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OceanExplorer

Newsletter of the Scottish Association for Marine Science

ISSUE 35 SUMMER 2010

Probing the Arctic

Disappearing sea ice may reduce carbon dioxide uptake by the oceans

WHALES OF OLD

Tracing the evolution of whales through their teeth

RENEWABLE ENERGY

Will marine renewable energy have environmental costs?

MARINE MANAGEMENT

Will an 'Ecosystem Approach' to management improve the health of Europe's seas?

Front cover **During the ICE CHASER I expedition, SAMS' Dr Keith Jackson is testing the solidity of the sea ice before the research team begins work.**

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Funders

Our main partners

ABOUT US

SAMS is a Company Limited by Guarantee registered in Scotland (SC009292) and a registered Scottish charity (009206). It is a Learned Society with 450 members and employs 143 staff at the Scottish Marine Institute near Oban.

SAMS administers its commercial services through a wholly owned commercial subsidiary company, SAMS Research Services Limited (SRSL).

SAMS also hosts The European Centre for Marine Biotechnology. ECMB is a business incubator for new marine biotechnology companies and currently hosts two tenants: Aquapharm Biodiscovery Ltd and GlycoMar Ltd.

SAMS is a collaborative centre of the UK's Natural Environment Research Council www.nerc.ac.uk and an academic partner of the UHI Millennium Institute www.uhi.ac.uk

GOVERNANCE STRUCTURE

SAMS is ruled by its members, who elect office bearers at the Annual General Meeting. SAMS Council, chaired by the SAMS President, has responsibility for strategy, risk management and appointment and performance of executive management. Council is supported by a Board and five committees. Council members are the non-executive directors of the company.

The director of SAMS is responsible for the effective management of the organization and is supported by an executive group. Research and teaching staff are managed within five departments: Ecology; Microbial and Molecular Biology; Biogeochemistry and Earth Sciences; Physics Sea Ice and Technology; and Education.

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Professor Laurence Mee Director

FACING THE FUTURE

Resilience is more than just an important concept in ecological and social systems: it enables life to adapt and prosper. It is the ability to absorb disturbances, to be changed and then to re-organise and still have the same identity. Resilience is also the property that has kept SAMS at the forefront of Scottish marine science for 125 years. As I leaf through over 100 years of annual reports on my office shelf, I am amazed at the determination and ingenuity of many generations of staff who enabled the organisation to survive financial hardship, new technology, growth spurts, two wars and two major uprootings. In none of these periods however, has SAMS been faced with the pace of change that we are facing today.

Let's give this some context. Since the dawn of history, the sea has been a place of peril and opportunity. It has supported ever expanding fishing, aquaculture, transport, mineral extraction and leisure; and rid us of waste. Just as we are beginning to appreciate the scale of our footprint on the seas, a new user has emerged: the offshore renewables industry. Management of all of these interests has been – to say the least – ad hoc and there is plenty of evidence of its consequence: inexorable environmental degradation. To make matters worse the climate is changing, further moving the goalposts for setting conservation objectives. In the past year, we have seen a remarkable cascade of new legislation that seeks to promote planning at multiple scales: The European Marine Strategy Framework Directive, the UK Marine and Coastal Access Act and the Scottish Marine Act. Implementing them and observing change in the marine environment (including social change) will require the best available science and the combined efforts of the marine science community. That is why we now have a high level UK Marine Science Coordinating Committee (I am one of its three non-Executive members) and a UK Marine Science Strategy. Scotland in particular has taken on a massive responsibility because of devolution of stewardship of some 63% of the UK's offshore waters: an area on our doorstep where scientific knowledge is far from complete.

Suddenly a revolution is happening in the way we join up knowledge to management of the sea. Music to the ears of many marine scientists? Not quite, because it is all happening in one of the worst economic recessions in history. Not only do we have to find solutions fast, but they must be smart, innovative and cost effective. And that is where SAMS' experience, innovation and ability to adapt play a role. Over the past twelve months we have restructured SAMS to become a more proactive participant in the quest for sustainable use and conservation of the sea. We have renamed the Dunstaffnage Marine Laboratory as "The Scottish Marine Institute", a name that goes all the way back to our roots when we were the pioneering Scottish Marine Station. Our work in research, business development and education has been boosted by continued success in competitive funding bids, the development of a new Highlands and Islands Enterprise Marine Science Park and the ongoing construction of a £6M education and outreach centre. Built in partnership with the UHI Millennium Institute, the education centre will also host the Graduate School of the Marine Alliance for Science and Technology Scotland (MASTS). The outreach centre will be the focus of Learned Society activities such as the SAMS Festival of the Sea this year.

The biggest change to SAMS' activities has been to focus our research into five problem-oriented areas where we have proven excellence: Arctic Research, Marine Processes in Climate, Marine Renewable Energy, Prosperity from Ecosystems, and Industrial Impacts on Oceans. These themes, together with our wider activities, will contribute the best science for today's challenges and maintain our resilience. This Newsletter will inform you about some of the exciting research taking place in these areas. We are keen to work with our members and welcome your feedback; together we will build a 21st century Learned Society that Scotland can be truly proud of.

EDITORIAL

Dear Reader

Welcome to the Ocean Explorer, our significantly updated SAMS Newsletter! And welcome to my new co-editor, Laila Sadler, (left in photo) who has done most of the editing in this issue.

