Newsletter of the Scottish Association for Marine Science | ISSUE 34

SCOTTISH ASSOCIATION *for* MARINE SCIENCE

SAMS

ISBN 1475-7214

Marine renewable energy research

Spring / Summer 2009

diary

Climate change and the oceans
CPD training for science teachers
9-10 May 2009
SAMS
www.sams.ac.uk/education

All Energy '09
Exhibition & Conference
20-21 May 2009
Aberdeen
www.all-energy.co.uk

Marine Measurement Forum
21 May 2009
Edinburgh
www.mmf-uk.org

Scottish Fluid Mechanics meeting
27 May 2009
SAMS
www.sams.ac.uk

Oceans 2025 annual science meeting
1-3 June 2009
Liverpool
www.oceans2025.org/registration.php

Observing the Arctic – summer school
27 June – 3 July 2009
Svalbard
http://school.nilu.no/

Marine phytoplankton taxonomy workshop
6-17 July 2009
Plymouth, UK
www.mba.ac.uk/phytoplanktonworkshop/

International SOLAS summer school
3-15 August 2009
Cargèse, Corsica
www.solas-int.org/summerschool/

ICE Coasts, marine structures and breakwaters
16-18 September 2009
Edinburgh International Conference Centre
www.ice-breakwaters.com

SAMS AGM and Newth lecture
6 November 2009 4pm
SAMS
www.sams.ac.uk

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Front cover: Oil oozing out of *Botryococcus* cells © Gordon Beakes, University of Newcastle.

About SAMS

The Scottish Association for Marine Science (est. 1884) is a learned society for marine scientists, students and enthusiasts with an international membership of around 500.

It is a Scottish Charity and a Company Limited by Guarantee. SAMS is the owner of a state-of-the art Scottish marine institute at Dunstaffnage near Oban with two research vessels, a dive centre, the Culture Collection of Algae and Protozoa, and a large research aquarium. SAMS employs currently 150 staff that deliver world-class research for sustainable seas. These researchers are active across all marine science disciplines including technology and policy, with significant expertise in multidisciplinary working. The SAMS portfolio includes research on the Arctic, climate change, biodiversity, management and governance, and energy issues. As a collaborative center of the UK Natural Environment Research Council SAMS contributes to the strategic Oceans 2025 research programme.

SAMS is an academic partner of UHI Millennium Institute, the future University of the Highlands and Islands. Under UHI's auspices SAMS delivers a BSc (Hons) Marine Science and a BSc (Hons) Marine Science with Arctic Studies, and trains PhD students. It also delivers continuous professional development training for science teachers and regulators, and provides field station facilities for universities.

Being committed to knowledge exchange and with a considerable track record in winning commercial contracts, SAMS owns a subsidiary company (SAMS Research Services Limited) and the European Centre for Marine Biotechnology, an incubation unit hosting three tenant companies.

SAMS is governed by an independent Council, which is supported by a Board and several committees.

SAMS Membership

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

Student: any person under 18, or registered students at Further or Higher Education Institutions. 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).

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To keep up-to-date on events at SAMS, please visit our website:
www.sams.ac.uk

Designed by Design Links

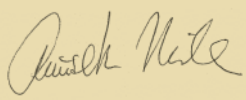
Dear SAMS member

Dr Anuschka Miller, EDITOR

Alongside food and freshwater, energy is perhaps the most important commodity for our civilisation underpinning every component of the world economy and modern living. As the era of fossil fuels is on the decline we are searching for the power technology of the future, which will have to be abundant, reliable, and cheap. Renewable energy both from terrestrial and marine sources are attractive options, and Scotland is currently competing for pole position in the development of marine renewable energy technologies, particularly for wave and tidal energy. This issue of the SAMS Newsletter highlights how our researchers contribute to developing marine biofuels, and how they work towards understanding and mitigating the impacts of marine renewable energy devices.

While the scale of SAMS' research institute activities dramatically increased under the leadership of Professor Graham Shimmield, our previous director, the learned society activities have not kept up with these developments. Our new director, Professor Laurence Mee, wants the learned society activities as well as teaching to grow over the coming years. We have thus developed a discussion forum on the SAMS website for SAMS members and I would like to invite you to voice your views and wishes about the future direction of the Association at www.sams.ac.uk/memberviews. Let us know what you want this learned society to do for you and the other members.

I wish you pleasurable reading and hope to hear from you online.



SAMSnews

CHANGE AT THE TOP

In spring 2008 our director of 12 years, Professor Graham Shimmield, left SAMS to take up the post of executive director of the Bigelow Laboratory for Ocean Sciences in Maine, USA. On pages 18-19 some students and staff share memories and thoughts about what Graham's leadership meant to them.

Deputy director Dr Ken Jones used his extensive understanding of SAMS to lead the organisation capably and responsibly for the six months until the new director, Professor Laurence Mee, could join us from his previous position as director of Plymouth University's Marine Institute. With a research background in marine policy, and extensive international experience of managing marine science, Laurence aims for SAMS research to contribute effectively to the development of informed governance and the truly sustainable management of the marine environment.

Professor Laurence Mee is the new direct of SAMS.

GOVERNANCE AND MANAGEMENT CHANGES AT SAMS

SAMS has more than doubled its staff numbers while its turnover has increased eightfold over the course of a decade. To ensure that SAMS' governance and management structures are fit for purpose we underwent a professional management review, and have made numerous alterations in response to its findings. At a governance level SAMS Council, which remains the ultimate authority, created a Board to Council which is further supported by the research, education, business development and audit committees.

> Professor Axel Miller is the first UHI Professor for SAMS

UHI AND EDUCATION DEVELOPMENTS

UHI Millennium Institute, our key partner for academic activities, was awarded taught degree awarding powers in 2008, thus achieving a major milestone on the long road to university title.
This new university will be critical for the socio-economic development of the entire region. SAMS' contribution to it was recently recognised by awarding a professorship to Axel Miller, SAMS' Head of Education and Academic Development.

At SAMS we plan to increase our education activities markedly: we have developed an MRes in Marine Systems Science in collaboration with the University of St Andrews, which we plan to run for the first time later this year.

We are further planning to construct state-of-the-art teaching facilities to accommodate growing numbers of under- and postgraduate students, and to increase our provision of specialist short courses and innovative field-based training.

DEVELOPMENTS IN SCOTTISH MARINE SCIENCE

Over the past years the Scottish Funding Council has invested significantly in pooling initiatives in various disciplines to enable Scottish researchers to compete with the large and well equipped institutes that exist in other countries. For a number of years now SAMS has been involved with the Scottish Alliance for Geoscience, Environment and Society, and two SAGES projects are described on pages 16 and 17. The SFC has only just announced that it will also fund a pooling initiative for marine science, called the Marine Alliance for Science and Technology Scotland (MASTS), which aims to build marine science capacity and collaboration in Scotland. SAMS will host the MASTS Graduate School under the leadership of Professor Axel Miller.

Early in 2008 SAMS had been approached by the University of London with a proposal to take over the management of the University Marine Biological Station, Millport. After a lengthy joint due diligence process, SAMS was unable to find a viable economic model for running the UMBSM business, thereby bringing discussions to a close. Much effort and consideration was invested on all sides, and it is disappointing that we could not identify a sustainable model for involvement in this very special and valuable facility.

LARGE EUROPEAN PROJECTS LED BY SAMS

> Minster for Energy Jim Mather MSP (left) launched the European BioMara project on 3 April at SAMS.

Scotland's Minister for Energy, Jim Mather MSP, launched the €6 million BioMara project that aims to develop and assess the potential and marketability of marine biomass from both micro- and macroalgae as sustainable sources of biofuel. SAMS lecturer Dr Michele Stanley, who coordinates the project, acknowledges the important role of Ian MacFarlane as an initiator of the project. BioMara is funded by the European Union (Interreg IVA) with further contributions from Highlands and Islands Enterprise, and the Crown Estate. On pages 6-7 Ian describes the rationale behind this highly praised and topical work. BioMara brings six new posts and two PhD studentships to SAMS.

The European Census of Marine Life is part of the global Census of Marine Life and aims to improve marine taxonomy, species data, biodiversity and ecosystem information in Europe. Its project office has been based at SAMS since 2005 and has recently won funding from the TOTAL Foundation and the Alfred Sloan Foundation to continue until the end of 2010, when the decade of the international Census for Marine Life comes to an end.

The newest European project led and coordinated from SAMS is KnowSeas (Knowledge-based Sustainable Management for Europe's Seas), headed by Professor Laurence Mee. A €5.74 million European FP7 project, KnowSeas has 31 partners from 15 member states and aims to develop a comprehensive scientific knowledge base for the application of the Ecosystem Approach to the sustainable development of Europe's four heavily impacted regional seas (Baltic, Black, Mediterranean and NE Atlantic). The project will provide scientific guidance for the implementation of new European marine environmental legislation and policy.

INFORMING, INSPIRING & ENGAGING TOMORROW'S SCIENTISTS

We have been increasing our public engagement activities over the past year in support of nation-wide initiatives to inspire more school leavers to follow a career in science, technology, engineering and mathematics. We are visiting increasing numbers of schools in the area, develop teaching materials and competitions, and run two training courses for science teachers. We welcome the new curriculum for excellence in Scotland and hope that teachers will be able to engage more with the marine environment through this format.

