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SCOTTISH ASSOCIATION *for* MARINE SCIENCE

SAMS

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The future of seafood and aquaculture p7

September | 2007

diary

Biannual Cod Meeting
20 August 2007
Scottish Centre for Ecology & the Natural Environment
E: e.etheridge.1@research.gla.ac.uk

Air Sea Interaction
20-24 August 2007
Portland, OR, USA
www.ametsoc.org

Polar Dynamics
29-31 August 2007
Bergen, Norway
web.gfi.uib.no/conference2007/info.htm

Earth sciences in the service of society
10-12 September 2007
QEII Conference Centre, London
www.geolsoc.org.uk

Ecology, Limnology & Oceanography
17-20 September 2007
Ancona, Itlaly
www.ecologia.it/congressi/XVII/index.php?language=en

Network of Marine Protected Areas
2-4 October 2007
Scarborough
www.coastms.ac.uk/MPA07.html

Coast GIS 07
8-10 October 2007
Santander, Spain
www.coastgis07.com

Marine Genomics: An Ocean of Techniques
8-11 October 2007
Orthodox Academy of Crete
www.marine-genomics-europe.org

SAMS AGM, Graduation and Newth Lecture
7 November 2007
SAMS
www.sams.ac.uk

Ecological Networks in Nature Conservation
13-15 November 2007
Nottingham
www.ieem.net/nottingham.htm

8th European Meeting on Environmental Chemistry
5- 8 December 2007
Eden Court Theatre, Inverness
http://emec8.uhi.ac.uk

AGU 2007 Fall Meeting
10-14 December 2007
San Francisco, USA
www.agu.org/meetings

Lyell Meeting 2008 (climate change)
20 February 2008
Geological Society, London
www.geolsoc.org.uk

2008 Ocean Sciences Meeting
2-7 March 2008
Orlando, USA
www.aslo.org/meetings.html

Ectocarpus 2008
4-8 June 2008
SAMS
E: fck@sams.ac.uk

Algal Culture Collections 2008
8-11 June 2008
SAMS
E: fck@sams.ac.uk

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Views expressed in this Newsletter are the views of the individual contributors and do not necessarily reflect the views of SAMS.

About SAMS

The Scottish Association for Marine Science (SAMS) is registered in Scotland as a Company Limited by Guarantee (SC009292). Its registered office is Dunstaffnage Marine Laboratory, Oban, Argyll PA37 1QA. SAMS is a charity registered in Scotland (9206), and a learned society (est.1884). SAMS is committed to improving our understanding and stewardship of the marine environment through research, education, maintenance of facilities and technology transfer. SAMS is a Collaborative Centre of the Natural Environment Research Council, and hosts the National Facility for Scientific Diving, and the Culture Collection of Algae and Protozoa. It is an academic partner of UHI Millennium Institute under whose auspices SAMS delivers the BSc (Hons) Marine Science and trains currently 20 PhD students.

SAMS employs circa 140 staff. Our research activities encompass the entire breadth of marine science. SAMS focuses much of its scientific activities on multidisciplinary research questions from Scottish coastal waters to the Arctic Ocean.

SAMS is funded by the UK's strategic marine science programme, Oceans 2025, the Scottish Funding Council, by commissioned research for other public and private organisations, and by donations and subscriptions from its ca 450 members. SAMS operates SAMS Research Services Ltd, which delivers SAMS' commercial activities, and the European Centre for Marine Biotechnology.

SAMS Membership

Ordinary: anyone interested in marine science. Subscription - £12

Student: any person under 18, or registered students at Further or Higher Education Institutes. Subscription - £5

Corporate: organisations interested in supporting marine science. Subscription - £60

Unwaged: anyone without a regular wage. Subscription - £5

For further information and application materials please contact the company secretary, Mrs Elaine Walton (Elaine.Walton@sams.ac.uk).

Editor

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To keep up-to-date on events at SAMS, please visit our website:

www.sams.ac.uk

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Dear SAMS member

Dr Anuschka Miller, EDITOR

I recently returned from six months maternity leave, and I am amazed at just how much has changed at SAMS and the wider marine science community. At Dunstaffnage I am slowly getting to know the 30 or so new colleagues and their varied research portfolios. But I am even more struck by how relevant to public debates and challenges our work is becoming.

Since society is waking up to the reality of climate change, reducing carbon emissions and adapting to a changing climate are becoming priorities. Renewable energy is hailed as an important contribution, and research into renewable energy sources is growing fast. Here at SAMS our interest focuses on marine biomass for the production of biofuels, and on the environmental impacts of marine renewables. On page 16 Maeve Kelly and Symon Dworjanyn introduce their ongoing work with seaweeds to produce methane. As biofuel production from terrestrial sources has severe implications for food production and pricing, freshwater use and deforestation, marine biomass may offer a real alternative that remains under-investigated.

Many uncertainties remain about the global carbon cycle and climate change that scientists are called upon to define further. Henrik Stahl explains on page 11 how we are investigating the critical role the deep seabed plays in elemental cycling and climate change. And Sam Wilson on page 15 introduces some complex interactions between different climate forcing gases that still remain to be unravelled in detail.

Aquaculture research is not new to SAMS, but the industry is set to grow. On page 7 Kenny Black suggests that aquaculture products will play a major role in feeding an increasing human population a healthy diet. This presents huge challenges for marine scientists as well as policy makers, coastal zone managers and regulators around the globe.

The development of a marine bill for the UK and Scotland suggests that society is moving towards a more integrated approach to managing our marine environment. It is amazing to see how much the first staff member with a policy portfolio – Tavis Potts – is in demand. His article on page 8 introduces the developments in British marine policy. On page 9 Lyndsey Dodds tells her inside story of the work that the Parliamentary Office of Science and Technology does in bringing the results of scientific investigations into parliamentary debates that inform legislation and decision making.

I hope you will find this issue both enjoyable and thought provoking.

SAMSnews

Professor Graham B. Shimmield, DIRECTOR

In the last SAMS Newsletter I reported on the major injection of funding (£5.6 million) to assist in developing our research capacity for the next Research Assessment Exercise, and to propel the research strategy agenda for the UHI Millennium Institute. I am delighted to report on the excellent outcome of this recruitment with staff appointed at professorial, senior lecturer, lecturer and research fellow levels, and backed up by ten technical staff. These appointments have come from the USA, Canada, Sweden, Denmark, Germany, South Africa, Australia, New Zealand and, of course, Scotland and the UK.

Professor Ronnie Glud from the Marine Biological Laboratory at the University of Copenhagen has recently taken up a new chair in Marine Biogeochemistry at SAMS.

Anni Glud will develop a new microelectrode sensor lab to complement our benthic lander technology programme, creating a real strength in benthic biogeochemistry lander capability in the UK.

A full list of the new academic staff and their areas of expertise may be found in the table on the right.

NEW RESEARCHERS AT SAMS AND THEIR AREAS OF EXPERTISE

Dr Elanor M Bell	Aquatic microbial ecology/Marine conservation
Dr Tim Boyd	Polar oceanography
Dr Elizabeth Cook	Invasive species
Dr Finlo Cottier	Polar oceanography
Dr Andrew Dale	Physical oceanography
Dr Vincent Le Fouest	Ecosystem modelling
Dr Clive J Fox	Fisheries ecology
Prof Ronnie N Glud	Sediment biogeochemistry
Dr Sheila Heymans	Ecosystem modelling
Dr Kim Last	Chronobiology and behavioural biology
Dr Tavis Potts	Marine environmental policy
Dr Henrik Stahl	Sediment geochemistry
Dr Michele Stanley	Algal functional genomics
Dr Robert Turnewitsch	Deep-sea landscapes
Dr Pushkar M Wadke	Marine technology/Sensor networks

SAMS UHI undergraduate students now have an opportunity to study at the University Centre in Svalbard in Longyearbyen at 78°N (© Nils Petter Dale, UNIS).