One role of a learned society like SAMS is to raise the profile of marine science. With most of our research funded by the tax payer, a spending review in progress, and a public mood critical of the integrity of scientists, it is more important than ever that we make every effort to explain our work to the public, and to share our excitement about the marine environment with them.

At SAMS we are developing two major new initiatives to raise the profile of our profession: This May we launched Oban's Festival of the Sea with 50 events that celebrated the marine environment. We hope to make this an annual event. Visit www.marinesciencefestival.com if you are curious to find out more.

Another initiative to raise the profile of marine science is the development of a marine science visitor and outreach facility at SAMS called the Scottish Ocean Explorer Centre. Not all funding is in place yet, but we are hoping to open this 200m^2 facility in about 12 months' time. The Scottish Ocean Explorer Centre will include displays about the marine environment and marine research, a small cinema space, a marine technology garden, and a multipurpose space for workshops, travelling exhibitions and events.

Both the Festival of the Sea and the Scottish Ocean Explorer Centre are part of your learned society, and if any member wants to contribute to either, I would love to hear from you.

I really hope that you enjoy this issue. While the content of the articles in this publication has always been exciting, we hope that the new design makes them also look exciting so that they become more accessible to more people. Let me know whether it works for you.

Dr Anuschka Miller Editor

anuschka.miller@sams.ac.uk

AUV comes to SAMS

During summer and autumn of 2009, the new SAMS Autonomous Underwater Vehicle (AUV), a Hydroid REMUS vehicle rated to operate at depths down to 600 metres, was tested in the local waters of Loch Linnhe and Ardmucknish Bay.

The AUV, named 'Selkie' after a mythological Celtic creature, was specifically designed to measure ocean turbulence concurrently with water temperature, salinity, and velocity, as if travels through the water. It has already made unique observations of turbulence beneath freshwater bores during these tests.

The SAMS Physics group is taking 'Selkie' to the Svalbard region this summer to take part in sampling during the Oceans2025 Arctic ICE CHASER II cruise, and will be sampling in the Firth of Lorn in September as part of a study of eddies created by the tidal flow through the Gulf of Corryvreckan.

NEWS

MAJOR NEW EDUCATION FACILITIES FOR SAMS

The European Regional Development Fund, the Scottish Funding Council and Highlands and Islands Enterprise have awarded £6M to SAMS to create a dedicated modern teaching facility. This will allow SAMS as an academic partner of UHI to expand its teaching provision and to offer Masters programmes and professional development courses. The facility will include a visitor and outreach area. SAMS has purchased and is significantly extending an adjacent building previously occupied by Argyll College.

The new facility will be completed by the end of October 2010.

SAMS IN ARCTIC GOVERNANCE CONFERENCE

In February, SAMS was invited to participate in an Arctic Governance conference at Wilton Park in Sussex. It was organised in partnership with the Norwegian Ministry of Foreign Affairs and the Government of Canada. The themes of the conference included geopolitics, governance, climate, energy, shipping and fisheries with speakers being drawn from the political area, industry and academia.

SAMS' Dr Finlo Cottier, Lecturer in Polar Oceanography and Head of the Physics, Sea Ice and Technology Department, led a discussion group on identifying priorities for science in the Arctic. The event was both an opportunity to promote SAMS' leadership in UK Arctic science and to contribute to wide-ranging discussions on how Arctic and non-Arctic nations view the opportunities and challenges of environmental change.

Further information

The Wilton Park conference centre specialises in international affairs and is part of the British Foreign and Commonwealth Office.

FORMING THE SCOTTISH MARINE PLAN

What are the social and economic challenges facing marine governance? How do marine plans incorporate social concerns, economic challenges and structure indicator systems? How do we revolutionise 'stakeholders' into 'contributors' and change the dynamics of coastal conflicts?

Ruth Brennan, Tavis Potts and Laurence Mee from SAMS have recently published a report for Marine Scotland on establishing Social and Economic Objectives for marine planning. The report details international, EU and Scottish policy drivers for marine governance, with a focus on the social, economic, cultural and governance dimensions. It is a timely report that takes on board a critical but often unexplored issue: how to place people and communities at the heart of the marine planning process.

Further information

The report, Social and Economic Objectives for a Scottish Marine Plan, is downloadable from the Marine Scotland website: www.scotland.gov.uk/Publications/2010/03/30180908/0

SAMS LED PROJECT IN THE TOP 100 SCIENCE STORIES OF THE YEAR

US-based DISCOVER Magazine voted a SAMS-led research project as one of the top 100 science stories of the year 2008. An international consortium of researchers (see right), led by SAMS scientist Dr Frithjof C. Küpper, had recently unravelled the biological significance and chemical speciation of iodine accumulated in kelp. These large brown algae accumulate high levels of iodide, which serves as an inorganic antioxidant, detoxifying reactive oxygen species at the algal tissue surface. Upon exposure to ozone (a major atmospheric oxidant) at low tide, high levels of molecular iodine are released which, after a series of secondary reactions, lead to the formation of cloud condensation nuclei. This work constitutes the first description of an inorganic antioxidant from a living system, with implications for atmospheric processes.