SAMS has been developing plans to run a marine science festival in Oban from 2010, and has been participating in a project to share our science with visitors to Scottish science centres. The annual open day at SAMS has been attracting growing numbers of visitors year on year, peaking with 500 earlier this year in March. This year our researchers developed many new activities specifically for children and young adults, making the entire day very interactive and colourful. Staff also built on the significant Newsnight coverage of our arctic research expedition late last summer (see pages 12-13) by developing International Polar Year outreach events.

As part of the new teaching facilities, we will develop a visitor centre to inform people about the marine environment, enthuse them about our research and engage with them in discussions about future directions in using the oceans. The visitor centre space will also allow us to strengthen our relationship with the membership and local community as a meeting space.

Offshore wind farms:
Do they have fisheries potential?

To anchor and protect structures like offshore wind turbines on the seabed requires *de facto* artificial reefs to be created.

Dr Tom Wilding, SAMS (tom.wilding@sams.ac.uk)

Winter storms cause a lot of damage along coastlines, and they are set to become worse on the west coast of Scotland according to climate change model simulations. Will we just have to live with this, or can we proactively do something to mitigate or reduce the damage? Can offshore wind farms make a positive contribution?

> The 30 modules of the Loch Linnhe artificial reef consist either of simple or of complex blocks to study the effect of structural complexity on the habitat.

The common answer to mitigating climate change is a now ubiquitous call to reduce carbon dioxide emissions. Scotland is characterised by a complex coastline, major offshore areas and frequent and strong winds which make offshore wind farms an attractive option for generating renewable energy. While land-based wind farms are commonplace around the UK and are making a small but growing contribution to our electricity supplies, the main growth potential may well lie offshore. Offshore sites are not only windier but windier more often, compared with their onshore counterparts. Currently the UK Government is licensing offshore sites for up to 2,400 wind turbines.

Offshore wind turbines consist of a hollow steel tube of 3 – 4 m in diameter that rises 80 m above the waves to support the rotor blades. Anchoring such a massive structure to the seabed poses unique challenges. The most common and simplest solution is to pile the turbine foundation into the seabed, sometimes by up to 30 meters.

Finding the right location for a wind farm is critical, and may require special engineering solutions. Many offshore farms – such as the London Array wind farm – are planned for areas where the seabed is characterised by sandbanks and shifting sediments. As currents swirl about the bases of turbines, they frequently create considerable erosion pits which can be up to 10 m in depth. These erosion pits can pose a major headache for engineers, particularly where they expose the electrical cabling that connects each turbine to the grid. The solution has been to protect the base of the wind-turbine from erosion by dumping rock boulders at the base. The turbine base and scour material create *de facto* artificial reefs, and may radically alter the receiving environment, particularly where hard substratum enters an otherwise sedimentary system. Also the water flow will alter around these sites with consequences well beyond the footprint of the turbine.

At SAMS we have developed the Loch Linnhe Artificial Reef over the past decade. This artificial reef consists of thirty separate reef modules that experience a range of current regimes over an area of approximately 0.5 km^2. Each module stands 3 – 4.5 m off the seabed and is made from approximately 4000 concrete blocks (200 x 200 x 400 mm). The blocks come in two designs: one is solid - creating simple block reefs - while the other contains two large voids and creates complex block reefs. Each reef is about 50 m in circumference and takes a few minutes to swim around. The replicated reef system has allowed us to investigate, in a uniquely systematic manner, the following:

> Artificial reef research can help us build offshore structures that are robust and create productive and diverse biological communities.

- Habitat complexity[1]
- Near-reef impacts[2]
- The interaction between the reef structures and the local current regime[3]
- Reef productivity[4]
- Epifaunal colonisation as a function of surface texture[5]

In terms of offshore renewables we want to use the Loch Linnhe Artificial Reef to find out to what extent habitat manipulations dictate why animals choose particular places to live.[6] Ultimately we want to be able to predict habitat requirements for individual species, including commercial species such as lobsters, so that offshore wind farms can be designed to facilitate fisheries. This would mean that offshore wind farms could benefit fishing opportunities for both recreational and commercial fisheries.

Once we understand species habitat requirements and can modify the design of offshore structures to suit these, this expertise can then be applied to any intervention in the coastal zone, including the offshore breakwaters that are likely to be required to afford some protection from the worst of storms of our own making. ●

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[5] Brown CJ (2005) Epifaunal colonization of the Loch Linneh artificial reef: Influence of substratum on epifaunal assemblage structure. *Biofouling* **21: 73-85**

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Driving on algae:
producing biofuel from marine biomass

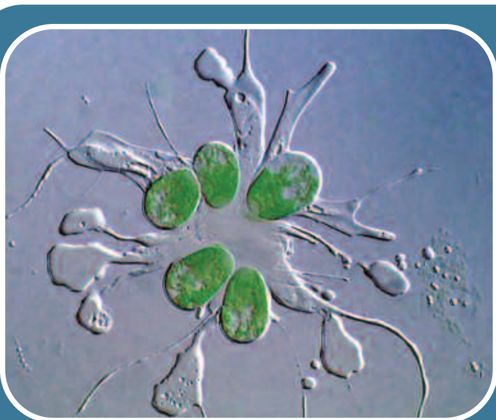
Ian MacFarlane (Ian.MacFarlane@sams.ac.uk)

To constrain global warming many countries have been introducing ambitious targets for the use of bioethanol and biodiesel to supplement transport fuel. These fuels are converted largely from crops grown on arable land, causing competition with food production and conservation. The solution to this serious conundrum may well lie in the sea.

Recent years have seen a surging demand for fuel crops like corn, rapeseed, soya, wheat and sugarcane. This, in turn, has led to fierce competition for the use of arable land for food and fuel production, making farming products more expensive and causing riots due to rising food prices all around the world. Although food and fuel prices have abated somewhat as a result of the recent world economic downturn, the situation will worsen again as demand certainly rises when recessionary pressures ease and as human population continues its inexorable growth.

The expanding need for arable land leads to pressure on the rapidly declining pristine areas of the world, most notably the rainforests of Southeast Asia and the Amazon Basin. Already large swathes of rainforest in Borneo are being converted into oil palm plantations and the Amazon is being burned to create pastures for soya production and cattle ranching.

Developments like these see rich countries, with their dependence upon motor travel, suck in biofuel feedstock from poorer areas of the world where both food and fuel supply are becoming increasingly restricted. The longer term social and political implications of this are hard to imagine.



< Some microalgae – like *Botryococcus* – naturally produce large quantities of oils, often as a response to stress. (Photo © Gordon W Beakes, University of Newcastle)

FUEL CROPS DON'T NEED TO COME FROM THE LAND!

Less than a third of the Earth's surface consists of land while 361 million square kilometres are ocean. This vast marine area currently produces around 100 million tonnes of high-quality food for human consumption per year, which is only 5% of the amount produced by agriculture that produces over 20 billion tonnes every year. The ocean is thus a barely tapped resource for biomass production, and the impact of generating biofuel biomass from the sea may be much smaller than terrestrial alternatives.

Over the past few years several scientists at SAMS have been turning their ingenuity to researching the potential of the marine environment for energy production. They are studying the environmental issues relating to the offshore production of electricity from wave, tidal and wind power as well as the production of the marine equivalent of agrifuels – marifuels. Marifuels include bioethanol and biodiesel but may also include more complex alcohols such as biobutanol, which is more energy efficient than bioethanol and may prove useful as an aviation fuel.

Marine algae, including some of the more common large seaweeds, are amongst the most productive plants on Earth. Their high oil content and rapid growth enables them to produce up to 30 times more oil per hectare than current biofuel crops. If research produces affordable methods of growing and harvesting algae and of converting them into biofuel, marifuels may take the pressure off agriculture, enabling most land crops to be grown for food production.

Microalgae comprise a large group of organisms of high genetic and morphological diversity that are ubiquitously distributed throughout the biosphere. Many of them naturally produce oils, which can be converted to biodiesel. Like plants they convert the energy of sunlight into chemical energy and produce complex organic molecules, including fats and oils. Because of their simpler cellular structure, microalgae are more efficient in this process of photosynthesis than land plants. This is one reason why they can produce more biofuel than land crops. An algal crop is produced in days where an equivalent field of rapeseed may take many months to mature and yield extractable oil.

Biodiesel produced from microalgae-derived oils has several advantages: it contains no sulphur, is non-toxic and highly biodegradable. It is also readily blended with mineral-derived diesel, unlike dirtier oils derived from agricultural and forestry crops or wastes such as wood chippings and straw. These characteristics make marifuels simpler, safer and potentially cheaper than their terrestrial equivalents.

Large brown seaweeds like kelp are the greatest potential source of marine biofuels. Immersed in seawater, these fast growing macroalgae are naturally highly productive and under the right conditions fix carbon at a rapid rate.

Macroalgae and the biomass produced as a by-product of microalgal biodiesel production can be anaerobically digested into methane and/or fermented to produce ethanol. Both of these can be used as transport fuels. Methane is also a useful fuel for local heat and power generation. Macroalgae are characterized by a lack of lignin and a low cellulose content, making them easier to digest into methane than land plants.

Some of the new methods SAMS scientists are working on may support the sustainable generation of energy at a local level so that isolated communities could eventually satisfy their needs regarding local transport, heating and power from local production. As this reduces costs of importing and distributing energy and does not require major infrastructure, local power generation schemes are particularly important for coastal and island communities.