BSC (HONS) MARINE SCIENCE WITH ARCTIC STUDIES

In April this year the honours degree course in Marine Science we run on behalf of the UHI Millennium Institute was revalidated for another five years. The team used this opportunity to add new options into the course, including an Arctic Studies strand. This allows students to study for one or two semesters during their third year at the world's northernmost higher education institution, the University Centre in Svalbard (UNIS), to learn about arctic biology, arctic geology, or arctic technology.

For those staying in Scotland in their third year, the course now includes optional modules in marine conservation and in diving science. The diving module allows students to gain the HSE professional diver SCUBA qualification. This module is run by members of the UK National Facility for Scientific Diving that is hosted by SAMS.

SCOTTISH ALLIANCE FOR GEOSCIENCE, ENVIRONMENT & SOCIETY

Over the past few months, our approach to developing partnerships across the academic community in Scotland has developed strongly. On the 25th May, the Scottish Alliance for Geoscience, Environment and Society (SAGES) was launched in Edinburgh attended by Stewart Stevenson MSP, Minister for Transport, Infrastructure and Climate Change, and Professor Alan Thorpe, CE of the Natural Environment Research Council. Professor Tom Crowley from the USA has been appointed Director of SAGES. SAMS is delighted to appoint Dr Dan Sinclair as a Lecturer in Palaeoceanography and the joint appointment with the University of Edinburgh of Dr Walter Geibert as Senior Research Fellow. SAGES is a tangible example of the progress that "pooling" initiatives are making in Scotland.

SCOTTISH OCEANS INSTITUTE

As part of strategic forward looking, SAMS and the UHI Millennium Institute have announced a desire to work with the University of St Andrews (incorporating the NERC's Sea Mammal Research Unit) to assess the feasibility of a joint venture with the working title of the "Scottish Oceans Institute". This venture would allow for integrated delivery of our education and research capabilities, maximising our facilities, training and staff development opportunities, whilst preserving the integrity of the Learned Society, and ensuring that the Association's longstanding reputation is preserved. Over the next months detailed feasibility studies will be carried out, and I will keep the members informed of progress through the Newsletter, website and, of course, at our AGM on the 7th November. This initiative is to be fully incorporated into the Marine Science Scotland "pooling".

NATIONAL AND EUROPEAN DEVELOPMENTS IN MARINE SCIENCE

The approach to building consortia is not unique to Scotland. In Germany, Dr Rolf Peinert has been appointed as Director of the Konsortium Deutsche Meeresforschung which involves most of the major German institutes and universities conducting marine research (*www.deutsche-meeresforschung.de*). In the UK, the NERC strategic marine science delivery - Oceans 2025 - commenced on the 1st April. On the 10th July SAMS hosted the kick-off meeting of all theme leaders under the able organisation of Dr Phil Williamson, the Oceans 2025 Scientific Coordinator.

It is thus no accident that the EU Green Paper on Maritime Policy has been stressing the importance of joined-up scientific delivery for the new emphasis on marine affairs across Europe. This was discussed and debated at the EurOceans meeting in Aberdeen on the 22nd June, where I gave a keynote talk on the need for a common vision on the value of marine science for Europe. The meeting culminated in the Aberdeen Declaration, further details of which can be found on *http://ec.europa.eu/maritimeaffairs/eurocean2007.html*.

With the start of Framework Programme 7, the organisation of marine research is starting to change shape quite dramatically. I look forward to SAMS playing a full and increasingly important role in these developments, and urge the members to support this Association in ensuring Scottish marine science remains at the forefront of research and education on the national and international stage.

> The UK's new £120 million strategic marine science programme 'Oceans 2025' had its first meeting at SAMS on 10th July. (© Jacky Wood, NOCS)

Obituary

Professor Sir Eric Denton FRS

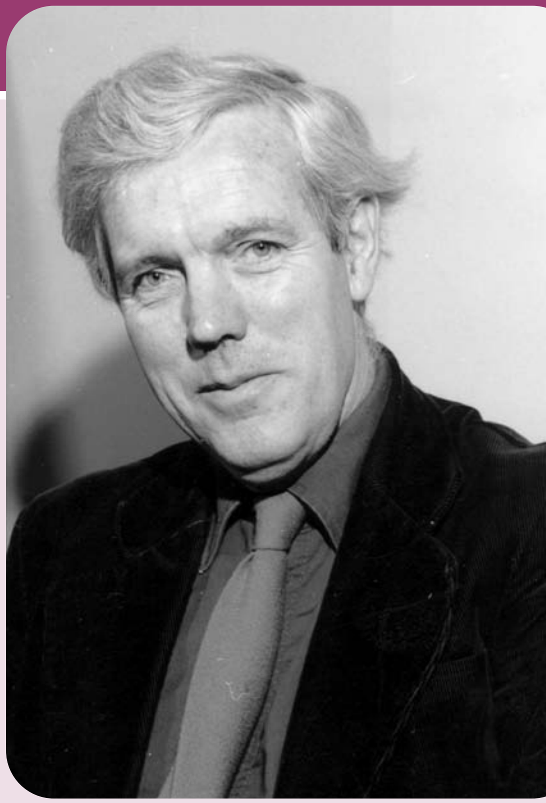


Photo courtesy of the Marine Biological Association of the United Kingdom

Eric Denton was one of the most distinguished marine biologists of the 20th century. He was the Director of the Marine Biological Association of the UK from 1974 to 1987 and served twice on our Association's Council (1971-77 and 1986-89). He died on 2nd January 2007 aged 83.

Eric first worked on radar at Malvern before taking a degree and doctorate at Cambridge University. With a primary interest in biophysics he joined A.V. Hill, the distinguished muscle physiologist, at London University in 1946 before taking up a lectureship in physiology at Aberdeen University. In 1956 he moved to the MBA at Plymouth, first as a member of staff, then as a Royal Society Research Professor and finally as Director. He stayed on as an Honorary Research Fellow until 2005.

Eric's primary interest was research but he managed to combine this with the exacting role of a laboratory director and many other commitments. He had a flair for identifying novel and exciting projects in marine biology and an extraordinary technical expertise for making ingenious, yet simple, apparatus for experiments. His research was highly original and always at the cutting edge of marine biology.

After working on the visual pigments of fish and other animals, showing how their maximum sensitivity was linked to the dominant wavelength of light in the environment, he turned to solving the buoyancy mechanisms of marine animals. Neutral buoyancy saves energy and different groups have developed different mechanisms to achieve it: Some squids float on sacs of ammonium chloride, some dogfish and sharks have low density oils in their huge livers, while some cephalopods vary the amount of air in the cuttlebone by an osmotic mechanism.

Eric next turned to camouflage. He was intrigued by the silvery sides of schooling fish such as herring and sprat. He showed that guanine crystals were orientated in the scales so that they acted as vertical mirrors, making the fish invisible. The knife-like keel of the fish made them difficult to see by predators feeding from below. This reduction of silhouette was achieved in mesopelagic hatchet fish by using the light from their downwardly-directed light organs to match the colour and intensity of the down-welling light. Eric was interested in whether the orientation of the guanine mirrors could be manipulated by abnormal patterns of light in early development and turned to workers at Dunstaffnage who were rearing herring. This led in the early 70s to a 30-year-long collaboration between Eric, John Blaxter and Bob Batty.

Eric next investigated the complex ear and lateral line of herring and sprat, collaborating further with John Gray from the Medical Research Council, Don Hoss from North Carolina and Jennifer Allen from Dunstaffnage. It was shown that the swim bladder was linked by fine ducts to gas-filled bony structures close to the inner ear, the otic bullae, which acted as localised amplifiers and improved the frequency range and sensitivity of the ear. The link with the swim bladder allowed the fish to move vertically without impairing hearing as gas flowed between the swim bladder and the bullae to maintain the gas in the bullae at a constant volume. Eric and his co-workers then investigated intra-specific signalling in herring and sprats, namely the sounds they make within schools and the changes in reflective pattern from the silvery sides. This work helped to explain the remarkable cohesion within schools.

As Eric's health deteriorated from Parkinson's disease, he applied himself to studying the disease itself and quickly established contact with research workers in the field, making a worthwhile contribution.