Further information

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Collaborating institutions
European Molecular Biology Laboratory, Radboud University Nijmegen, CNRS – Station Biologique de Roscoff, University of California Santa Barbara, University of Konstanz, University of Delaware, University of York, Paul Scherrer Institute, University of Manchester.

The kelp *Laminaria digitata*: When ground-level ozone reacts with iodide at the seaweed surface, the resulting high levels of molecular iodine emissions can easily be smelled.

INTERNATIONAL ALGAL MEETING

Despite harsh winter conditions in early January, 96 delegates arrived at SAMS for the 58th Winter Meeting of the British Phycological Society.

Hosted by Dr John Day and Christine Campbell, curators of the SAMS based Culture Collection of Algae and Protozoa, the meeting covered a wide range of topics including both microalgae and macroalgae, and applied and blue skies science. There were special sessions on "Productivity and photophysiology" and "Host pathogen interactions". The meeting was a resounding success, with a stimulating mix of exciting science and valuable networking.

A GREAT RACE

Dr Andy Dale of SAMS has been awarded £390,000 by the Natural Environment Research Council to study eddies and ocean mixing.

His research will investigate the Great Race, the plume of water that is ejected westward on each flood tide from Argyll's Gulf of Corryvreckan. The Race extends for up to ten kilometres into open water, spawning eddies on its flanks and creating a spectacular natural laboratory.

By measuring how these eddies evolve and interact he aims to improve model representations of the sorts of complex tidal systems that typify western Scotland.

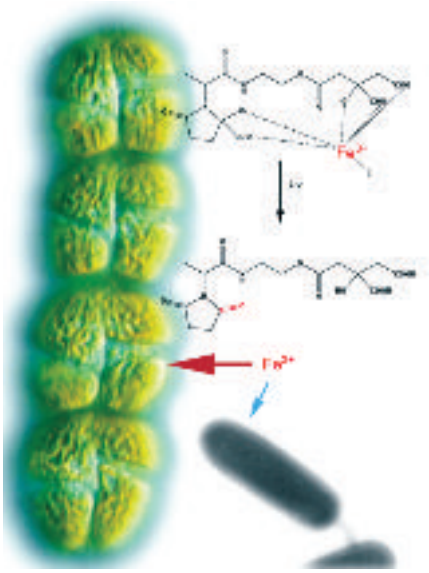
NEW RESEARCH AQUARIUM

October saw the opening of the refurbished SAMS research aquarium. It is named after the late Dr Alan Ansell who spent most his professional life at SAMS, studying bivalves and other animals on the shores around the world, and in the "old" aquarium. The development was carried out with major funding from the European Regional Development Fund and the Scottish Funding Council, and the aquarium now extends over 160m^2 with indoor and outdoor facilities, open plan experimental areas, constant temperature and photoperiod rooms, quarantine areas and a video observation office. It will serve SAMS for research, teaching and commercial use and is also a facility that scientists from around the world can access through the ASSEMBLE project.

IRONING OUT THE OCEAN'S SECRETS

Dr David Green, SAMS

If you study the ecology of an organism, and you always find another type of organism living with it, you start to think that there must be a reason for this association: maybe symbiosis? When I first observed that certain marine algae nearly always have a particular species of marine bacterium living with them, I began to wonder whether these bacteria might provide algae with a nutritional advantage. Thus started an international collaboration with colleagues of Frithjof Küpper at San Diego State University in the USA. Carl Carrano and his PhD student, Shady Amin, are structural chemists, and they identified that our algae-associated bacterium produces an iron-binding compound called vibrioferrin. Our joint research has now revealed that this iron-binding compound can significantly increase the availability of iron to the algae. This is important because iron is an essential nutrient for humans and algae alike but, in the ocean, it is often in very short supply. Algae may thus be limited in their growth, and their ability to fix carbon dioxide from the atmosphere, by a lack of iron. We concluded that our bacterium is likely to be a symbiont that helps supply this essential mineral to algae, enabling them to grow and to photosynthesise efficiently even when iron is in low concentration in the surrounding sea water.



Further information

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SAMS TAKES FIRST STEPS TOWARDS THE UNITED ARAB EMIRATES

Last October, SAMS signed a Memorandum of Understanding with the Madinat Zayed Colleges (MZC) of the Higher Colleges of Technology (HCT) based in the United Arab Emirates. The MoU was signed during a visit by Dr Phil Quirke, Director of HCT Madinat Zayed Colleges, to discuss the possibility of developing a new marine education and research centre on Delma Island.

The hope is to develop new degree courses and to facilitate staff and student exchanges between SAMS and HCT, to support the UAE in further developing its skill base in areas of sustainable management and conservation of the marine environment.

INFLUENCING MARINE POLICY

The report "Recovering Scotland's Marine Environment - Making the Case" recently received wide coverage in Scottish newspapers and was cited by MSPs in the parliamentary debate on the Marine (Scotland) Act. Written by Dr David Hughes and Dr Thom Nickell of SAMS, the report was commissioned by the Scottish Environment LINK Marine Task Force (MTF).

The report gives an overview of the published historical and archaeological evidence for human impacts on Scotland's marine environment, and presents case studies of species and ecosystems that have been damaged or depleted by human activity. Examples include maerl beds, native oysters, fan shells and North Sea demersal fish communities.