To meet the EU target of 5.75% biofuel content of transport fuel by 2010 would require about one-quarter of the EU's arable land to be used for energy crop production, assuming that all biofuel was generated within the EU. This means that even if all arable land in the EU was to be given over to the farming of energy crops, we could at most produce 23% of our current demand of transport fuel. These numbers are sobering, and we should urgently explore and develop the production, harvesting, and conversion of algae for biofuel production.

> Dr Michele Stanley and her colleagues will be screening the Culture Collection of Algae and Protozoa to identify candidate strains of microalgae for biofuel production.

BioMara

The Sustainable Fuels from Marine Biomass project (BioMara) is a UK / Irish research project to demonstrate the feasibility and viability of producing third generation biofuels from marine biomass.

Researchers from SAMS, the University of Strathclyde, the University of Ulster, Queen's University, Belfast, the Dundalk Institute of Technology and the Institute of Technology, Sligo are investigating the potential use of both micro- and macroalgae as alternatives to terrestrial agri-fuel production.

The practicalities of using algal biomass as a competitive, sustainable biofuel source are considered in concert with wide stakeholder engagement, whist environmental impacts of algal cultivation and extraction are also a core element of the research.

The €6 million project is funded by the European Union through the INTERREG IVA Programme, the Crown Estate, and Highlands and Islands Enterprise.

For more information contact: Laila.Sadler@sams.ac.uk

SAMS Drifting Ears:

Listening to marine renewable energy devices

Dr Ben Wilson, SAMS (Ben.Wilson@sams.ac.uk)

It may still be early days for wave and tidal energy solutions, but commercial-scale developments are likely to appear in the sea soon. In the race to commercialise the winning renewable power technologies, we are in real danger of disregarding the impacts such installations may have on the receiving environment. This article considers the sound pollution such designs might cause, and introduces a new device for estimating underwater sound from fixed installations: the SAMS Drifting Ears.

> There is a staggering variety of designs for harvesting the energy of waves and tides, all of which will have different effects on the receiving environment.

UNDERWATER SOUND POLLUTION

Marine wave and tidal energy technologies are new and their environmental impacts unknown, but lessons from other marine activities like naval manoeuvres, shipping and oil extraction give us ample warning that care should be taken. One particularly relevant area of concern is the potential polluting effects of underwater sound. Too much sound and sensitive species may be excluded from ecologically important marine areas. Conversely, too little sound and the devices may be undetectable to animals that navigate using sound and so put animals and devices at risk of harmful collisions (see article on page 9).

NEW: DRIFTING EARS

To investigate the underwater sound output from tidal energy devices, we have been collaborating with the European Marine Energy Centre (EMEC) in Orkney to develop industry applicable methods of measuring how noisy these devices are.

Measuring sound levels in the punishingly energetic marine environments is not a simple task. Normally underwater sound is measured by lowering a hydrophone over the side of a boat and making a recording.

> The SAMS Drifting Ears on their first deployment at the Falls of Lora tidal narrows.

This method can be complicated by the sounds the boat may be generating - from water slapping the hull to footfalls of the crew on deck or even a lost nut rolling around in the bilge. With care, we can prevent these problems. But when we work in a strong current, like a tidal energy site, we normally need to use the engine to maintain our position - making it impossible to get accurate ambient sound measurements. When the engine is turned off and the boat allowed to drift, even a gentle wind will move the boat at a different speed and direction to the current, which generates unwanted noise as water flows around the hydrophone.

To get around these problems we have developed a boat-free, mobile method to record underwater sound called the "SAMS Drifting Ears". A sound recorder, GPS and power supply are encapsulated in a small floating case and attached to a hydrophone and drogue. The drogue secures the hydrophone and recording gear to a single portion of the flowing water. Where that segment of flowing water goes, the hydrophone does too and without the unwanted flow noise. Also the recording case has neither engine nor crew (nor lost nuts)!

The drifter package is dropped upstream of the submerged renewable device and allowed to flow with the current downstream towards and over its target, recording as it goes. On recovery the GPS track can then be combined with the sound recording to determine exactly how loud the device was at a variety of distances.

FIRST TRIALS AND RESULTS

Initial deployments of the drifters at the Falls of Lora tidal narrows at the mouth of Loch Etive presented us with a steep learning curve. If the surface part of the drifter was too big, the wind would dominate where the drifter went and the recordings would be useless. If the submerged drogue was too big, the water would get too much grip on the device and a strong down-current could easily drag the whole set-up to the depths. After some tinkering, the drifters were ready for a test at a real tidal energy site.

We conducted these trials at the Fall of Warness experimental tidal test site in Orkney. The site lies between the islands of Eday and Muckle Green Holm and is subject to anything up to 7 knots of current. EMEC have set up hook-up points on the seabed to which developers can attach their prototype devices. But we first needed to determine how much noise is in the surrounding environment. To do this we visited Warness in January 2008 when no experimental devices were operating to launch our drifters on both flood and ebb tides. By simultaneously deploying several Drifting Ears in a line across the flow and letting them drift down stream as a group, they recorded enough sound information (20 GB) for us to create a sound map of the site.

As the marine renewable energy industry continues to develop and the EMEC site becomes populated with devices, we will deploy the Drifting Ears again. By comparing the sound levels when there are operating devices with our background recordings at the undeveloped site we will get an indication of what sort of noise tidal-stream machines emit in coastal waters with all the realities of corrosion, fouling and turbulent flow. This will help us comprehend what an animal like a marine mammal or a fish will hear as it approaches a tidal energy device and from there understand what acoustic environmental impact this new energy source will have in our coastal waters. We will then be one step closer to knowing how green marine renewable energy can be. ●

Avoid or collide:

How will marine mammals interact with marine renewable energy technologies?

> Marine mammals are agile, with excellent eye sight and hearing. Still they may no be able to detect a marine renewable energy device in time to avoid a collision with potentially devastating consequences.

Caroline Carter (carter.caroline@ymail.com)

Waves and tides may prove to be green and clean sources of energy, capable of supplying 20% of the UK's electricity demand, but like all human activity marine renewable energy devices will have environmental impacts. This article explores the potential collision risk to marine mammals from underwater tidal energy devices.

> The author (2nd from right next to SAMS President Sir John Arbuthnott) was awarded a Masters with distinction for this research at the SAMS AGM and graduation event in 2008.

COLLISION RISK

While clean energy is desirable, one potential barrier to the development of marine energy devices is the collision risk to pelagic animals. Developers and consultants generally state that these structures will pose little danger to marine mammals because they assume these agile and intelligent animals should be able to navigate around such devices. My Masters thesis explored the validity of this assumption by reviewing the collisions of marine mammals with existing moving and stationary man-made structures. Ship strikes are a known cause of cetacean mortality and many marine mammals worldwide are threatened by high rates of incidental fisheries capture, which kills hundreds of thousands of individuals every year. Also, like marine mammals, birds and bats are agile with good sensory perception, but collisions with man-made structures including wind turbines are well documented.

These parallels suggest that in contrast with the industry's assumption marine energy devices could indeed pose a risk to marine mammals. Especially when you consider that these devices will be sizable structures and that they are likely to be deployed in high numbers in 'energy farms'. Preferred sites for tidal-stream devices will be restricted passages, for example between islands and the mainland, or around headlands and we know that marine mammals are frequently observed in such locations.

DEVICE DETECTION MODEL

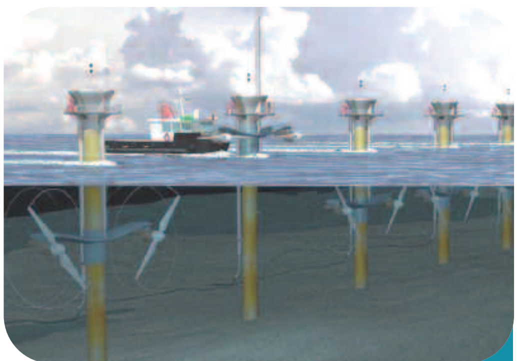
At this early stage in the industry's development, it is impossible to study the collision risk directly. Instead, the warning time and distance that would be available to marine mammals upstream of a device, under different scenarios, was explored using a model. Tidal stream devices were focused on because, intuitively, they may present the greater risk due to the combination of rotating blades in a fixed position together with the tidal flow driving the blades' rotation. Additionally, the device placement in restricted topographical passages may limit marine mammals' manoeuvrability.

Marine mammals are well adapted to their underwater environment with good vision, hearing abilities and, for cetaceans, echolocation. Light, however, does not travel well through water severely limiting underwater visibility. Marine mammals will most likely rely on their hearing to detect and avoid underwater devices. To explore how much warning and avoidance time might be available to marine mammals, an acoustic device detection model (based on sound propagation formulae) was constructed. To estimate the audible distance, the model compared the received levels of device sound with ambient noise levels and the hearing capabilities of marine mammals.

The model was run for a range of scenarios, and highlighted conditions when the warning time available would be less than one minute. This may be insufficient warning, bearing in mind decision and reaction time, the size of the devices and tidal flow. There are currently significant data gaps, in terms of acoustic warning: The levels of device noise and shallow water ambient noise are not well known, and crucially the marine mammal behavioural response to tidal stream devices is poorly understood. If we are to mitigate the impacts of tidal devices on marine mammals and thereby make them more successful, we urgently need to improve our understanding of all these factors.