It is not surprising that he received many honours: a Fellowship of the Royal Society, and its Royal Medal in 1987, and the prestigious International Prize for Biology of the Japanese Society for the Promotion of Science in 1989.

Eric's friends would sum up his attributes as an amalgam of charisma, great motivation and energy, technical expertise all linked to friendliness and a very well developed sense of humour. He and his wife Nancy were the most hospitable of hosts and they extended this hospitality to young visitors as well as the "great and the good". At their house in St Germans you could meet Nobel Prize winners as well as young visitors to the MBA. Some of Eric's success can be put down to the support of Nancy and her dedication to his career. Latterly, his son-in-law David Rowe played a major role in allowing him to continue research when he became seriously disabled.

It seems doubtful whether any past, present or future marine biologist can ever match the range of Eric's achievements. ●

John Blaxter

Where do larval sea lice go?

Modelling sea lice dispersal in sea lochs

Drs Philip Gillibrand and Kate Willis, SAMS

Sea lice are ectoparasitic copepods of farmed and wild salmonids that cost the global salmon aquaculture industry more than US$100 million a year in fish losses and disease control. They further contribute to the decline of wild salmonid populations in the North Atlantic.

DISTRIBUTION

The sea louse *Lepeophtheirus salmonis* has three free-swimming planktonic larval stages: two nauplii and the infective copepodid. The non-feeding larvae drift with the prevailing current until the copepodid encounters a host fish.

The source, dispersal, and distribution of sea lice larvae in coastal waters are presently the subject of some debate. Until recently, larval sea lice were only found consistently within, or close to, salmon cages or, sporadically, in the vicinity of river mouths. This led to the conclusion that sea lice were retained within the farm cages, and that wild salmon and sea trout, rather than lice dispersing from fish farms, were responsible for lice at the river mouths. But in 2004 scientists reported larval sea lice in open water of a Scottish sea loch quite some distance away from a salmon farm, throwing this conclusion into question

MODELLING SEA LICE DISPERSAL

Environmental conditions influence the spatial distribution of sea lice larvae, but intrinsic larval behaviours such as diel vertical migration and aggregation at salinity discontinuities also play important roles in dispersal. Nevertheless, previous models have failed to include the entire set of key environmental parameters, and none have included lice behaviour. Models that consider larvae as passively drifting particles in the surface layer are over-simplistic and should not be used as management tools. Models that incorporate key parameters such as river flow, wind speed and direction, and larval behaviour increase the accuracy of predicted lice dispersal and zones of infection. They are valuable tools for coastal zone managers in identifying zones of transfer of sea lice to wild salmonids.

> Sea lice infections cost the salmon industry over $100 million every year. (© J. Treasurer, Ardtoe Marine Laboratory)

We developed a computer model to investigate the influence of environmental conditions and larval behaviour on the dispersal of sea lice larvae from a discrete source (salmon farm) in an idealised sea loch. The model parameters for eight simulations of varying environmental and behavioural settings are shown in the table.

LARVAL BEHAVIOUR MAY INCREASE ABUNDANCE

The inclusion of larval behaviour in the model increases retention of larvae within the loch and elevates predicted surface distributions relative to passive particle simulations.

Run No	River Flow	Wind	Behaviour*
1	Low	None	No
2	Low	Oscillating	No
3	Medium	Oscillating	No
4	High	Oscillating	No
5	Low	None	Yes
6	Low	Oscillating	Yes
7	Medium	Oscillating	Yes
8	High	Oscillating	Yes

*Diel vertical migration, depth & salinity avoidance

The model results suggest that larvae accumulate in the sub-littoral regions of sea lochs, particularly in the absence of wind stress. This could explain how migrating salmonids in some lochs become heavily infected with sea lice, and why sea lice infection levels on wild salmonids can be higher in areas with intensive salmon farming.

Sea lice infection of wild salmonids occurs soon after sea entry. Sea trout in particular are very susceptible to sea lice because the post-smolts remain in surface waters close to or within the littoral zone in fjords and coastal areas close to their home river during the summer. In the presence of along-loch winds, the distribution of copepodids increases both vertically and horizontally. As river flow increases, lice are washed out of the system in greater numbers. Modelled surface concentrations of sea lice increase considerably when behaviour is included in the model, as the daily upward migration of larvae elevates numbers at the surface.

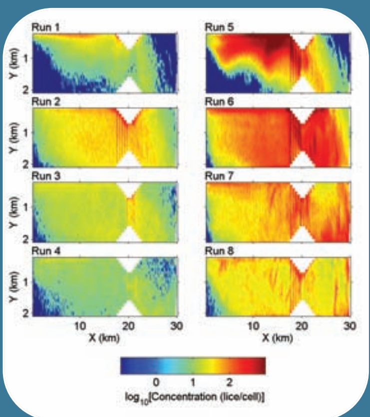
INFECTIVE SEA LICE TRAVEL FAR

The model results support field observations suggesting that larval sea lice can travel considerable distances from their source whilst remaining infective. Distances of several kilometres separating infective lice and fish farms do not eliminate the farms as the potential sources of the lice. Moreover, the phototactic (light responsive) nature of sea lice larvae may cause them to aggregate near sea loch shorelines, where wild salmonids also congregate.

Because little is known about sea lice behaviour under natural conditions, further model development would benefit considerably from detailed field data describing larval behaviour in coastal environments. ●

For more information on this study, see Zooplankton Dynamics research at www.sams.ac.uk/research/departments/ecology/

> Model results by run number show the predicted maximum larval concentrations in the surface waters of the sea loch.



> Dispersal of infective larvae is influenced by environmental parameters and larval behaviour.

The future of seafood and aquaculture

Dr Kenny Black, SAMS

> The demand for seafood is increasing due to population growth, greater affluence and growing awareness of health benefits. (Photo: T Nickell, SAMS)

Aquaculture will soon become the dominant food-related use of the sea, requiring significant changes in what we farm, what we eat, and how we regulate human activities in the ocean.

AQUACULTURE PREDICTED TO OVERTAKE FISHERIES

Food and Agriculture Organisation statistics reveal a meteoric 9.1% per annum increase in global aquaculture production (excluding aquatic plants). Global fisheries production, on the other hand, peaked in 2002 at 96 million tons and is expected to stagnate or decline over the coming decades. Taking these statistics together, the FAO predicts that global aquaculture production will exceed that from fisheries around 2030. Thus in about one human generation the principle mechanism of exploitation of aquatic resources, established over centuries, will be superseded.

The drivers for this change are complex and include social, economic and environmental issues and challenges. Firstly, with a predicted increase in human population from currently over six billion to over nine billion by the middle of the century, the demand for all food sources is likely to continue to rise sharply. The demand for seafood, as for meat, is currently increasing particularly rapidly. Aquatic production doubled to 130.2 million tonnes in the 30 years to 2001. Most of this increase comes from aquaculture rather than fisheries: in 1970 aquaculture accounted for only 3.9% of fisheries production, rising to 29% by 2001. Growing seafood consumption has been driven not only by population growth but also by increased affluence and the realisation of the human health benefits of seafood that is rich in omega-3 fatty acids.

GROWTH IN MARINE AQUACULTURE

The past 30 years have seen profound increases in inland aquaculture, particularly of carps, tilapia and milkfish. But increased population and growing affluence put pressure on land and freshwater resources for agriculture, industry and domestic use. Climate change may further exacerbate this situation with more extremes of weather. There is also a limit to the abstraction of water beyond which serious environmental degradation occurs. For these reasons, significant increases in future aquaculture production must come from the sea.

FEEDSTOCK ISSUES

In the past, carnivorous finfish in aquaculture were fed largely on a diet of fish meal and fish oils obtained from increasingly depleted fisheries. These days, processed vegetable flours and oils are playing a more important role. As long as the finishing diet for salmon is rich in fish oil, the harvested fish remains rich in omega-3 fatty acids, and thus as healthy to eat as ever. Despite this feed substitution, aquaculture will soon consume almost all the world's fish oil production. Vegetable diets on the other hand require freshwater. To reduce freshwater demands while increasing aquaculture production, we will have to make use of marine organisms lower in the trophic chain that are cultured for human consumption, for example bivalves (such as mussels), omnivores (such as sea urchins), and primary producers (mainly seaweeds).