The aim of LINK MTF was to support the case that the Marine (Scotland) Act, then in passage through the Scottish Parliament, should have as a key outcome a significant improvement in the health of the country's marine ecosystem as a whole, not just local improvements within the confines of Marine Protected Areas.

Further information

Scottish Environment LINK is an alliance of environmental campaign groups including the Marine Conservation Society, the National Trust for Scotland and the Scottish Wildlife Trust.

ANIMALS ON THE ARTIFICIAL REEF

In 2005, a 36 module artificial reef system was constructed in Loch Linnhe, within a few miles of Dunstaffnage. Built from approximately 250,000 concrete blocks, the aim of the reef is to facilitate studies into the factors that control the development of subtidal communities on offshore structures. For example, ongoing research aims to model fine-scale fluid flows around the reef units and link this to the distribution of sedimentation occurring on the concrete blocks.

Scientific diving is frequently carried out on the Artificial Reef complex. Last year, divers measured the physical parameters of 30 of the separate reefs, to compare with measurements from remote sonar imagery.

Further information

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National Facility for Scientific Diving
www.sams.ac.uk/diving

***Dendronotus frondosus*, a nudibranch observed recently on the artificial reef.**

Dr Martin Sayer, NFSD

RETURN OF THE SEAGLIDER

The first ever deep water deployment in UK waters of a marine glider came to a successful end on 10th March, when Captain Sean Rathbone (left in photo) of the Northern Lighthouse Board vessel *Pole Star* returned the pink instrument to SAMS' physical oceanographer Professor Toby Sherwin.

Professor Sherwin had deployed the glider off Tiree in October 2009, and the unmanned underwater vehicle had collected data on ocean water temperature, salinity and oxygen concentrations. It dived repeatedly along a deep transect between the Scottish Shelf and Rockall, known to oceanographers as the Ellett Line. (Read Professor Sherwin's article on pages 22 and 23.)

The Seaglider navigates through the ocean by changing its buoyancy and shifting its internal mass to dive to depths down to 1000 metres. Its design and hydrodynamic shape minimise power consumption. Although the glider travels at only 0.5 knots (0.5 mph) it is capable of running continuously for many months whilst travelling thousands of kilometres.

Professor Sherwin explained the significance of this technology: "The Seaglider is the future face of oceanography. It is an immensely capable technology that provides us with information about conditions in the top 1000 metres of the sea, over a large area, via a six hourly satellite transfer of data. It is important for us to understand changes in ocean currents and conditions – which relate, for example, to our weather and climate. The five month deployment yielded the same quantity of oceanographic data as about 25 research cruises, very cheaply, and is the way ahead for a much clearer understanding of the oceanography of our oceans."

Professor Sherwin's team had planned to navigate the glider close to Tiree and pick her up in mid March. But they received a 'Help me' message on 8th March from the Seaglider, which had encountered a problem with its propulsion system far from land. By a lucky coincidence the *Pole Star* was in the area and volunteered to retrieve the instrument. The glider had hardly a mark on her - or any fouling - after a long journey that included a number of North Atlantic winter storms.

Further information

www.sams.ac.uk/glider

UK OCEAN ACIDIFICATION PROGRAMME LAUNCHED

The UK's first research programme to investigate the scale and impacts of ocean acidification has recently launched. Involving over 100 scientists from 21 UK institutions, including SAMS, the £12.4M programme will focus on six major research areas: variability in oceanic carbon dioxide (CO_2) uptake; the biological and geochemical seabed impacts of acidification; the biological and geochemical impacts of acidification on the surface of the ocean; the relationship between ocean acidification and climate change; the geochemical and ecological responses of Arctic and UK regional seas to acidification; and the effects of rapid ocean acidification in Earth's past.

About half of the CO_2 in the atmosphere produced by fossil fuel burning is taken up by the oceans. Once dissolved, the CO_2 forms a weak acid thus leading to ocean acidification. SAMS scientists will be researching the impact of ocean acidification on seabed communities and on plankton in the surface ocean.

The five year UK Ocean Acidification Research Programme is funded by the Natural Environment Research Council, the Department for Environment, Food and Rural Affairs, and the Department of Energy and Climate Change.

Further information

www.oceanacidification.org.uk

REST ASSURED: YOUR FISH IS CERTIFIED

Dr Clive Fox, SAMS fisheries scientist, plays a key role on accreditation teams for the Marine Stewardship Council (MSC) via the accreditation body Moody Marine. MSC certification ensures that fisheries conform to approved standards, giving processors and the public assurance that products bearing the MSC logo come from fisheries managed to promote sustainability. The accreditation process involves extensive site visits and consultation with the fishery and other stakeholders such as environmental NGOs.

Evaluation and scoring is carried out against three principles: the status of the target stock, the impacts of the fishery on other species and the environment; and the legal and enforcement framework in which the fishery operates. The accreditation process is very open, with all reports being peer reviewed and put on the MSC website (www.msc.org). Certification lasts for five years, and annual audits of the fishery during this period ensure that standards are maintained.

The Ekofish group, whose vessel PD147 *Enterprise* is shown here, achieved certification last year for its North Sea plaice fishery. www.ekofishgroup.nl

UHI ANNUAL LECTURE 2010 TO BE HOSTED AT SAMS

On Thursday 16th September SAMS will play host to UHI's annual flagship event at the Scottish Marine Institute. The 2010 Annual Lecture of the prospective University of the Highlands and Islands will address the demanding issue of how best to manage our fisheries and will be presented by Poul Degnbol, Head of the Advisory Programme at the International Council for the Exploration of the Sea and former scientific advisor on fisheries issues to the European Commission.