In conclusion, it cannot be assumed that marine mammals will always be able to avoid tidal stream devices despite their agility and their excellent sensory capabilities. ●

Caroline's work was one of 12 MSc projects throughout the UHI network funded by the European Social Fund and co-ordinated by the Environmental Research Institute at the North Highland College UHI in Thurso. She was based at SAMS and supervised by Drs Ben Wilson and Kenny Black. This 12 month MSc programme was distinctive in the UK as it was undertaken fully by research, and examined by thesis and viva. Caroline graduated with distinction in November 2008.



> Marine renewable energy devices currently under consideration often have rotating blades or other moving components that could injure animals that come into contact with them.

Renewable Marine Energy: The New Gold Rush and the Law

David Bone and Andy McFarlane, Wright, Johnston & Mackenzie LLP (amm@wjm.co.uk)

Announcing the introduction of Scotland's first Marine Bill at the end of April 2009, the Rural Affairs and Environment Secretary, Richard Lochhead stated that "Scotland holds a quarter of Europe's total tidal and offshore wind resource and 10% of its potential in wave power". Whether Scotland ultimately exploits that potential will depend on how successfully it promotes the emerging renewable energy technologies. In this article we explore some of the economic and legal challenges in creating a thriving renewable marine energy industry in Scotland and what steps are being taken to tackle them.

COST AND TECHNOLOGY

The cost of producing energy from Renewable Marine Energy (RME) is still significantly higher than energy that comes from mature technologies, both renewable and otherwise. Whilst RME should become more competitive over time through technological consolidation and economies of scale, the Scottish Government is taking steps at this time to ensure developers have an incentive to invest in wave and tidal power where Scotland has a perceived technological lead. That lead must be maintained and prototype technologies need to show that they can be developed on a larger scale to commercially viable projects. Perhaps more column inches should be devoted to the Scottish Government's bold plan to award five Renewables Obligation Certificates (ROCs) for every megawatt hour of wave power generated and three ROCs for every megawatt hour of tidal power. This compares to offshore wind, which currently receives two ROCs for each megawatt hour.

GRID CAPACITY

One of the difficulties facing any developer in Scotland is the limited capacity of existing grid infrastructure. Without significant upgrading of the grid, the attractiveness of the remoter areas of Scotland (where the best wave energy resources are located) as places to develop RME will be hampered. This problem is not going unattended, however, and at this year's SRF Conference the National Grid outlined its plans for a major upgrade of the grid in Scotland. National Grid called upon developers to apply for grid connections now in order that a co-ordinated plan could be in place to ensure that the necessary expansion would be available to service projects. At a cost of £80,000 per application developers will have to make a financial commitment in order that their projects can join the queue to be "managed" by National Grid.

REGULATORY FACTORS

Assuming working technology and a satisfactory grid position, developers are still faced with the task of obtaining all necessary consents and property rights for their projects. The first draft of Scotland's Marine Bill sets out a new marine planning framework with the newly created Marine Scotland tipped to become a central regulatory authority for all aspects of marine issues.

The draft bill also includes new licensing provisions notably that any application for a marine licence in respect of a project that would require planning consent under Section 36 of the Electricity Act 1989 will be considered as a joint application in a single process. Whilst the bill still has a long journey through Parliament ahead, any streamlining of the consents process is to be welcomed. Currently any RME installation with a capacity of 1MW or more, and within Scottish territorial waters (out to 12 nautical miles) or the Scottish part of the Renewable Energy Zone (out to 200 nautical miles), will require planning consent from the Scottish Government under Section 36. A full Environmental Statement detailing those aspects of the marine environment likely to be affected by the development must support such an application. Interestingly, for onshore wind farms only local authority consent is required for anything less than 50 MW.

< The 500 kW Islay LIMPET Wave Power Plant has been successfully supplying energy to the electrical grid in the UK since November 2000.

The draft bill envisions the drawing of a national marine plan giving weight to factors other than development, such as the protection of marine life, the ecosystem and the livelihood of fishing communities. Developers should welcome some certainty in this area. Whilst the current indications are that the Government is keen to determine planning applications for RME projects quickly, it would be comforting to know that when the inevitable increase in volume happens, applications can be processed fast and along clear guidelines.

There is insufficient detail in the draft bill to determine whether the granting of a marine licence to a developer will eliminate the need for other regulatory requirements. There are currently many different bodies in the UK with various responsibilities and rights (created under different Acts of Parliament) in respect of UK waters that evolved over time and which did not envisage development of offshore installations.

Any national marine plan is likely to highlight preferred areas for development. In the meantime attention is being focused by the Crown Estate who recently completed the tender process for the licensing of the "Round 3" offshore wind farms in Scottish territorial waters. They are now in consultation with developers regarding the Pentland Firth development which they envision delivering 700 MW of new offshore wave and tidal power by 2020.

The Crown Estate owns almost the entire UK seabed out to 12 nautical miles along with half the foreshore. If a project falls within the area owned by the Crown Estate then the developer should seek to enter into an agreement to lease the area required.

In an attempt to create a uniform approach to marine development the Scottish Government is currently in talks with the UK Government about formalising a proposal that Scotland will take responsibility for all coastal waters within the Renewable Energy Zone. This additional area is not subject to Scotland's Marine Bill but the arrangement between the devolved government and Westminster may be reflected in the UK Marine Bill. ●

The authors are solicitors specialising in renewable energy development with leading firm Wright, Johnston & Mackenzie LLP, Glasgow.

Plankton powers SciArt project

Plankton Power: An arts/science project exploring the past, present and future significance of plankton and its link to the cultural heritage of coastal Scotland

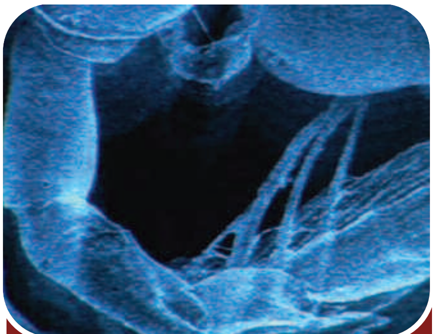
> The artists were recording the plankton images directly from the SAMS electron and confocal microscopes.

Kenny Munro (munro64@btinternet.com) and Edward O'Donnelly (e.odonnelly12@btinternet.com), artists

A 2008 SAMS bursary supported the formulation of the 'Plankton Power' SciArt project that generates aesthetically striking images of plankton to raise community awareness about the relevance of plankton to life and human activities.

LIVING LIQUID LIFE

The initial working relationship between us and SAMS was established in 2000 when we examined bioluminescence in plankton for a project entitled 'Living Liquid Light' funded by the Arts Council Lottery, SNH, Hi-Arts and Highland and Islands Enterprise. This took the form of a residency with schools on the Isle of Skye and included a touring event to reach out to communities on the west coast like the school on the island of Canna. After a brief introduction to the significance of plankton, we exposed the children to large-scale scanning electron micrograph images of dinoflagellates to stimulate ideas for creating artworks and sculptural lanterns. The project was literally 'highlighted" with an evening voyage in the glass-bottomed boat from Kyle of Lochalsh which revealed plenty of phosphorescence like an underwater firework display.



> Art projects can aid science education about plankton by creating fascination about their beauty and functionality and by engendering a sense of wonder and appreciation.

Local and international exchanges brought us together with David Mann of the Botanic Garden in Edinburgh, Mike Latz of the Scripps Institute in San Diego, and Chris Bolsch from Tasmania. Further meetings with staff at Dunstaffnage provided the project with continuity and momentum.

Since 2003 the video collaboration with Edward O'Donnelly has enabled us to explore several environmental themes in Scotland, Australia and India.

BRINGING DIGITAL VIDEO TO BEAR ON PLANKTON: 2007-2008

The opportunity to re-engage with SAMS was inspired partly by support from the Royal Scottish Geographical Society which has historic links with SAMS via the 19th century polar explorer William Speirs Bruce and his research work in the Arctic and Antarctic.

During the summer of 2007 a pilot video was made at SAMS which included images taken with a scanning electron microscope and a confocal microscope. These images were intercut with contemporary location footage edited together with music and text. Our approach was to extend the scope of plankton research presentation by combining objective information with imaginative interpretation through the medium of moving image, text and music/soundscapes.

The renewed relationship with SAMS was assisted by a bursary in 2008 to refine the project further and formalise an application for development funding. The key objective of the developed proposal was an art/science venture focusing on the cultural and scientific significance of plankton locally and internationally. An essential aspect of the proposed project was to explore the subject through engagements with Scotland's coastal communities at identified arts centres and other venues in the Highlands and Islands region.

We applied to the new Scottish Arts Council 'Inspire Fund' but regrettably the application was not successful. We now want to identify the most feasible and stimulating way to get our plankton message disseminated into the public domain. To attract fresh interest and ideally a commitment of support we have been invited to prepare this article.

As artists we feel we can make a unique contribution to an increased awareness of the existence and the environmental and cultural relevance of marine microorganisms and therefore are keen to work more closely with SAMS in the future. We believe we can provide a broader cultural context by calling in historical and contemporary literary and visual sources.

WEBSITE DIALOGUE

As an extension to the SAMS bursary, SAMS have offered to host a dedicated page on their server to display some of the striking images and film footage we are generating, and to allow us to acquire anecdotes, reports and images related to plankton from around the world. These submissions can then inform our artistic practice as well as serve community art projects in the future as sources of inspiration and images.

PAST VIDEO PROJECTS

Our video work includes 'Language on Stone', a film themed around the poem Scotland by Alastair Reid. The project was commissioned by StAnza Poetry Festival in 2007.