> Marine organisms lower down the trophic chain such as seaweeds and marine invertebrates should make up a greater proportion of the seafood of the future. (Photo: C Suckling, SAMS).

ENVIRONMENTAL CHALLENGES

The potential environmental impacts of fish farming are relatively well understood and include reduced benthic diversity, reduced water quality, interactions of escapees with wild populations, and disease and parasite transmission. These, together with the issues of coastal space utilisation, potential conflicts with users from the fishing and tourism industries, and aesthetic aspects, are real challenges for the regulators and policy makers around the globe. ●

CASE STUDY: PHILIPPINES VS EUROPE

We have recently been working on an EU funded project looking at the rapidly expanding aquaculture industry in the Philippines, where regulators have insufficient resources. While finfish aquaculture industry in western Europe is dominated by large companies, in the Philippines farmers may own a single cage that supports entire families. Consequently thousands of cages have proliferated in sheltered marine waters and lakes and are providing a huge boost to a fragile economy. In this situation, overstocking often generates large fish kills with locally catastrophic consequences. The environmental damage of this system is neither well understood nor closely monitored.

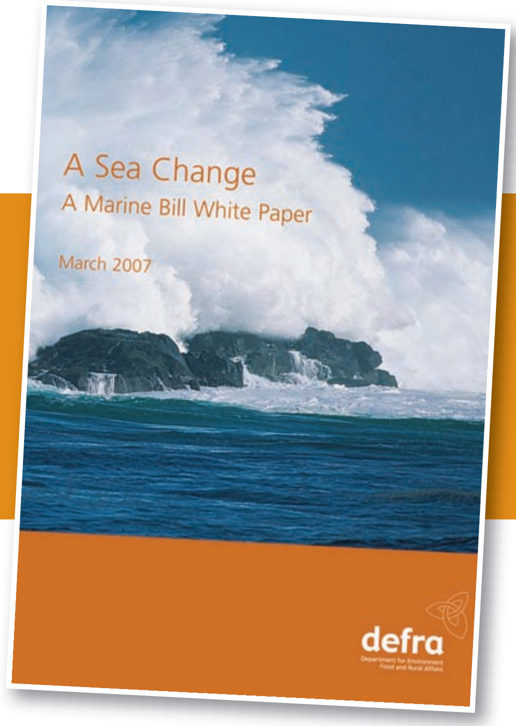
In western Europe, by contrast, regulation of aquaculture is complex and bureaucratic, with many sectoral interests involved in the location and scale of new developments. While the European Aquaculture Strategy calls for sustainable expansion, increased production can be difficult to achieve in some areas for a range of socio-political reasons, while in other areas rapid expansion continues without the same constraints. The EU ECASA project (*www.ecasa.org.uk*) aims to provide the European industry and its regulators with a tested set of tools to support more consistent and scientifically robust planning decisions and impact monitoring.

Marine Policy in the UK:

Moving towards integrated management?

Dr Tavis Potts, SAMS

The development of the oceans for socio-economic activity is increasing around the world. New uses of the oceans for renewable energy, aquaculture, tourism and conservation are competing with traditional uses such as fisheries, shipping and recreation. As a result, new approaches for holistically managing ocean uses are being implemented in coastal and marine systems. The integration of science with policy is one of the key challenges facing integrated oceans management everywhere.



INTERNATIONAL BACKGROUND

The recent advance of oceans policies is a consequence of considerable activity in the international regime for the management of the oceans over the past decade. In 1992, Agenda 21 called for integrated approaches to the development of the oceans and introduced the concept of ecosystem based management. The 1982 Convention on the Law of the Sea entered into force in 1994. UNCLOS has placed many demands on nations for the management of ocean zones and the various economic and environmental activities that occur within them. The 1992 Convention on Biological Diversity, the 1995 UN Fish Stocks Agreement, and the 2002 World Summit on Sustainable Development contributed towards a stronger regime for ocean development and conservation. The WSSD in particular called for several oceans commitments including applying the ecosystem approach by 2010 and establishing global networks of marine protected areas by 2012.

EU AND UK REFORMS

More than 100 multilateral agreements relating to marine and maritime affairs affect the EU and its member states. The European Commission is responsible for a broad portfolio of marine conservation and maritime issues spread across several directorates, including Transport and Energy, Regional Policy, Fisheries and Maritime Affairs, Enterprise and Industry, and Environment.

The 2000 Water Framework Directive provides a European legal framework to deliver 'good environmental status' of Europe's surface waters, coastal waters and groundwater from source out to one nautical mile, which in Scotland has been extended to three nautical miles. The implementation of the WFD in the UK is the policy responsibility of DEFRA, the Scottish Executive, Welsh Assembly Government, and the Department of the Environment Northern Ireland. Much of the implementation work, however, will be undertaken by the competent authorities, in Scotland the Scottish Environment Protection Agency.

The emerging European Marine Strategy Directive will become an important influence on UK marine policy. This instrument, once in force, will require EU member states to develop strategies to achieve 'good environmental status' for their marine areas by 2021. The directive takes a regional approach to marine planning, and focuses on areas outside the WFD from the territorial sea baselines to the limits of exclusive economic zones.

The European Maritime Policy - recently submitted to consultation in form of a green paper - is being developed alongside the European Marine Strategy Directive. The green paper identifies the need for an overarching framework to coordinate maritime issues at the EU level without outlining the specific role, governance structure or objectives of a potential EU Maritime Policy. It is conceivable that the emerging UK Marine Bill and any Scottish marine initiatives will respond to this development and act as implementing instruments for the broader EU objectives.

THE UK MARINE BILL

The recently released UK Marine Bill white paper demonstrates a move towards integrated rather than piecemeal ocean management. It is responding to the increasing complexity of management and regulation in the marine environment, conflict over limited resources and space, the recognition of the benefits of conservation, and the need to implement domestic, EU and international commitments. The white paper identifies five themes for legislative and policy reform:

- A marine management organisation to deliver marine policies guided by an overarching policy statement
- A marine spatial planning mechanism that regulates interactions and development in marine regions
- A marine licensing system that streamlines licensing activities and reduces 'red tape'
- Marine biodiversity conservation reforms and tools
- Modernising the fisheries management regime including recreational fisheries

The UK Marine Bill will have ramifications for Scotland but will only apply to issues that are not under devolved competence. However, the exact relationship between the UK Marine Bill and Scottish marine jurisdictions is still unclear and will depend on negotiations between authorities for an ecosystem based approach. What is clear is that Scotland retains authority over key areas of competency such as fisheries to 200nm and planning in the inshore areas up to 12nm, and any responsibility of implementing the policy measures will be subject to negotiation and cooperation between authorities. Furthermore, the Scottish Executive has recently announced that it is developing its own Marine Bill that will take into account similar issues such as marine spatial planning within the Scottish devolved context.

We watch with anticipation as marine reforms gather pace across the UK, and as integrated oceans management becomes a reality. ●

An insider's view of science and Parliament:

Being a fellow at the Parliamentary Office of Science and Technology

Dr Lyndsey Dodds

> Lyndsey completed her PhD on the ecophysiology of the cold-water coral *Lophelia postusa* in April. At the Parliamentary Office of Science and Technology, she produced a briefing paper on 'new industries in the deep sea.' (www.parliament.uk/documents/upload/postpn228.pdf)

After her time at POST, she will work as a marine policy officer for the WWF.

As a PhD student at SAMS I was always intrigued to understand how the important and exciting research in the institute translates into policy within Parliament. When the opportunity arose to spend three months working at the Houses of Parliament in London, I jumped at the chance. I was awarded a three month fellowship at the Parliamentary Office of Science and Technology (POST), offered through a joint NERC/POST scheme.