The event will include the award of fellowships and student prizes, an exhibition of SAMS work, tours of the Scottish Marine Institute and will conclude with an evening ceilidh.

If you would like to attend the event, please contact Paul at
e Paul.Ellison@uhi.ac.uk or **t** 01463 279344

ARCTIC SEA ICE
A CENTRAL COMPONENT OF THE GLOBAL CO_2 HOUSEHOLD

Professor Ronnie Glud SAMS

Sea ice plays a critical role in the functioning of polar marine ecosystems. However, an accelerating increase in the temperature in polar regions has dramatically reduced the area and thickness of the Arctic sea ice cover.

In the last 30 years the extent of Arctic sea ice has been reduced by an area corresponding to 20 times that of Scotland. This has profound effects on the biology in the region but also for the oceanography, chemistry and exchange of energy and gasses between atmosphere and ocean. All are factors that strongly interrelate with the global climate system, and recent discoveries add new complexities to this interplay: complexities that are not accounted for in the current climate models or incorporated in the conceptual understanding of the polar carbon cycle and carbon dioxide (CO_2) household.

Through most of the long winter sea ice acts as a lid on the polar oceans. It impedes free exchange of gases between the sea surface and the atmosphere, and strongly reduces the light reaching the underlying light-limited biological production, especially during periods of snow cover. However, during the winter and spring, sea ice gradually develops its own special biotope with a number of unique features: a matrix of ice crystals forms containing nutrient enriched heavy brine that gradually sinks out of the ice. Specially adapted bacteria and microalgae exploit this unique habitat and form the base of an ice-associated food web, where flagellates, ciliates, copepods and fish larvae graze on the developing food source. The system is extremely dynamic and is affected by constant changes in air temperature, snow cover, advection and light, all involved in regulating local freezing and melting events.

During spring sea ice gradually develops into an ever more photosynthetically dominated system that fixes CO_2 into biomass and produces oxygen (O_2). During late spring sea ice becomes fragile and permeated by brine and melt channels so that it no longer forms a coherent lid on the ocean. As sea ice gradually recedes, the remaining nutrients within it are released, at the same time as light - now unhindered - can reach the planktonic microalgae. These then form a spring bloom along the ice edge. Most of this biomass is grazed by larger organisms but, in one form or another, a proportion of the CO_2 that has been fixed by the microalgae leaves the productive surface layers and sinks towards the deep ocean in the form of dying algae, faecal matter or carcasses that often agglutinate into marine aggregates (further increasing the sinking speed). This biologically mediated transport of CO_2 from surface waters towards the deep ocean is know as "the biological CO_2 pump". It is intensified along the ice edge but occurs all over the Arctic Ocean.

Another important pump in the Arctic is the so-called "solubility CO_2 pump", which is the net result of gradual cooling of north flowing water. The cooler sea water can hold more CO_2, which it takes up from the atmosphere. However, as it cools the sea water also gets heavier and ultimately begins to sink towards the deep ocean along with the absorbed CO_2. This mechanism is a central motor in the global oceanic current systems.

Recently another pump has been discovered and its overall importance for transporting CO_2 from the atmosphere to the deep ocean is a hot topic in Arctic research. This pump is called the "sea ice CO_2 pump". The research that led to its discovery has shown that the physical processes of freezing and thawing also affect CO_2 and O_2 dynamics within sea ice.

As sea ice forms, gases accumulate in the brine along with salts and nutrients. The heavy brine sinks taking the dissolved gases down with it. This occurs to such an extent that the springtime melt water is strongly depleted in both O_2 and CO_2. These gases are then replenished from the atmosphere. Measurements have shown that melting sea ice can be almost completely O_2 free. In addition, bacteria that respire using one important nutrient (nitrate - NO_3) have been found to be active in the melt water. This suggests that melting sea ice can be an important but hitherto unrecognized nutrient sink where microbial processes transform nitrate to inert dinitrogen (N_2). These processes were previously only

thought to take place in the seabed or in oxygen depleted water bodies, but apparently this nutrient sink is also active in melting sea ice. This can have important consequences for the microalgae that rely on nutrients for their photosynthesis and thereby affect the function of the biological CO_2 pump.

The direct draw down of CO_2 via the sea ice CO_2 pump is, however, only one component of the physical-chemical dynamic of inorganic carbon in sea ice. As a consequence of the salt accumulation in the brine, calcium carbonate appears to precipitate out. This liberates CO_2 into the sinking brine, which transports it out of the sea ice and leaves the carbonate crystals behind. Recently at least two research groups have found carbonate crystals in sea ice. If during sea ice melt, the carbonate crystals sink to the deep ocean, they will take the associated inorganic carbon along with them.

Alternatively the crystals can dissolve in the surface layer. This, however, will be associated with a further draw down of CO_2 from the atmosphere, though this time the CO_2 will be kept in the surface water.

We still know very little about the function of this new sea ice pump, but its efficiency depends on a number of factors. Key outstanding questions include: To what depth does the CO_2 enriched brine sink? What are the dynamics of brine drainage? To what extent do carbonate crystals form, and what is the fate of these crystals?