The National Trust for Scotland & Museums of Scotland sponsored 'Words Fly from this Place' celebrating 500 years of printing in Scotland. The film captures process footage at Smails Printworks Innerleithen (NTS) and intercuts with archive film footage from Scottish Screen Archive NLS and music by 'Found'. 'Words Fly' is on display on Level 4 at the Museum of Scotland, Chamber Street, Edinburgh. ●

How do microbes respond to melting arctic sea ice?

Report from the 2008 ICE CHASER expedition

Laila Sadler, SAMS (Laila.Sadler@sams.ac.uk)

Humpback whales, white beaked dolphins, bearded seals, walrus and 28 polar bears: An impressive sightings list for any arctic marine cruise. But this SAMS research cruise had gone to the Arctic to study life at the very base of the food chain. The microbes and planktonic flora and fauna that capture carbon and integrate it into the arctic ecosystem's food web play a critical role in this remote environment, yet little is known about them. And with climate change high on the global agenda, the role of marine microorganisms in sequestering carbon from the atmosphere is of growing interest.

The 2008 ICE CHASER (CHAnging Sea-ice and Ecosystem Response) expedition was funded by the UK National Environment Research Council's *OCEANS 2025* strategic marine research programme, and was part of the International Polar Year PAN-AME and PAME research clusters. Led by Dr Ray Leakey, Head of Microbial and Molecular Biology at SAMS, the aim of the cruise was to improve our understanding of the ecology and biogeochemistry of the region, thereby helping to refine models of ecosystem response to environmental change. The dynamics of the marine microbial community and the potential effects of ocean temperature change on carbon cycling and food webs were key components of this work.

A follow-up expedition, ICECHASER II, planned for 2010 will enable a comparison of the microbial and planktonic plant and animal communities, providing valuable insight into changes brought about by climatically-driven variation in sea ice.

The Arctic is one of the most rapidly warming regions on Earth. Just three weeks after our return to SAMS in September 2008 the arctic sea ice reached its minimum coverage for the year: 4.52 million square kilometres. Though ice cover remained above the 2007 minimum (when arctic sea ice cover reached the lowest area ever recorded), still the 2008 melt season has resulted in the greatest loss of sea ice on record: 10.58 million square kilometres (an area larger than Europe) had melted away. The arctic climate is changing in ways never before witnessed, with greater ice loss in summer and rapid growth of thin ice in autumn and winter.

BBC NEWSNIGHT ONBOARD

With media interest in climate change at an all-time high, we invited BBC Newsnight's science editor Susan Watts to participate in the ICE CHASER cruise.

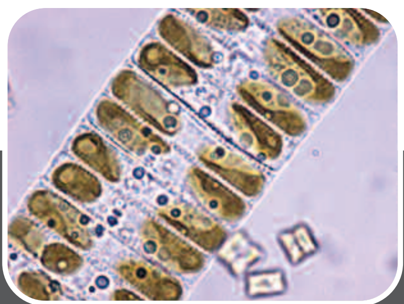
Two weeks prior to the expedition, the Newsnight crew visited SAMS to interview key scientists: Dr Ray Leakey, microbial ecologist and cruise leader; and Dr Jeremy Wilkinson, an expert in sea ice research. During the cruise, Ray along with microbiologist Dr Elanor Bell and biogeochemist Dr Henrik Stahl wrote regular journal entries for the BBC website. A BBC cameraman was onboard filming the ongoing science and Susan Watts joined the ship for the last three days in the Arctic. Coming onboard in Ny Alesund, Svalbard, she came to find out what the cruise had achieved.

'OUR' SHIP FOR FIVE WEEKS

The ship, the *RRS James Clark Ross*, is an outstanding polar research vessel operated by the British Antarctic Survey. She provides extensive lab facilities, freezers, water sampling devices and underwater imaging sonars capable of distinguishing fish from zooplankton and of mapping ancient glacial scours on the seafloor. In addition, she boasts very comfortable living quarters with steward-served meals, a (very small) gym, and satellite-based internet access (until we sailed north of latitude 80° and entered the satellite shadow).

THE PARTICIPANTS

The scientific party consisted of 17 researchers and students from SAMS and scientists from seven other institutions, giving this collaborative project a truly international feel with researchers from Norway, France, South Africa, Greece, England and of course Scotland, on board.



> Arctic phytoplankton will be affected when sea ice melts allowing light to penetrate earlier and deeper into the water than before. Being the bottom of the food chain changes in phytoplankton might affect the entire arctic ecosystem. (Photo: CCAP)

> Many arctic zooplankton species are characterised by a high lipid content. Should changes in phytoplankton cause different species of zooplankton to thrive, this will in turn affect the fish, birds and mammals that feed on these organisms, sometimes very selectively.

THE SCIENCE

The scientific programme aimed to generate a detailed picture of the arctic environment: what organisms are there? how well are they growing? how susceptible are they to changes in temperature or light intensity; and how much carbon are they storing – or releasing?

Joining the expedition from France, Dr Eric Fouilland and Emilie Le Floch were focusing on phytoplankton: This microscopic plant life grows in surface waters using the sun's energy to photosynthesise. The process absorbs carbon from the environment and turns it into biomass – the first step in the organic carbon cycle. By measuring phytoplankton biomass and primary production Eric and Emilie studied how much carbon and energy is available for all other organisms. They found that that an increase in water temperature may lead to a decrease in phytoplankton growth, a critical finding with regard to global warming.

The sea is teaming with viruses, bacteria and protozoans. These organisms carry out three critical roles: they infect, they degrade and they eat. Dr Elanor Bell was interested in all three processes because they lead to the rapid release of carbon back into the environment, stalling the transfer of carbon up the food web. By identifying and measuring microbial activity, her aim was to calculate how much carbon was being liberated at this early stage. She found an abundant and active bacterial community in the water column suggesting that considerable amounts of energy, carbon and nutrients are recycled by the microbial community rather than being transferred up the food web to larger organisms.

Zooplankton is the next step in the transfer of carbon and energy up the food web. In the Arctic, they are very effective at storing energy in the form of lipids, like little packets of butter. They are therefore a key link in the transfer of energy from microbial life to the more familiar whales, fish, polar bears and seals. Our Norwegian colleagues, Dr Stig Falk-Petersen and Anette Wold, - as well as providing armed polar bear guard whilst researchers were out on the ice - regularly collected zooplankton samples to study their distrubution and diel migration. They found healthy populations of large herbivorous zooplankton in deep waters at their study sites. These arctic species had stores of high energy lipids accumulated whilst feeding on phytoplankton earlier in the summer, and had entered winter "hibernation". This suggests that their food supply must have been active and abundant in a low-light environment underneath the sea ice earlier in the year. It also suggests that a substantial quantity of energy and carbon had been transferred up the food web to larger organisms during spring/early summer.

> The *James Clark Ross* was a comfortable home and excellent work space for our five-week-long research cruise.

> Taking sea ice samples for methane analysis needed skill, strength, warm clothing and an armed polar bear guard.

When organic debris reaches the sea floor, some is consumed and recycled by benthic microbes, worms, brittlestars and other organisms whilst some carbon is buried and locked away over geological timescales. Samples of intact marine sediment – often with invertebrates happily sitting on top – were brought up using a mega-corer. Some was incubated to investigate carbon flux in a near *in situ* system whilst other cores were sectioned and samples stored ready to be analysed back at the lab.

Dr Henrik Stahl was deploying marine landers (see Newsletter 33) to record gas fluxes within the top layer of seabed to better understand movement of carbon particles into, and gaseous compounds out of, the seafloor.

Meanwhile the gas of importance to Drs Mark Hart and Arlene Rowan was methane. They sampled sea ice, sediments in the water column, and even the gut contents of copepods, in the search for methanogenic microorganisms whose metabolisms may release this powerful greenhouse gas into the environment.

A month after the SAMS scientists left the ship, the *James Clark Ross* returned to Britain. Three scientists travelled down from Oban to the docks at Immingham to off-load the equipment and samples. Now safely in the lab, the arctic samples are being incubated and analysed, whilst results are collated and analysed. These will help inform the scientists as they design sampling protocols and experiments for the second ICE CHASER expedition to the Arctic in 2010. ●

You can still read about the expedition and its preliminary findings on the SAMS website at www.sams.ac.uk/arctic-cruise.

Scottish squid: developing a sustainable fishery

Jennifer M. Smith, University of Aberdeen (jennifer.smith@abdn.ac.uk)

With the present state of decline that surrounds most of the world's finfish fisheries, cephalopod fisheries have almost exclusively experienced a rise in landings worldwide during the past few decades. These fisheries are becoming an increasingly important economic resource as commercial fishers shift towards available catch as a supply of income. In spite of this, many of the world's cephalopod fisheries, including those in UK, operate without regulation or management schemes.

Cephalopods have numerous biological characteristics that make them particularly vulnerable to fishing and environmental changes. Most experience a short lifespan, with the fishery consisting entirely of new recruits each year. Stock abundance fluctuates annually, and cephalopod abundance is thought to be highly susceptible to environmental conditions such as sea temperature and currents during the recruitment phase of their life cycle. Knowledge of cephalopod maturation and growth processes is necessary to understand the fishery dynamics, to ensure sustainable resource use and to prevent stock collapse due to inappropriate fishing methods.

LOLIGO FORBESI – A STOCK AT RISK?