POST is charged with providing independent and balanced analysis of public policy issues that have a grounding in science and technology. POST is an influential body within Parliament and acts as the interface between science and policy. Briefing papers produced by POST give a clear and concise overview of important science topics and policy implications, and are a valuable source of information for parliamentarians. One of my jobs at POST was to produce such a briefing note for MPs and Peers on the marine environment. I used the knowledge and skills gained during my PhD research at SAMS to investigate policy issues for government, industry, academia, and environmental groups.

Working at POST also allowed me access to different aspects of Parliament and to gain first-hand experience of how policy takes account of science. Select Committees are another important link between science and Parliament. A Select Committee is made up of parliamentarians appointed from either the House of Commons, the House of Lords, or as a Joint Committee of both Houses. The party allegiances of Select Committees reflect the balance in the House of Commons and / or the House of Lords. The general purpose of Select Committees is to oversee the work of government departments and agencies and to scrutinise the legislature. Most committees deal with science and technology issues in some of their work. Examples of committees that work very closely with science include: Science and Technology, Environment, Food and Rural Affairs, and Trade and Industry. Select Committees conduct specific inquiries and call for both written and oral evidence from government, academia, industry and public interest groups before reporting to Parliament.

Climate change is rapidly moving up the political agenda and a number of Select Committees have recently reported on this. The Joint Select Committee on Climate Change has been considering the form of the Climate Change Bill and reported at the end of July 2007. There also appears to be increased interest in the Houses of Parliament in marine issues. The UK Marine Bill White Paper was published in March 2007, after consultation by government with academia and other interest groups. It is hoped that the Bill will form part of the Queen's speech in November, after which time the Bill will become an Act of Parliament. The House of Commons Science and Technology Select Committee has recently completed an inquiry on 'Investigating the Oceans'. This committee drew evidence from a wide range of sources, including SAMS. I attended many evidence sessions and found them fascinating, both to hear the evidence submitted and also to see how the committees function. I found it reassuring to see the research that scientists do, at institutes such as SAMS, informing parliamentary scrutiny.

There are other links between science and Parliament, for instance through All Party Parliamentary Groups and the Learned Societies. All Party Parliamentary Groups cover topics ranging from science and conservation to malaria, terrorism and even cheese! The Royal Society has 'Links Days' where scientists and parliamentarians can meet to foster links. The Royal Society also offers the MP-scientist pairing scheme to build bridges between leading researchers and MPs. Other schemes are offered by the British Ecological Society and the Royal Society of Chemistry to integrate the activities of researchers with Parliament.

Working in the Houses of Parliament has been a fascinating experience that I would recommend to anyone. I believe the fellowship scheme at POST is a wonderful way for young scientists to get involved with policy. There are many opportunities available to scientists to influence and inform policy and I believe this an important role that the scientific community should embrace. ●

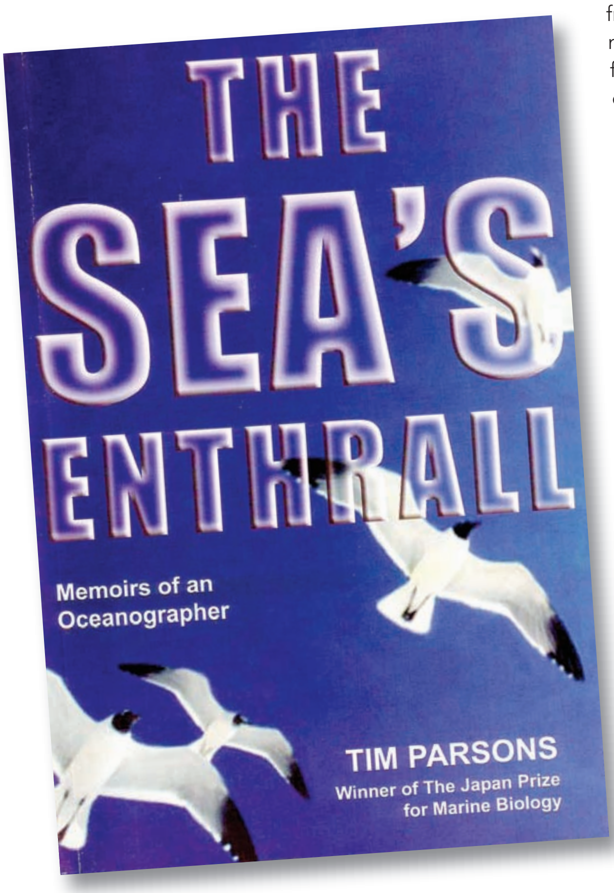
The Sea's Enthrall

Memoirs of an Oceanographer

By Tim Parsons

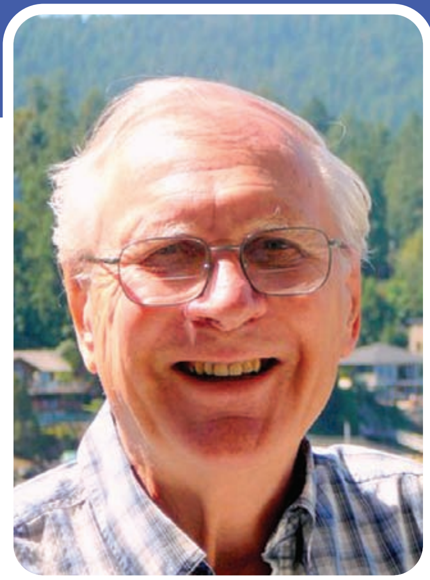
As marine scientists we have a view of the world that is quite out of the ordinary. The very nature of marine science and all the disciplines that fall within it, determines that what is our field of work is other people's boundary. Too often, perhaps, that translates as an area of peripheral interest to many, yet ours is the "Blue Planet" and the practical demands of going to sea require us to experience and interact across a wide spectrum of scientific disciplines: Biological Oceanography is a prime example of interdisciplinary science.

What is not unique to marine science, of course, are the fantastic advances that have been made in science and technology in recent decades, and the development of ever more sophisticated scientific concepts. The increasing reliance on computerized information can make it all too easy to overlook the body of knowledge and understanding, built up over past years, that still remains on the bookshelf and in the minds and records of those who collected the samples, made the measurements and analysed the results. That is one reason why this is an important and timely book.



Tim Parsons' scientific career spanned these decades of development and transition. His highly successful career was recognized in 2001 by the award of the Japan Prize for his "great contribution to the development of biological oceanography". In his book, The Sea's Enthrall, he writes of his life that took him geographically from Ceylon, as it then was, via England and its public-school system, to academia and government institutions in Canada and the USA, and professionally from a boyhood fascination with natural history, via biochemistry, to biological oceanography. In the course of his book he expands on the scientific concepts that he was instrumental in developing, concepts that became fundamental in the study of ecosystems at all scales, from microcosm to mesocosm to natural systems in lakes and fjords. He also delivers his verdict on some of the aspirations that became popular from time to time, in particular on the scientific principles that should underpin fisheries management - something that still seems not to be properly encompassed within existing political structures.

Tim tells us also of the ups and downs of his life and how these experiences caused him to question his received understanding of religion. At this time, when, by coincidence, I was enjoying a sabbatical year working with him in Vancouver, Tim had met a kindred spirit in an elderly man, an impoverished Russian immigrant, whom he befriended. Together they discussed the purpose, divine or otherwise, that lies behind the evolution of human society.



> Biological oceanographer Tim Parsons tells of his life in marine science.

Tim summarizes the choice that faces us with a quotation from Shakespeare's Comedy of Errors:

Let us once lose our oaths to find ourselves,
Or else lose ourselves to keep our oaths.