This process may be highly significant, as a recent theoretical model study suggested that up to 50% of the CO_2 draw down in the Nordic seas can be associated with the sea ice CO_2 pump.

On a global scale, the sea ice pump can potentially mediate a CO_2 draw down of a scale comparable to the reduction in CO_2 emission that would result from full implementation of the Kyoto Protocol.

With ever declining sea ice cover it becomes critical to understand the relative importance of the different CO_2 pumps and how they interrelate. For instance, will a reduction of the sea ice CO_2 pump be compensated for by an increase in the biological CO_2 pump?

One of the aims of the 2010 SAMS ICE CHASER II research cruise to the Arctic is to further elucidate the chemical/biochemical processes occurring within sea ice. Novel under-ice instrumentation was deployed to measure gas exchange across the sea ice/water interface.

Both temperature and the extent of sea ice cover in the polar regions are undergoing dramatic changes, and this has very important implications for the oceans' capacity to act as a buffer for the increasing accumulation of atmospheric CO_2. The consequences of changing sea ice cover for the exchange of CO_2 between oceans and atmosphere, and for the biological function of the Arctic ecosystems, are central research questions to be addressed by the newly formed "Greenland Climate Research Centre" based in Nuuk.

Researchers at SAMS are partners in the centre and are responsible for one of the nine key projects that form the centre's research focus. The centre provides excellent research facilities and easy access to field sites in the region, providing an outstanding platform from which SAMS scientists can conduct their research.

Further information

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Greenland Climate Research Centre: www.natur.gl

ICE CHASER II Expedition: www.sams.ac.uk/arctic-cruise2

SEAWEED AND OOMYCETE DIVERSITY IN THE CANADIAN MARINE ARCTIC

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Global climate change is expected to alter the Arctic and Antarctic bioregions faster than any other marine environment on Earth. For this reason an international team, coordinated by Dr Frithjof Küpper of SAMS, conducted an expedition to Baffin Island in the Canadian Arctic, in order to investigate the diversity and diseases of the region's little known seaweeds. The major objectives of the expedition were to complete an inventory of the seaweed flora of this part of the Arctic and to characterise seaweed-associated, eukaryotic pathogens, such as oomycetes. The trip also planned to document this seaweed-dominated ecosystem both for research and public outreach purposes, using underwater photography and video as well as sample collection.

After almost three years of preparation, our team of seven scientists and divers finally met in Montreal on 16th August 2009. We were joined by Bob and Joanne Wilce from Amherst, Massachusetts – Bob had been working in this region for over four decades. Whilst he was unable to join the expedition for health reasons, Bob's advice – and a donation of 150 Meals-Ready-to-Eat (MREs) from the US army – proved invaluable. From Montreal, we continued our trip to the Inuit village of Pond Inlet in the north of Baffin Island, with stopovers in Kuujjuaq and Iqaluit. After spending two days sorting out last pieces of equipment and supplies in Pond Inlet, we headed out to Bay 11 in the Ragged Channel/Cape Hatt area, in the western Eclipse Sound, which was to be our field camp for the next two weeks, with logistical support from our Inuit guide and outfitter, Sheatie Tagak and his aides, Joshua and BJ.

We conducted two to four dives a day, collecting seaweed specimens, sediment samples and taking photographs and video footage. After collection, specimens and samples were processed in our tent laboratory – algal isolates were made, fresh water samples were taken for oomycete isolations, seaweeds were mounted on Bristol paper and fixed on microscope slides for herbarium specimens, and part of the tissues were conserved in silicagel and two types of buffers stabilizing DNA and RNA (for a molecular approach in the lab, aiming to capture the diversity of associated, eukaryotic pathogens and microbes). Sediment samples were collected for algal and microbial isolation work in the lab by ourselves and a number of collaborators, including Marcel Jaspars, Rainer Ebel and Deng Hai at the University of Aberdeen. One objective was to recollect specimens of two endemic Arctic macroalgae, *Platysiphon verticillatus* and *Platyarcticus glacialis*, in order to clarify their taxonomic status and life cycle. Within the framework of our collaboration with Julia Kleinteich and Daniel Dietrich at the University of Konstanz we also collected cyanobacterial mats from freshwater habitats around Cape Hatt.

Preparations for this expedition had been challenging, and several times before our departure, everything seemed to be on the verge of failure. The complicating factors were mainly because there was no scientific base infrastructure or research vessel to rely on, so we had to contract logistics locally in the Inuit village of Pond Inlet. Because of the long distance to the nearest recompression chamber in Montreal (48 hours from our field site), all diving had to be restricted to a maximum depth of 15 metres. In retrospect, the team plus two local Inuit guides performed superbly well, accomplishing an ambitious, diving-based research program in a highly remote Arctic location.

A team of scientists and scientific divers investigated the diversity and diseases of Baffin Island seaweeds in a highly remote area.

In the remoteness of an Arctic field camp with very basic living and working conditions and a satellite phone as the sole means of communications with the outside world, a great team spirit developed. Besides generating over 10,000 images, over 20 hours of video footage and hundreds of live isolates, herbarium specimens and samples for a range of different purposes, our expedition also documented some of the effects of climate change, which are impacting the Arctic much faster than most other parts of our planet. In fact, this particular region has become completely free of summer sea ice within only about the last five years, and glaciers in the region are receding rapidly.