The veined squid *Loligo forbesi* is a commercially important species occurring in the northeast Atlantic and present in Scottish waters, including the Moray Firth and the Firth of Forth. Research has shown that *L. forbesi* has a one year life cycle with spawning typically occurring from January to March and recruitment taking place in autumn. However, landings trends in the Moray Firth over the last five years have been variable with record landings in 2005 and the fishery's failure to materialise in 2006, suggesting that seasonal shifts in life-cycle events, habitat preferences, or reactive over-fishing have occurred.

My research gathers the baseline data needed to establish a foundation for rational and sustainable management of *L. forbesi* stocks in Scottish waters. Of particular importance is the identification of those factors responsible for determining the timing of recruitment, maturation and breeding. To that effect I have been studying the relationship between somatic and reproductive growth in *L. forbesi* at different stages caught in Scottish waters. I am also investigating how to use the knowledge of Moray Firth fishers as a management tool, with the aim of combining accounts of spawning ground locations, catch and effort details and socio-economic information to augment scientific data. This could provide the basis for a successful management regime in this niche-market fishery.

> In the UK the cephalopod fishery operates without regulation or management schemes.

> Cephalopod landings have been rising worldwide against a trend of falling catches in many finfish fisheries.

SOMATIC AND REPRODUCTIVE GROWTH

Despite previous studies on the life history of *L. forbesi*, the various internal and external factors determining growth and maturation are not well understood. I have been using generalised additive models to evaluate the effects of multiple explanatory variables without having to assume linear relationships. Results show that, once the effect of body size is removed, gonad weight in both sexes is affected by month and digestive gland weight. This suggests a seasonal triggering of maturation and that the energy for gonad growth is derived from food.

I also found a negative relationship between somatic and ovary growth in females, which might indicate remobilisation of somatic tissue to grow the ovary. In males, relationships between variables tend to be more complex, probably because two or more growth patterns lead to different sizes at maturity. My results confirmed that males start to mature 1-2 months earlier than females, which suggests that a sex-dependent internal facture is implicated.

THE MORAY FIRTH FISHERY

Fieldwork - which was in part supported by a SAMS bursary - involved the use of structured interviews to collect information from fishers in the Moray Firth that have actively participated in the directed squid fishery. Most fishers had used vessels under 10 m and fished from sunrise to sunset approximately 2 nm off the coast of the southern Moray Firth, from Burghead to Buckie. They identified seasonal migratory patterns for *L. forbesi*, and suggested that the fishery consists of two breeding cohorts, which agrees with evidence from the growth relationship analyses. In the opinion of fishers the decline in landings during the 2006 season was due to early and heavy fishing by large vessels which removed animals from the fishery before they were to size, damage of spawning grounds by hopper trawls, changes in water current and temperature, and changes in availability of cephalopod food sources. The fishers expressed a preference for the following management strategies: limits on catches of new recruits (90%); on-board monitoring or observing (90%); restricted entry (80%); and protecting spawning grounds (70%). Quotas (35%) and early closure options (20%) found little support of the fishers.

REMAINING QUESTIONS

Further research for my PhD will continue growth and maturation analyses in *L. forbesi* throughout its range, as well as an investigation of environmental parameters affecting both the seasonal and local abundance of *L. forbesi* stocks in Scottish waters. Assessment of the population, detailed mapping of suspected spawning grounds and the determination of seasonal migratory patters is currently under investigation. I hope that the continued dialog between directed fishers, scientists and fishery officers can lead to the effective management and sustainability of this marine resource. ●

Acknowledgements
I would like to extend my appreciation to my supervisors, Drs. Graham J. Pierce and Ioannis Theodossiou, as well as to the fishers of the Moray Firth and employees of the Scottish Fisheries Protection Agency (SFPA) for their invaluable knowledge throughout this project.

Scottish Marine Group:
Winner of the 2008 SAMS prize for the best postgraduate presentation

A simple method for the routine monitoring of primary production

Elisa Capuzzo, Napier University (E.Capuzzo@napier.ac.uk)

Carlingford Lough, the most southerly of Northern Ireland's sea loughs, is characterised by sheltered conditions and restricted water exchange. However, a wide range of human activities associated with urbanisation and land use influence this coastal water body. The Lough is also used for the cultivation of bivalve molluscs and in recent years there has been a major expansion of this industry. In particular, the annual production of mussels and Pacific oysters cultivated in Northern Ireland has risen to around 28,000 tons and 603 tons respectively. The total production for the sector is valued at ca £8 million per annum (Ferreira *et al.*, 2007).

From an ecological point of view, we are concerned about the introduction of anthropogenic nutrients to coastal water bodies. Inputs of nitrogen and phosphorus can stimulate primary production and can lead to eutrophication. As a requirement of the EU Water Framework Directive, waters have to be monitored to assess water body quality status. In addition, sustainable bivalve cultivation is dependent on good water quality and a balance between stocking density and an adequate supply of food.

As the main primary producers in marine waters, phytoplankton is the base of the marine food web and influences the abundance of most marine organisms. Estimates of phytoplankton primary production can be a useful measure of ecosystem vigour to support the assessment of coastal eutrophication (Tett *et al.* 2007). Primary production is also a key element when quantifying the carrying capacity for shellfish cultivation.

Traditional methods of estimating production are, however, time consuming, require specialist training and equipment, and are generally inappropriate for routine monitoring programmes. The current project aims to develop a simple and robust methodology for the routine estimation of primary production in Carlingford Lough. The methodology uses models to estimate production, based on equations relating primary production and environmental variables. The data used to create these equations were derived from samples collected from April 2006 until March 2008 in close proximity to a permanent instrumented mooring which provides continuous temperature and salinity data.

> Elisa is developing a simple and robust model for the routine estimation of primary productivity from variables that are easier to obtain than primary productivity measurements

During every sampling trip, we measured temperature and salinity profiles, nutrient and chlorophyll concentrations, phytoplankton composition and profiles of submarine irradiance. Primary production was estimated using a standard 14C technique, incubating water samples for 2 hours in a light gradient incubator. This technique adopts the radioisotope as a tracer to estimate the phytoplankton carbon assimilation rate during photosynthesis. Underwater light measurements and chlorophyll concentration were used together with photosynthesis data to calculate daily column production. Environmental variables influencing primary production were identified and their relationships quantified. Finally, annual production was calculated using a simple numerical model which also used the relationships between primary production and environmental variables to improve the estimates of annual production.

The water column was generally vertically well mixed. Nutrients showed the typical seasonal pattern with a winter maximum and spring-summer minimum. Considering phytoplankton composition, diatoms were the dominant group, both in terms of abundance and biomass, with a main peak in spring and a smaller one at the end of the summer.

Daily primary production ranged between 4 mgC m^{-2} d^{-1} and 1900 mgC m^{-2} d^{-1} showing variability during the year.

> The developed method is a useful tool for routine monitoring programmes that are an important component in managing waters like Carlingford Lough

A relationship between chlorophyll standing stock, ammonium concentration and irradiance explains 91% of the primary production variability. The estimate of annual production derived from the model was 155 gC m^{-2} y^{-1} with 95% confidence limits at 108 and 223. Adding the relationship between primary production and environmental variables to the model, the estimated annual production was 151 gC m^{-2} y^{-1}, with a reduction of the 95% confidence limits to 120 and 193.

This simple model and the relationships between primary production and environmental variables can be a useful tool to obtain reliable estimates of annual production from routine monitoring for use in the management of Carlingford Lough. ●

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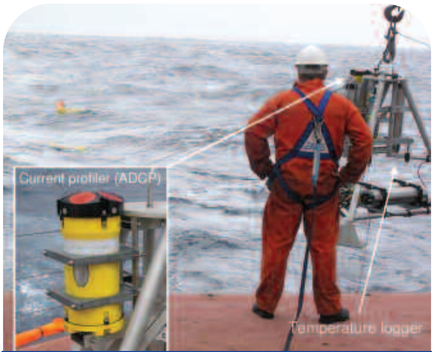
Acknowledgements
I would like to thank my supervisors: Dr Linda Gilpin and Professor Paul Tett from Napier University, and Dr Richard Gowen from the Agri-Food and Biosciences Institute. I would like also to acknowledge the Northern Ireland Lough Agency and all the staff in AFBI.

Stirrings in the Deep

A tidal bore on the flanks of the Mid-Atlantic Ridge

Dr Andrew Dale, SAMS (Andrew.Dale@sams.ac.uk)

Running north-south for the length of the Atlantic, the Mid-Atlantic Ridge is a complex and fractured rise marking the plate boundary from which the ocean floor is spreading. The ECOMAR (Ecology of the Mid-Atlantic Ridge) project seeks to understand how this feature affects the physics, chemistry, biology and ultimately the deep-sea communities of the North Atlantic. The first ECOMAR cruise, one of the first cruises of the new *RRS James Cook*, threw up some intriguing observations of tidal behaviour on the flanks of the ridge. SAMS physicists are investigating!



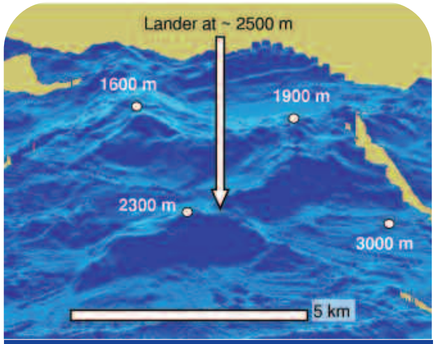
> During an ECOMAR cruise the Oceanlab lander was deployed on the eastern flanks of the Mid-Atlantic Ridge at 2500m with SAMS instrumentation mounted to measure its physical environments.