This is a book full of varied interest, a very readable record of scientific research, written with the insight of one at the centre of marine science, and a frank account of an active life. More than that, it provides us with thoughts on what that life may be all about. I would strongly recommend it to oceanographers at any stage in their careers, to give those just starting out an idea of the history that they are building upon, to give established scientists a professional account that they can compare with their own experiences. Importantly too, non-oceanographers will gain insight into a field of knowledge - and the spirit that drives scientific inquiry - that is fundamental to understanding the workings of the world we live in. ●

Publication and selling arrangements have changed since the book was first published by Ecce Nova in 2004. Publishing rights for the book (now ISBN 1-4251-1413-x) have been taken over by Trafford Publishing of Victoria B.C, Canada, http://www.trafford.com/06-3172. They are also maintaining the Amazon sites.

Professor Jack Matthews,
SAMS Fellow, former SAMS Director

Landing on the sea floor

Using advanced *in situ* technologies to investigate benthic carbon cycling

Dr Henrik Stahl, SAMS

> SAMS benthic chamber- and profiling landers in the Arabian Sea

SEDIMENTS CONTROL GLOBAL CLIMATE

The ocean covers 71% of the Earth's surface and plays a major role in controlling the climate on this planet. It regulates global biogeochemical cycles of elements such as carbon, which is essential for life on Earth and important for the climate system.

When dead algae and debris, produced in the lit surface layers of the ocean, sink to the sea floor, they serve as the primary food source for the microbes and animals living there. This detritus acts as the driver for a wide range of sedimentary processes including its re-mineralisation and burial.

The intense degradation and recycling of organic matter in the sediment are important for re-fertilising the ocean surface waters with nutrients and carbon dioxide and thus for maintaining primary productivity. Burial of organic matter in marine sediments, on the other hand, is Earth's main long-term sink for carbon, and thus contributes to controlling global climate. It is essential that we understand the factors and processes that control the recycling and burial of organic matter at the seafloor.

BENTHIC BUGS

Sediment bacteria catalyse the mineralisation of organic matter to carbon dioxide and nutrients through several metabolic pathways. Aerobic bacteria are the most effective mineralisers followed by organisms living deeper down in the sediment that utilise suboxic- and anoxic respiration pathways.

Although it is well known that bacteria account for most of the organic matter mineralisation in sediments, several studies show that burrowing macrofauna also play a role in benthic mineralisation processes and oxygen dynamics. Macrofauna significantly enhances rates of organic matter mineralisation by mixing down fresh organic matter from the sediment surface and constantly reworking the sediment (= bioturbation), and by pumping oxygenated water through their burrows (= bioirrigation) to sustain their metabolic needs.

QUANTITY AND QUALITY OF ORGANIC DEBRIS

The quantity and quality of incoming biogenic debris have a profound effect on the recycling and burial rates of organic matter in the sediment. Fresh algae are more rapidly degraded than more refractory organic matter of terrestrial origin, while larger quantities of organic matter input can sustain greater activity and biomass of benthic organisms. If, however, rates of organic matter deposition become extremely high, as for example in upwelling areas, massive bacterial activity can lower oxygen concentrations in bottom waters to such an extent that most macrofauna can no longer survive in these areas.

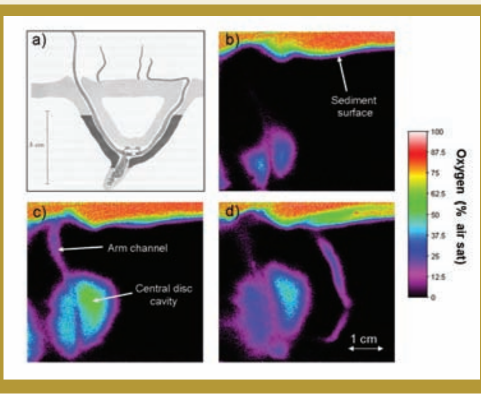
THE ROLE OF BENTHIC LANDERS

Rates of benthic organic matter recycling and burial are more reliably measured *in situ* than from cores in the laboratory, especially in deep waters. Sediments brought up to the surface from great depths are typically subject to rapid changes in temperature and pressure that affect the microbial and faunal activity in the sediment. Measurements conducted from *in situ* benthic landers can avoid such artefacts. These deep-sea robots are used to conduct a variety of measurements and experiments on the sea floor and to bring samples and collected data back to the surface.

Typically, a benthic lander is deployed from a ship and sinks by its own gravity through the water column. Once it has landed smoothly on the sea floor it starts measuring the predetermined parameters. At the end of the deployment an acoustic signal tells the lander to release its ballast and return to the surface using positive buoyancy.

Different landers have different functions: Chamber landers measure fluxes of oxygen and carbon dioxide across the sediment-water interface in sediment enclosures, whereas profiling landers use fine tipped microelectrodes to measure detailed (>100 µm resolution) profiles of oxygen, pH and hydrogen sulphide in the sediment.

We also deploy planar optodes from landers. These are instruments that allow us to visualise and quantify changes in oxygen concentrations within the sediment that may for example be caused by burrowing animals (see figure).



< a) The burrowing brittlestar *Amphiura filiformis* (after Ockelman & Muus, 1978)

b) to d) Time series of planar optode images showing the oxygen distribution around an *A. filiformis* that is injecting oxygenated bottom water into its burrow cavity.

CHALLENGES AHEAD

Since lander deployments only provide a snapshot of current conditions, a major challenge for the future is to better understand the causes of short and long term variability in the factors that control benthic carbon cycling, and to relate these to changes in global climate. By establishing networks of permanently deployed benthic observatories that integrate multiple technologies and are capable of intelligent sampling (e.g. are responsive to external physical or chemical stimuli) we could significantly enhance our understanding of the benthic carbon cycle and its importance for global climate. ●

Large planktivorous sharks: Trials and trends

Dr Mauvis Gore, University Marine Biological Station Millport

> Does the warmer temperature of our winter seas change the migration patterns of basking sharks? (©: N Clark)

The two largest fish species globally, whale sharks (*Rhincodon typus*) and basking sharks (*Cetorhinus maximus*), inhabit different habitats but share a similar food source: zooplankton. I am involved in two studies on these megaplanktivores: here in west Scotland I study basking sharks with Rupert Ormond and Howard McCrindle, and in the Indian Ocean I work on whale sharks with David Rowat and Rupert Ormond.

Basking and whale sharks are not closely related, but fill identical niches in the temperate and tropical seas respectively. Basking sharks occur in cool to warm temperate coastal waters of 8-14°C in both hemispheres. Whale sharks on the other hand live in tropical oceanic and coastal waters of between 21-35°C, but tolerate water down to 6°C or colder (Rowat & Gore 2007). To feed on zooplankton, basking sharks passively filter water over their gill rakers during swimming. To their advantage, whale sharks like megamouth sharks can also use suction to actively pump water over their gill rakers.

Our research with whale sharks in the Indian Ocean around the Seychelles has been focussing on regional scale horizontal migration and local scale vertical movement. This involves boat-based searches as well as aerial surveys. Satellite tags allow us to follow the animals both vertically and horizontally. Individuals are identified from marker tags and by use of complementing photographs of the star pattern formation on the shark skin. Zooplankton samples provide us with important information on the amount and type of food available.

> The tropical whale shark is the world's largest fish and feeds on plankton. (© R Ormond).

Our research on basking sharks investigates where they feed year round and at what depths, as well as establishing their population trends. We are also very involved in increasing public awareness of basking sharks and their conservation. We deliver accessible talks, write for general audiences, and hold workshops for interested observers. An observer network assists us with sightings, which has proved itself extremely valuable.

For our research we sample zooplankton as the food resource, and use seabird and marine mammal sightings as indicators of habitat productivity. We gauge fish stocks and zooplankton swarms with the help of sonar surveys. Thanks to a good relationship with fishermen we obtain basking shark by-catch material to study their DNA, toxicity and anatomy. We also take photographs of the dorsal fin for individual identification with our own and other photo-galleries of basking shark fins. Dorsal fins are identifying features in basking sharks, and their large surface makes identification somewhat easier than in cetaceans. An important aspect of our work is to tag the sharks for information on depth, temperature and location. We are using acoustic tags for the relatively enclosed Clyde Sea area, and PAT satellite tags for open areas of the sea. Given that basking sharks can possibly dive to almost 2000m and appear to be one species globally, we are keen to know how they use their habitat both vertically and horizontally.