Our trip also provided us with a unique insight into the local Inuit community – their cultural transition into a 21st century society, their social and economic struggles, their geographical isolation from the rest of the world, and their testimonials of how climate change is rapidly transforming their natural surroundings and lifestyle. We collaborated with Pond Inlet High School, using their facilities and borrowing microscopes. In return, Frithjof gave a talk to students, teachers and the wider Pond Inlet community, on the objectives and preliminary findings of the expedition. Several lines of follow-up work in our laboratories - mostly related to algal/microbial culturing and molecular investigations of the specimens collected, but also on the public outreach side - are now under way and will take several years to complete. Altogether this was a lifetime experience for us all.

Further information

This project is supported by SAMS and NFSD core funding (Oceans 2025 from the UK Natural Environment Research Council) and the TOTAL Foundation (Paris).

Expedition members' organisations

1 Scottish Association for Marine Science

2 Aberdeen Oomycete Laboratory, College of Life Sciences and Medicine, University of Aberdeen

3 UK National Facility for Scientific Diving, SAMS

4 Kobe University Research Center for Inland Seas, Japan

5 Lycée Honoré d'Estienne d'Orves, Nice, France

6 Department of Biology, University of Massaschusetts, USA

UNRAVELLING THE OCEAN METHANE PARADOX

Dr Angela Hatton and **Dr Arlene Rowan** SAMS

Methane is responsible for about a fifth of global warming potential, second only to carbon dioxide in its importance as a greenhouse gas. Its predominant sources are made up of both natural and man-made components and include wetlands, landfills, fossil fuel production, biomass burning and agriculture (particularly rice cultivation and intestinal methane from livestock such as cows and sheep). The study of these potential sources of methane has gained much interest in the past few years, due to the importance of methane in past, present and future climate change and its increase in atmospheric concentration over the past 150 years.

Methane emissions may have a greater impact on climate than previously thought, due to interactions with airborne particles called aerosols. Evidence suggests that terrestrial sources, such as increased livestock and intensification of rice paddies, have been the major contributors to increased levels of atmospheric methane, however other environments also play an important role in methane production and recycling.

The world's oceans, for example, represent a relatively small but important natural source of methane (1- 4% of global annual emissions). Despite its global significance we know very little about oceanic methane production, particularly in the upper oceans. Elevated concentrations of methane exist in the oxygenated upper oceans, yet we do not fully understand why. Until recently the only organisms known to produce methane within marine waters were known as the methanogens. Methanogens are strict anaerobes (do not require oxygen for growth) and it was thought that they would die quickly upon exposure to even low concentrations of oxygen. This resulted in the suggestion that methane production in oxygenated waters was paradoxical. However, the 'methane paradox' can be reconciled in two ways: firstly if we consider the occurrence of low oxygen (anaerobic) micro-sites (such as within the intestines of small oceanic animals, their excreted faecal pellets and other particles (sediment) falling through the water (sedimenting material)); and secondly, through the newly-hypothesised process of aerobic (requiring oxygen) methane production (via the breakdown of methylphosphonate by bacteria under oxygenated conditions).

The microbial biogeochemistry and biogases research group at SAMS received Natural Environment Research Council (NERC) funding to test the anaerobic micro-site hypothesis that marine zooplankton, their excreted faecal material and other sedimenting material contain active methanogens, and could therefore be sites for methane production in the upper oceans. Samples of marine zooplankton were collected from local sea lochs off the west coast of Scotland (Loch Creran & Loch Linnhe) by net trawl and maintained in culture for incubation experiments. Faecal pellet samples were either collected from freshly caught mixed zooplankton populations or from distinct zooplankton types maintained under controlled culture conditions. For sedimenting material, sediment traps were deployed for short periods of time in areas containing high particulate material. Samples were used to investigate the occurrence of methanogens and active production of methane in these sites. Our work, using DNA based methods, has now clearly identified the presence of methanogens within marine zooplankton faecal pellets and sedimenting particles. This, along with data confirming the production of methane from these sites during anaerobic incubations of sedimenting material, has led to an intriguing insight into how this anaerobic process may be actively occurring in oxygenated waters.

The group had previously worked on zooplankton faecal pellets and sedimenting material to investigate the fate of an environmentally significant, biologically produced gas called dimethylsulphide (DMS). DMS is the major gaseous sulphur species in the oceans (considered to be the "smell of the sea") and hence the dominant source of biologically generated sulphur compounds in the atmosphere. Once in the atmosphere, DMS is oxidized to form aerosol particles, which act as cloud condensation nuclei (a focal point around which cloud droplets can form). These can contribute both to the natural acidity of rainwater and to an increase in clouds' reflectivity. Therefore DMS plays an important role in the Earth's climate system, reflecting back incoming sunlight and so potentially having an important cooling effect. DMS is formed from the breakdown of a salt, dimethylsulphoniopropionate (DMSP). Marine phytoplankton (the minute plant life that fills our oceans) produce this compound to help them survive in salty seawater.