In contrast to the turbulent, energetic ocean surface, the deep ocean is often seen as a sluggish place, far removed from the heating, cooling and winds that drive ocean circulation. Nevertheless, the flows that occur far beneath the ocean surface, and in particular the more intense flows that have the potential to mix and stir water properties, have a profound influence on global ocean circulation. Without deep mixing drawing heat down from above, the oceans would gradually fill from the bottom with dense water from polar regions. Circulation and heating would be restricted to a shallow surface layer and the capacity of the ocean to buffer the climate system by absorbing heat would be drastically reduced. To understand ocean circulation, we need to understand how and where mixing takes place, and deep-ocean mixing is particularly important and difficult to observe.

During the ECOMAR cruise, a baited camera lander from the University of Aberdeen's Oceanlab was repeatedly deployed to study benthic fish. SAMS instrumentation piggy-backed on the lander to measure its physical environment. In its first deployment, the lander spent a day on the seabed on the eastern flanks of the Mid-Atlantic Ridge at a depth of 2500 m. The temperature records from this deployment held a surprise: Temperature would rise steadily during each 12 hour tidal cycle and then suddenly crash, taking less than a minute to return to the level it had been at 12 hours previously. Measurements of currents revealed that a wall of cool, dense water was pulsed past the lander on each tidal cycle as a tidal bore: something like the Severn Bore of the deep ocean.

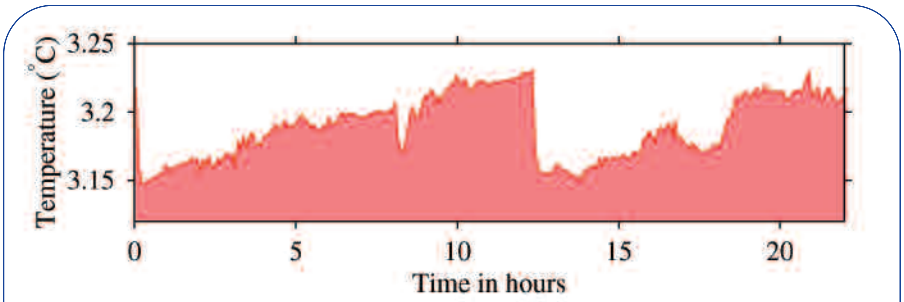
Multibeam sonar allowed a closer look at the topography surrounding the lander site, providing clues as to what was going on. The site was a saddle point – the low point of a ridge separating two bumps. The scale of these features was rather familiar, with their size and gradients being similar to those of a Scottish mountain submerged with its summit a mile beneath the surface. On each tidal cycle, a slug of dense water was pushed up the steep eastern flanks of the ridge and squeezed through the saddle, presumably to trickle down the shallower slope to the west.

So what is the connection with mixing? The temperature drop as the bore rolled past the lander was an unspectacular tenth of a degree or less, but in the context of the deep ocean this is large. You'd have to move a couple of hundred metres vertically



> A 3D visualisation of the bottom topography surrounding the lander site shows it is a saddle point, where dense water can be pushed up the eastern flank during each tidal cycle.

to see a temperature change of that size, but here it was squeezed into a few metres horizontally. So, the constriction of the tide through this saddle had sharpened gradients, and any turbulence generated there would have an impact on a par with mixing a column of water hundreds of metres high. It has long been suspected that areas of complex topography are the main sites for deep mixing, but the mechanisms involved and the split between tidal and non-tidal processes are still in doubt. Surprisingly, the amount of energy lost by tides in the ocean can be accurately determined: not by observing the ocean, but by measuring gradual changes in the Moon's orbit as it spirals ever closer to the Earth due to energy dissipation by the tide. Not all of this energy is used for mixing, however. Some processes are more efficient mixers than others, so we really need to know what is going on down there, and ECOMAR is on the case. ●



> The temperature at the site displayed a steady rise for 12 hours followed by a drop to its starting temperature within a minute.

Bridging the gap from modelling to observation in the ocean by means of naturally occurring radionuclides

Dr Walter Geibert, SAMS & the University of Edinburgh (Walter.Geibert@sams.ac.uk)

> A CTD with 24 bottles is ready for deployment to sample ^{227}Ac in the Weddell Gyre. Due to the minute concentrations of actinium, about 50 L of sea water are required for a single analysis.

To this date, approximately one half of the anthropogenic emissions of carbon dioxide have been taken up by the oceans. This may cause concern about ocean acidification, but fears are probably even greater that the uptake of carbon dioxide by the ocean might be slowing down. If this was the case, atmospheric levels of CO_2 would rise increasingly, giving our society even less time to adapt to climate change than current models assume. Our strategies to adapt to global change strongly rely on the capability of Earth system models to predict future conditions. But how can we be sure that the models do a good job?

Considerable progress has been made in the predictive capabilities of models, narrowing the range of uncertainties. Part of the improvement is due to the impressive computational power that is now available to solve the relevant equations. However, the processes that are expressed in a model's equations remain to be identified by other means, and models have to be validated by measurements. Ideally, modelling and observations go hand in hand. Models can help to identify promising sampling locations, and observations that deviate from current models can be used to improve our understanding of the Earth system.

There is, however, often a fundamental gap between the type of information that marine records can provide, and the type of input that models require. Biologists, chemists and geologists studying aspects of the ocean will often find qualitative connections between compartments of the system, like a geologist stating that there is more dust deposition in periods of higher wind speeds. The modeller, trying to convert this information into a model scenario, will need to know what "more" means, when expressed in figures. Modellers need a quantitative description of the process.

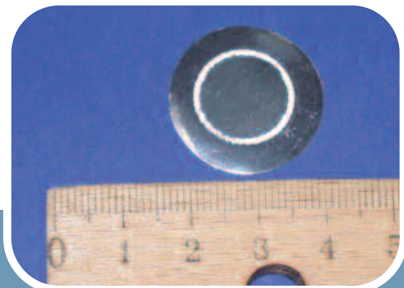
The step from qualitative findings to quantitative information, or from concentrations to fluxes, depends mostly on the availability of accurate information on timing. Such information can often be gained from naturally occurring radioisotopes: Uranium and thorium are naturally occurring radioisotopes, which turn into a series of shorter-lived decay products including rare elements like protactinium, actinium, radon and radium, before eventually turning into stable lead. These elements all differ in their chemical response to environmental conditions. Thus, transport processes of individual elements become naturally labelled with the half-life of the radioisotopes.

To give an example, we can follow the fate of the relatively rare uranium variety with mass 235 (^{235}U) in the marine system. Under open ocean conditions, uranium is stably dissolved in sea water. Its distribution in the ocean is nearly uniform, varying slightly with salinity. However, a fraction of ^{235}U decays to the isotope protactinium-231 (^{231}Pa). This radioactive element with a half-life of 32,760 years tends to stick to particles. It is continuously removed from sea water by sinking debris, and the disequilibrium of ^{231}Pa and ^{235}U in the ocean can be used to constrain particle flux. As the mean residence time of ^{231}Pa in sea water is in the order of 200 years, the distribution of ^{231}Pa is also affected by ocean circulation. Therefore, modellers use this isotope for constraints on particle flux and circulation scenarios.

^{231}Pa flux to the sediment is greater where the ocean is deeper, simply because the inventory of uranium in the overlying water column is larger. This means that highest ^{231}Pa concentrations are found in deep-sea sediments. ^{231}Pa decays to actinium-227 (^{227}Ac). In contrast to ^{231}Pa, this element is again soluble in sea water, and therefore released from the sediment to the overlying sea water. Due to its comparably short half life of 21.77 years, it can never build up to substantial amounts in the ocean. Actually, the whole ocean contains just in the order of 10 kg ^{227}Ac. Yet, its distribution can give valuable information about vertical mixing. Being released almost exclusively from the deep-sea floor, its presence in shallower waters can be ascribed to vertical transport of water. The specific half-life of actinium can then be converted into mixing coefficients, which are of crucial importance for global circulation models.

The exploitation of ^{227}Ac as a tracer is just at the beginning, and the measurement is still challenging, but SAMS has the required facilities for a successful measurement of ^{227}Ac. Samples were taken on board *RV Marion Dufresne* south of Africa, in a co-operation with Spanish, French, and German researchers. A comprehensive dataset of ^{227}Ac from the ocean would be an excellent tool for the validation of global circulation models, in particular in polar regions. This is one example that illustrates how the distribution of naturally occurring radionuclides can be used to construct a bridge from models to observations ●

> Sample processing: Potassium permanganate is added to sea water samples as a first step towards isolating actinium. (Photo: C. Hanfland)



> An actinium sample, electroplated onto a silver disc, is ready for measurement in the alpha-spectrometer. (Photo: C. Hanfland)

Graham Shimmield: some memories

Collated by Helen McNeill, SAMS (Helen.McNeill@sams.ac.uk)

Professor Graham Shimmield was director of SAMS from 1996 until 2008. Under his leadership SAMS doubled its staff base, built up new research areas such as geochemistry (his own discipline), Arctic studies, biotechnology and marine policy, created its first undergraduate degree course, diversified and increased its income base, and created a light-filled, spacious, well-equipped new laboratory building. In 2008 he took up a new position as executive director of the Bigelow Laboratory for Ocean Sciences in the United States.