> Sightings of basking sharks have increased in Scotland over recent years. (© M Gore)

Basking shark sightings have been increasing in Scotland recently, according to the Marine Conservation Society. As climate change is considered to be a major factor for population changes in fauna and flora, it is interesting to note the temperature change over the years at Keppel Pier, Millport: While summer water temperatures are largely unchanged, winter sea temperatures have become warmer (Peter Barnett, UMBSM, pers. comm.).

For large marine planktivores, temperature is a key factor. The sea surface temperatures in the Clyde Sea Area have increased by around 1.5°C over the past 20 years. This raises key questions for the conservation of these top predators: If the seasonal appearance of basking sharks is related to their migration to feeding areas, might climate change then affect their timing or location? Similarly, is the increase in basking shark sightings related to a general population trend or simply to tracking food? We hope to find answers to aid in the conservation of these awe-inspiring fishes. ●

Reference
Rowat D & M Gore (2007) Regional scale horizontal and local scale vertical movements of whale sharks in the Indian Ocean off Seychelles. Fish. Res. 84 (1): 32-40

Growth of juvenile plaice in the Forth Estuary

Julian Augley, Napier University

> Juvenile plaice were unexpectedly discovered in the Forth Estuary.

FISH NURSERIES IN COASTAL HABITATS

Estuaries and shallow coastal areas are used for a diverse range of activities including recreation, transport, waste disposal and land claim. They are, however, threatened by sea level rise in the face of predicted climate change. The exploitation of coasts and estuaries places stresses on their ecological functioning and, if not managed appropriately, can impair their ability to provide the functions that make these areas so important in the first place. There are also links between open seas and coastal areas that add to the importance of the coastal areas. For example, many species of commercially exploited fish utilise coastal and estuarine areas as juveniles, taking advantage of the greater feeding opportunities and predator refugia provided by the habitats found there. Only then will they migrate offshore to join the spawning populations and become available for commercial exploitation.

The juvenile habitats that provide the greatest number of recruits to the adult populations are known as nursery habitats, according to recently developed definitions of nurseries. Thus, the ability to determine which coastal and estuarine habitats provide the best quality nurseries and the reasons behind this are of vital importance for fish stock conservation and management.

PLAICE IN THE FORTH ESTUARY?

Plaice (*Pleuronectes platessa, L.*) is one of the best known and most most widely studied marine flatfish species in Europe. Despite the voluminous literature, the use of the Forth Estuary as a nursery has been relatively poorly investigated, compared to the enormous nurseries of the southern North Sea and the better known nurseries on the west coast of Scotland. The Forth Estuary has even been suggested as unsuitable for juvenile plaice.

A pilot study at the beginning of my investigations, however, suggested that juvenile plaice settle onto estuarine intertidal habitats in the Forth at densities equivalent or higher than the nearby Firth of Forth (where plaice nurseries were previously investigated). To determine the quality of the estuarine areas as nurseries, we decided to compare growth rates of plaice in the estuary with growth rates of plaice in the Firth of Forth.

> The Firth of Forth (Image by NASA)

SIZE MATTERS

Growth is important for young fish because size influences the individual's ability to forage and also reduces the risk of mortality from predators. It might thus be expected that the fastest growing individuals have a greater chance of surviving the nursery phase. Habitats that support fast individual growth are therefore expected to contribute more juveniles to the adult population, which implies that growth rates may serve as an indicator of the potential of a habitat as a nursery.

One of the aims of the current study was to assess the intertidal areas in the Forth Estuary as potential nurseries. Growth rates and density indices of juvenile plaice were measured at two estuarine sites and two sites in the Firth of Forth, using two methods during 2005 and 2006.

The growth rates at all four sites showed similar patterns, but also revealed high interannual variability. The growth rates during 2005 ranged from 0.29 to 0.43 mm per day, while in 2006 they ranged only from 0.18 to 0.25 mm per day. Densities in 2006 were approximately three times higher than densities in 2005, which may have played a role in the lower growth rates. Analysis of otolith microstructure indicated that the plaice had settled at all four intertidal sites during the same period in 2005. This indicates that they had all been spawned around the same time, most likely by the same adult population (at Fife Ness off the east coast of Fife).

CONCLUSION

This study indicates the potential of the Forth Estuary to contain plaice nurseries. It demonstrates that previous plaice population estimates for the area are too conservative, and that further work is required to understand the factors that make the estuary suitable for juvenile plaice. ●

Acknowledgements

I would like to thank Katrina Drennan and Marina Mocogni from Napier University. I also want to acknowledge my supervisors, Drs Mark Huxham and Teresa Fernandes from Napier University, and Dr. Alastair Lyndon from Heriot Watt University. I am further indebted to staff at the Environmental Research Institute, North Highland College, UHI.

> The author collects juvenile plaice from the soft sediments in the Forth Estuary.

Steller sea lions in the Gulf of Alaska:
Modelling effects of environmental variation and fishing

Dr Sheila Heymans, SAMS and Drs Sylvie Guénette, Villy Christensen and Andrew Trites, University of British Columbia Fisheries Centre

> Steller sea lions have increased in the western part of their distribution but decreased in the east. (Photo: A Trites, UBC)

> Both environmental variations and fishing are contributing to the decline of Stellers in the Gulf of Alaska. (Photo: Sherman Lai, UBC)

Steller sea lions (*Eumetopias jubatus*) in the Gulf of Alaska have declined in the western part of their distribution, and increased in the east. They are currently on the endangered species list and have precipitated the closure of important fishing grounds in the northeast Pacific. There are various hypotheses on why they may decline, including

- changes in the environment
- competition with flatfish for food
- loss of food due to fishing
- predation by orcas and
- changes in their food base, also called the nutritional stress or "junk food hypothesis"

In this project we used ecosystem models of two sub-systems in their range, the central and western Aleutian Islands and Southeast Alaska, to test the first four hypotheses.

MODEL RESULTS

First we tested whether fishing or environmental change caused the changes in these two ecosystems. The results showed that fishing combined with climate change, expressed by the Pacific Decadal Oscillation (PDO) index, constrained the models better than fishing alone and increased the fit of the model to time series data. The PDO was negatively correlated to the changes experienced by the ecosystem in the Aleutian Islands and positively in Southeast Alaska due to the differences in sea surface temperature and pressure in the two ecosystems. Specifically, the effects of the PDO combined with fishing on both the Aleutian Islands and Southeast Alaska showed the best fit to most species. In the Aleutians the best fit was obtained when the –PDO was used in conjunction with fishing, while in Southeast Alaska the +PDO fitted the data best. When only fishing was considered, most species, including Steller sea lions, pollock, Atka mackerel and arrowtooth flounder in the Aleutians, and herring, halibut and sablefish in Southeast Alaska fitted not as well. In both systems the decline in Pacific Ocean perch was driven mostly by fishing, thus their fit was not improved by the inclusion of the –PDO. Also, it was not possible to fit salmon in this model, as salmon migrate through this system to the larger Pacific Ocean, and are affected by trophic interactions there that are not defined in this model.

We then tested four hypotheses for the decline in Stellers in the Aleutians by removing each factor consecutively to see how well the model fitted the data. We found that if there was no environmental variation Stellers would not have declined as much after the 1980s, but most other causes would only have reversed the decline after 1990. Specifically, if competition with flatfish was removed after 1977, Stellers would have started to rebound after 1990. Similarly, if the effect of fishing on their prey species was removed, Stellers would have started to rebound even earlier, and if all orcas were removed from the system they would have stabilised at around 20,000 individuals rather than going down to less than 10,000. Thus, all these factors seem to have contributed to the decline of Stellers in this system. ●

< Map of the modelled areas in the central and western Aleutian Islands and Southeast Alaska. (Image: S Gontarek, SAMS)

MY PhD

BIOGENIC GASES IN THE OCEAN

Sam Wilson, SAMS UHI

The oceans play an important role in both regulating and buffering the Earth's climate. One of the key mechanisms that link the oceans and the atmosphere is that the oceans act as both a source and a sink for major greenhouse gases such as carbon dioxide, methane, nitrous oxide, as well as aerosol species and their precursor compounds *e.g.* dimethylsulphide (DMS) and other biogenic hydrocarbons.

