. This is a book that will encourage the best students and a whole generation of scientists to explore anew 'the vasty deep' – the frontier of our Earth in our time.

For those of us unlikely to become mermaids any time soon, this book is as good as it gets.

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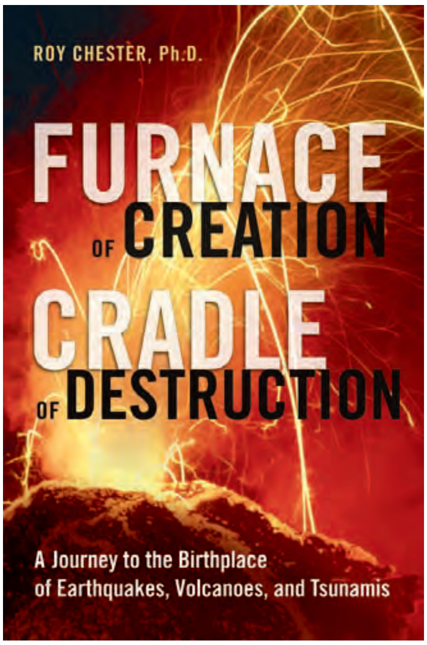
Eruptions, earthquakes and tsunamis

Furnace of Creation, Cradle of Destruction: a journey to the birthplace of earthquakes, volcanoes, and tsunamis by Roy Chester (2008) AMACOIM Books, 242pp. £19.99 (hard cover, ISBN-13: 978-0-8144-0920-6).

Chester's stated aim in this book, which arose out of a series of public lectures that he was invited to give after the Indian Ocean tsunami of Boxing Day 2004, is to 'portray the progress of human understanding from ancient mythmaking to scientific enlightenment'. He refers to volcanoes, earthquakes and tsunamis as 'that great trinity of natural disasters' although he is duly careful to distinguish tsunamis as consequences of earthquakes, volcanic eruptions and other causes (such as landslides or impacts from space) rather than as primary hazards in their own right.

About half the book is given over to the history of Earth Sciences, culminating in the exploration of the ocean floor and the establishment of the plate tectonics paradigm but also digressing into subsequent advances such as understanding the links between ocean-floor hydrothermal vents and the rock cycle, and the origin of life, which are of peripheral relevance to earthquakes, volcanoes and tsunamis. History is interwoven with notable examples of eruptions, earthquakes and tsunamis described in the context of present-day understanding.

I am left wondering who will benefit from this book. Geologists and laypeople alike who are intent on boning up about Chester's 'trinity' will probably be frustrated by



the extent to which the history of science pervades the narrative, and may wish that Chester would cut to the chase sooner. Those seeking to learn about or be entertained by the development of ideas would be better served by modern classics such as Robert Muir Wood's *Dark Side of the Earth*, and H.W. Menard's *The Ocean of Truth*.

I did enjoy aspects of the book. Some ancient cosmogonies seeking to explain why earthquakes occur rival Sir Terry Pratchett's Discworld (which is supported by four elephants riding on the back of a turtle). A restless turtle is actually invoked by one North American myth, but the earthquake explanation that caught my attention was one from Africa, which has a cosmic fish carrying a stone on its back, on which stands a cow balancing the Earth on her horns.

However, I am afraid that there are too many errors for me to recommend this book strongly to science novices. For example: Figure 5-4 botches the definitions of amplitude and wave-height, and pages 125-6 twice incorrectly punctuate the description of ocean crust layering so that it reads 'gabbro-dike, swarm-pillow, lava' (once with and once without the second comma) instead of the unambiguous 'gabbro, dike-swarm, pillow-lava' and the book fails to mention that in fact on fast-spreading ridges other lava morphologies are at least as widespread as pillow-lava. Page 126 also tells us that subducted sediments 'contain volatiles that cause intense volcanic and earthquake activity'. It is true enough in that volatiles in supra-subduction zone settings encourage magma-genesis and largely dictate the nature of the common eruptive processes. However, I know of no role for volatiles in causing earthquakes, and in fact, if anything, volatiles ought to lubricate stick–slip motion (a term strangely absent from the book) and therefore reduce the magnitudes of local earthquakes. Chester's description of the monitoring and hazard zonation performed in the run-up to the famous 1980 eruption of Mount St Helens is fine so far as it goes, but there is no hint that the eruption (when it 'blew its top', according to Chester) began as a totally unanticipated sector collapse, which avalanched the northern flank of the volcano across the neighbouring terrain and led to a paradigm-shift in our understanding of the scope of volcanic hazards.

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How personality affects climate policy

Why We Disagree About Climate Change: understanding, controversy, inaction and opportunity by Mike Hulme (2009) Cambridge University Press, 392pp. £45.00 (hard cover, ISBN-13: 978-0-521-89869-0) and £15.99 (paperback, ISBN-13: 978-0-521-72732-7).

On first seeing this new book by Mike Hulme, Director of the Tyndall Centre at the University of East Anglia, I thought it was going to be about the battle between climate scientists in general and the climate sceptic community. In fact, while there is a little on this particular debate, the book dominantly focusses on the vast range of approaches found in the scientific, policy, socio-economic and media fields to addressing the problem of climate change. The reality of climate change, and its future as a pressing issue for the planet, are taken as given. So read this book if you wonder why there is no international agreement about 'solving' climate change, in contrast to the rapid and successful efforts to find a solution to the ozone hole problem, set in action by the Montreal Protocol.

Mike Hulme takes a sociological approach to the question. The early chapters are concerned more with the science of climate change - our understanding of the term 'climate', how humanity has realized that climate changes, how the science of climate change works, and the origin of the range of predicted futures the lay person is often presented with. The question of the different ways in which humanity perceives the results of climate change is next addressed. Is there purely a financial measure of climate change? How do we value changes to ecosystems culturally?

However, it is the second half of the book where the reader sees most clearly where Mike Hulme is directing us. His thesis is that the way we as individuals respond to the issues of climate change depends on the psychology of our personality. If we are individualists we will believe that Nature is benign and the risks of climate change are small or can be adapted to. If we are fatalists we will tend to believe that Nature is capricious and there is little we can do to stave off climate disaster. On the other hand, hierarchists will believe that Nature will respond to management, so they propose globally-based solutions to the dangers of climate change, through regulation or even geo-engineering. Lastly, egalitarians see Nature as being in a precarious position, close to system tipping points, and so requiring urgent attention to avoid catastrophe. These different psychological personas are seen to determine our response to the climate problem, to its risk, to its solutions and to the importance of the balances between the developed and developing countries.

Fundamentally, this is a depressing assessment for me because its implication is that without a clear and present threat – as the ozone hole was in the 1980s – human reactions are too varied to allow a globally united approach to slowing down an unprecedented environmental experiment anytime soon. Nevertheless, by understanding the psychology underlying the frictions within international and national climate policy discussions Mike Hulme offers a way forward, where the different voices are listened to and a diverse treatment of the climate change issue may meet the needs of both humanity and the world. If you want to better understand the dilemmas of climate politics then read this book.

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The book's cover image: Psychology as well as physics can determine how we approach climate change