LINDA ROBB, marine ecologist & trade union representative

Graham arrived at SAMS with enthusiasm and charisma to lead a rather disenchanted staff of 66 who had been reviewed to death and suffered the trauma of losing colleagues in two redundancy rounds. He was still Director designate when NERC announced yet another downsizing event requiring 20-odd people to lose their jobs in the Centre for Coastal and Marine Sciences (CCMS) which included Dunstaffnage. After 18 months of negotiations, it transpired that our corner had been well and truly defended and no-one here would lose their job but Graham had little time to congratulate himself before the next blow struck. When the Director of CCMS resigned, Graham inherited the task of having to break the news to those on the redundancy list in other CCMS laboratories. He did this with compassion, but inside sources say this was at a huge emotional cost to himself. There must have been times when he wondered what he had done to deserve this directorship.

With staff numbers at Dunstaffnage critically low and a building which was nearing the end of its useful life, Graham set out to take on the rest of the world with vision and vigour. There were times when the goals he aimed at seemed unbelievably risky and a bit scary but one by one they were all attained: a multi-million pound new building, a growing marine science degree course, new staff bringing our number up to 140 and much, much more. As a trade union representative, I consider myself privileged to have had regular meetings with Graham in both dark days and times of celebration and to know that one of his main priorities was to ensure he never had to repeat the heartbreaking task of making people redundant.

All good things must come to an end and Bigelow stole our man. Graham was preceded and will be succeeded by other good leaders but he will go down in SAMS' history as the director who took us from nothing to something in 12 difficult years.

FINLO COTTIER, lecturer in polar oceanography

Graham was always a great vanguard for SAMS being involved in Arctic research. He was cruise leader on SAMS' first two Arctic research cruises to Svalbard and the Fram Strait. During the first cruise he managed to 'lose' a lander in 1400m of water of the west coast of Spitsbergen - then spending 24 hours with the ship dragging and trawling away at the seabed: No luck. The lander eventually turned up four years later off the coast of Greenland!

His final cruise whilst at SAMS was also to the Arctic, in August 2007 on board Jan Mayen to recover SAMS' moorings around the Svalbard coast. Graham's finest hour as a professor in geochemistry came when he set to with a toilet brush to clean out the sediment traps. To cap off that cruise, he took the plunge and swam briefly in the Arctic Ocean…

ALISON DAWSON, PA assistant to the Director

Ever tried to hire a skidoo in Svalbard? Only possible if you hire a rifle to take with it! Apparently something to do with polar bears, and just one of the snippets of information you glean when arranging Graham Shimmield's travel.

Graham's many and convoluted journeys were quite a challenge, complicated by the fact that he tried to fit as much as he could into the shortest possible time span: Start from SAMS, hit a meeting in St Andrews in the afternoon, a dinner in Aberdeen in the evening, meeting in Aberdeen the next morning, flight from Inverness to London in the afternoon, meeting in London the following day, flight back to Glasgow in the evening. So he arrives at Glasgow Airport in the evening, but his car is at Inverness. Rethink. Drive to Edinburgh and leave car in car park. Hire car to St Andrews, Aberdeen and return at Inverness Airport. Flight back to Edinburgh instead of Glasgow. Pick up car and drive home. Then you start on the hotel reservations! How he ever knew where he was when he woke up I'll never know! I lived in fear of him arriving at some remote airport on the wrong day for a meeting which had happened the week before, or coming in to Edinburgh when his car was in Glasgow. A minefield of possible screw-ups! I can only commend his energy – just thinking about it exhausted me!

CHARLIE WILSON, former undergraduate student

I feel I owe a great deal to Professor Graham Shimmield for two reasons: the first is his unwavering support of the marine science degree, even when student numbers were falling and pressure was increasing from other stakeholders to compromise the quality of the programme. Graham's involvement in the lectures themselves was invaluable, and his input during the final year palaeoceanography module was really informative and enjoyable. The ongoing success and high quality of the UHI Millennium Institute's Marine Science degree on its own provides an excellent testimony regarding Professor Shimmield's tenure as Director of SAMS.

My second reason for gratitude to Graham is that he intervened to allow me as an undergraduate to take part in a SAMS research cruise to the Arctic in 2005, an experience which led to a summer internship at a major Norwegian oil company.

During the cruise I had the opportunity to get to know Graham. I was struck not only by his drive and determination, but also by his patience and forbearance when confronted by offensively loud heavy-metal blaring constantly through the science bridge. His tendency to spend long hours in the ship's sauna was completely understandable under the circumstances…

GARETH LAW, PhD student

Graham's work-load was always full. However, he somehow always found time to discuss new findings over a seemingly endless supply of Jaffa cakes. Given Graham's wide knowledge of marine geochemistry, this time proved invaluable.

ANUSCHKA MILLER, activities manager

Being line-managed by Graham wasn't always easy as one could not really impress him or shine – and many of us tried to our peril. He was so strong and could work such unbelievably long hours without losing concentration, competence or professional judgement that I sometimes thought he must have an identical twin sharing the job… His commitment was quite infectious though, and I could never bring myself to telling him when I was at the end of my tether.

There always remained some distance with Graham, there was very little chit-chat, and I never sussed out whether he is shy and private as a person, or had become a director through and through, or a bit of both. He didn't much share his worries or problems beyond a deep sigh, and we felt pretty much safe in our jobs and futures. He was kind of a benign patriarch, who commanded a lot of respect, trust and confidence from the vast majority of his staff for pretty much the entire time of his tenure.

He wasn't precious about what he did either. I shall never forget the opening ceremony for the new building in 2004 which was conducted by the Princess Royal. While we were nervously waiting, Graham spotted some dust in the foyer. With just a few minutes left he scuttled off, found himself a Hoover, and - in his very best suit - demonstrated just how house-proud he was to an amazed staff audience who were sitting at their computers to follow the ceremony over a webcam.

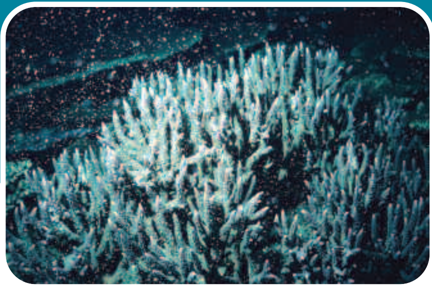
TIM BRAND, support scientist in geochemistry

I worked with Graham in his early days as a 'new blood' lecturer at Edinburgh University. When he started the lectureship he was, I think, the youngest lecturer in Britain and during this time he expanded the Marine Geoscience group that had been run by his PhD supervisor, Dr Brian Price. Graham always had his eye on developing new scientific collaborations and expanding his field of interest, traits that would see him go on to push SAMS into the limelight.

More importantly perhaps, he did have an enormous sense of commitment to his staff. He went to great lengths to keep me on a succession of fixed term research contracts whilst at Edinburgh and enabled SAMS to more than double in size during his tenure.

Coral 'orgies' fuel algal blooms

Dr Daniel Sinclair, SAMS (Dan.Sinclair@sams.ac.uk)



> A colony of *Acropora* corals casts its eggs into the mêlée during mass spawning on the Great Barrier Reef. (Image courtesy of the Great Barrier Reef Marine Park Authority)

A "cnidarian orgy" is how Elizabeth Pennisi, reporter for the journal Science, describes coral mass spawning. While many scientists scramble to unlock the biology of this reproductive exuberance, researchers like Professor Ronnie Glud use the natural fertilisation event to study element cycling in an otherwise extremely oligotrophic tropical environment.

In 2005, Ronnie Glud and a team of biologists, microbiologists and chemists visited Australia's Great Barrier Reef on the few nights of the year when it all happens: In mid October, synchronised by the light of the full moon, countless billions of scleractinian corals release eggs and sperm in a truly massive spawning feast ... and the scientists were waiting.

They were interested in the impacts such an enormous event has on the nutrient chemistry of the reef waters. "Chock-full of nitrogen and phosphorus, the gametes fuel a bloom of microalgae which then nourishes other parts of the ecosystem, including fish and bacteria" says Professor Glud, who with his colleagues published the research in a series of papers in 2008.

As if inspired by the ardent mood of the corals' reproductive excess, other levels of the ecosystem displayed an ebullient response to the massive nutrient input. Immediately following spawning, sediment and water column primary productivity increased manifold, which in turn inspired a frenzy of grazing by macrozoans. After five frenetic days, the party was over, with photosynthesis returning to pre-spawning levels. Particulate organic levels remained elevated for up to two weeks.

The results demonstrate the profound effect coral mass spawning has on the entire reef community. The most surprising result, however, was the efficiency with which the reef system recycled the injected nutrients. Interestingly, it seems to be the microbes living in sandy reef sediments which play the key role in this efficient nutrient processing: "Much of the sand is permeable, so it acts as a biocatalytic filter", explains Ronnie Glud.

This reef-sand filter system may play an important role in the health of the reef. By efficiently processing nutrient spikes, the sands/microbes allow the reef to handle eutrophication peaks. However, benthic algal overgrowth – a problem in many of the world's reefs – may compromise this function if eutrophication persists. This would leave the reef system defenseless against large nutrient exposures, which are becoming ever more prevalent as humans affect the reefs and the adjacent land.

> Professor Ronnie Glud inspects the slick of gametes that colours the shoreline red in the days following mass coral spawning.

> Special chambers embedded in the sediments measure nutrient fluxes from the Great Barrier Reef sands.