My PhD research focused on the production and interaction of two of these contrasting biogenic compounds: DMS and methane.

PRODUCTION OF THE COOLING GAS DMS

DMS is the most abundant natural volatile sulphur compound in seawater and concentrations of DMS are typically supersaturated in the surface waters of the ocean. Once released to the atmosphere, DMS is rapidly oxidised and its oxidation products serve as nuclei for water vapour resulting in cloud formation. These clouds have a cooling effect and are therefore an important offset to greenhouse gases. The main source of DMS in the marine environment is a compound called dimethylsulphoniopropinate (DMSP) which is produced by certain groups of marine phytoplankton, especially the dinoflagellates and prymnesiophytes.

I measured an increase in DMS when copepods graze on dinoflagellates. This may be due to the release of DMSP from the dinoflagellates and its subsequent degradation to DMS by marine bacteria. These results highlight the important role of algae, bacteria and grazers in determining surface concentrations of DMS in the water column.

PRODUCTION OF THE GREENHOUSE GAS METHANE

The production of methane in the oceans represents a more enigmatic process. In the euphotic zone of the oceans methane concentrations are frequently two or three times supersaturated with respect to atmospheric equilibrium. This is unusual because the water column is saturated with oxygen while the microbes that produce methane are thought to die in the presence of oxygen. In addition, sulphate is a major constituent of seawater while methane production typically does not begin until sulphate is nearly depleted. At the moment there is no consensus explanation for this aptly named 'oceanic methane paradox'.

My PhD research focused on potentially anaerobic micro-environments in the water column, such as particulate material. The faecal pellets from copepods may contain areas of very low oxygen because the many microbes living and respiring in and on these pellets may use oxygen faster than can be replenished by diffusion through dense bodies. In this context I characterised the methane-producing microbes from faecal pellets using the molecular methodology of 16S rDNA analysis. The results revealed a much wider diversity of methane-producing microbes than typically suggested in the scientific literature. This work has enabled us to ask more defined questions about the processes that occur at the micro-scale to facilitate the production of methane in the oxygenated water column.

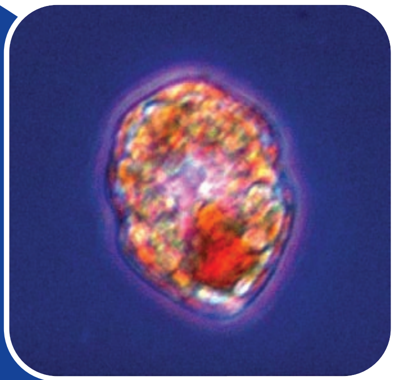
CONVERTING DMS INTO METHANE?

One of the more challenging aspects of my PhD was to study the interaction of DMS and methane. We know from studies on marine sediments and cultures of methane-producing microbes that DMS is a metabolic substrate for some methanogens. It was therefore hypothesised that within the upper water column the production of methane could potentially counter-act the production of DMS. To investigate this hypothesis, sample material collected from the upper water column was incubated over a two-week period, amended with DMS, DMSP and other substrates, and methane concentrations were measured. We found that the addition of DMS indeed increases the production of methane. This work is continuing at SAMS to clarify the exact role of algal-derived compounds in the process and to identify the main methanogenic groups responsible. ●

Sam recently submitted his thesis and was supervised by Drs Angela Hatton, Anuschka Miller and Mark Hart from SAMS, and Dr Cliff Law from the National Institute of Water and Atmospheric Research, New Zealand. He has taken up a Postdoctoral position with Professor David Karl at the University of Hawaii.

< The common neritic copepod *Temora longicornis* was used in grazing experiments to look at DMS production and to provide faecal material for the analysis of methane-producing microbes.

> The dinoflagellate *Scrippsiella trochoidea* produces copious quantities of DMSP, the precursor to the cooling gas DMS.



Seaweed: the blue biofuel?

Drs Maeve S Kelly and Symon Dworjanyn

> In contrast to terrestrial biofuel crops, seaweeds do not compete for land or freshwater, making them exciting candidates for biofuel production.

Whatever your opinion as to how we should meet our future energy needs, making good use of whatever renewable resources are locally available is only common sense. In response to the threat of global climate change and dwindling oil reserves, EU and UK politicians have set bold targets to increase the energy supply from renewable sources. As early as 2010, 5% of our transport fuel is to come from plants. Scottish targets for 40% of our electricity to come from renewable sources by 2020 are also ambitious. So in addition to the energy we might derive from water and wind on land, there are also hopes for emerging technologies to allow the generation of electrical energy from the sea, particularly from power-laden waves and tidal-streams. But what about our other marine resources?

BIOFUEL FROM MARINE BIOMASS

In Scotland, a cool climate, limited hours of sunshine and the relative scarcity of good agricultural land means that our options for growing terrestrial bioenergy crops for transport fuels such as bioethanol and biodiesel are very limited. However, there is one form of biomass that grows abundantly well in our temperate climate: seaweed or macroalgae, particularly the large brown species often referred to as kelp.

The concept is not new: More than 30 years ago researchers in the US embarked on a marine biomass energy research programme and showed that seaweeds performed as well as many terrestrial crops in anaerobic digesters, where naturally occurring microbial consortia converted the seaweeds to biogas containing around 60% methane. Methane can be combusted to produce electricity and heat and can also be used as a transport fuel, in engines designed to run on compressed natural gas. Marine biomass can also be used to produce ethanol, depending on chemical conditions and the make-up of the bacterial community in the digester.

Using marine plants for biofuels circumvents the building conflict over the use of land for fuel as opposed to food production and also conserves precious freshwater resources otherwise needed to grow terrestrial crops. Farming the sea may help in the battle to prevent massive deforestation to produce the cheapest biodiesel crop - oil palms.

For a number of reasons seaweeds appear to be excellent candidates for biofuel production: They grow rapidly, perhaps because they do not have to spend energy on developing internal transport systems for nutrients and water, and they are suited to anaerobic digestion as they lack lignin and have low concentrations of cellulose.

The technology behind anaerobic digestion is well established. In Europe the methods and equipment used on farms to digest manure could be adapted to digest seaweed (and fish processing waste). However, methane yields will be affected by many factors including the operating conditions of the reactor and the seasonal and geographic variations in the biochemical composition of seaweed.

< Current research is evaluating the potential of seaweeds for biofuel production.

> Tiny (<5 mm) plants of the brown seaweed *Laminaria hyperborea* growing on culture strings (Photo: S Dworjanyn, SAMS)

SEAWEED FARMING AND HARVESTING CAPACITY

A major issue when considering the use of seaweeds for biofuel production is their supply source. Should they come from cultured or wild harvested sources, or a mixture of both? Techniques for seaweed cultivation are well developed in other parts of the world, particularly in China, where millions of tonnes are grown annually, primarily for food. Researchers at SAMS have also been cultivating seaweeds for over four years, investigating their ability to utilise the additional dissolved nutrients in seawater around salmon cages. The sporeling plants are raised in the lab, and transferred to sea when they reach 0.5-1cm. Here they grow rapidly, reaching a length of 2-3 m in a matter of months.

Scottish crofting communities have a long tradition of collecting storm-cast seaweeds and there was a sizeable seaweed industry in days gone by. Many Scottish coasts still boast seaweeds in harvestable densities, and there has been a recent resumption of harvesting intertidal seaweeds in the Western Isles. However, it is the subtidal seaweeds that are likely to be most suited to anaerobic digestion. Methods such as those currently used in Norway must be developed to harvest these in a low-impact and sustainable way.

At SAMS our immediate research will focus on evaluating the potential of the different native species of seaweed for biomass and biofuel production. As well as investigating their growth characteristics in culture we will be researching their performance under anaerobic conditions and developing methods to maximise methane production.