The process by which DMSP is released from phytoplankton cells into the sea is not fully understood, but many researchers think it may occur when the phytoplankton are grazed by zooplankton. Physical damage to the grazed plant cells may cause DMSP to be released into the water, where it is broken down to DMS. However, it is also likely that a considerable amount of this DMSP is consumed by the zooplankton and packaged into their faecal pellets, which sink through the water removing DMSP, and therefore a source of DMS, from surface waters. Earlier research by our group had shown that DMSP entering zooplankton guts can be packaged into their faecal pellets, where it is then broken down to DMS and subsequently removed. We found that this DMS can be oxidized to dimethylsulphoxide (DMSO) by marine bacteria, though this pathway may only remove a fraction of the DMS generated. We therefore hypothesised that phytoplankton-derived DMS could in fact be linked to methane generation, with DMS providing a substrate to methanogens present in anaerobic micro-sites. Results from these experiments have revealed that zooplankton faecal pellets and sedimenting particles can contain a type of methanogen which has been shown to utilise compounds

Within zooplankton faecal pellets micro-organisims produce the greenhouse gas methane while the climate cooling gas dimethylsulphide is removed.

like DMS. Furthermore, incubation experiments demonstrate that these methanogens are both active, and also show enhanced methane production on addition of DMS. Research at SAMS indicates that anaerobic micro-sites may be instrumental both in the production of a greenhouse gas (methane) and in the removal of a climatic feedback gas (DMS). This work enhances our understanding of the role that biologically produced oceanic gases play in regulating the Earth's climate. Demonstrating methane production in anaerobic micro-sites may also help to explain the occurrence of other anaerobic processes within oxygenated surface waters.

This work represents the first multidisciplinary study to examine the interlinked role of both a greenhouse and a climatic feedback gas in biologically driven oceanic biogeochemical cycling. We hope to expand this area of research through an in-depth multidisciplinary study to characterize and understand the role of methanogens present in micro-sites, to identify their substrate use, interactions with other microbes and their response to changing environmental conditions. We also plan to test these micro-sites for the newly hypothesized aerobic production of methane.

Further information

The microbial biogeochemistry and biogases research group comprises

Dr Angela Hatton, Dr Arlene Rowan, Dr Mark Hart and Dr Sam Wilson.

SETTING STANDARDS FOR MARINE ENERGY

Dr Bob Batty SAMS Honorary Research Fellow

The need to source energy from renewable sources is driven by climate change, the increasing cost of fossil hydrocarbon fuels and the need to improve energy security. Both hydro power and wind power have a long history, though only in recent years has the latter made a significant contribution to our energy supply.

Now, marine energy – from waves and tidal streams – brings the potential to deliver vast quantities of power. Most of the energy in the oceans is too diffuse and too far from shore to be exploited, but there are areas where waves and currents are sufficiently dense to be exploitable. Much of this resource is in Scottish waters. The Pentland Firth, for example, is often touted by Scottish politicians as the Saudi Arabia of marine power. Tidal stream power has the advantage that its availability is predictable, unlike wind power. However its disadvantage is that the marine environment is often hazardous and difficult to work in.

Unlike hydro and wind power, the development of wave and tidal stream power is in its infancy; many devices are being conceived, developed and tested. Some demonstration scale projects are now feeding power to the grid, such as the Marine Current Turbine in Strangford Loch. However, unlike wind power, where almost all wind turbines are of a very similar three-bladed horizontal axis design, the marine energy devices are remarkably diverse in their characteristics. To some extent, devices are being developed to exploit different environments with differing characteristics, but even allowing for this there is remarkable diversity. This makes it very difficult for investors, energy companies and regulators to asses such a diverse range of devices with different attributes, benefits and limitations, in an equitable manner. And so, this is why the EquiMar project was conceived.

EquiMar is the acronym for "Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact". The project aims to provide a suite of protocols to evaluate marine energy converters (both wave and tidal stream) on an equitable basis. It aims to answer the questions: which are the best locations to develop? And, which is the most appropriate device to use in a particular location, in terms of performance and environmental impact? The protocols will cover every stage of the process of marine energy development including site selection, device engineering design, the scaling up of designs, the deployment of arrays of devices, environmental impact (in terms of both biological & coastal processes),

and economic issues. The project itself brings together representatives of nearly all aspects of the marine energy sector, from university scientists and engineers, device developers, energy companies, certification agencies, and even journalists with an interest in renewable energy. Now at the half way stage, the three year project is funded by the European Commission as part of its 7th Framework Programme under the Energy topic and currently includes 22 partners from 10 member states.

At SAMS we are contributing to work on Environmental Impact Assessment, collaborating closely with colleagues from the Wave Energy Centre and the Sea Mammal Research Unit. The environmental impacts of marine energy extraction are far from being fully understood and are difficult to predict. An important task, therefore, was to compile a review of the main uncertainties regarding environmental impacts of ocean energy devices. The major areas of uncertainty include: interference with benthic habitats; artificial reef effects (which may be beneficial); noise disturbance; electromagnetic fields; and interference with marine animal movements. There may as yet be no actual evidence of negative effects in these areas, but because the risk is unknown, or not quantifiable, the consequences of negative impact could be severe.

A major concern is the risk of collision between marine vertebrates (mammals, fish and diving birds) and marine energy converters as well as the potential to disturb migrations or exclude animals from a region around a device.

In an effort to understand the processes that lead to a risk of collision between animals and the moving parts of marine energy converters (the tips of turbine blades can be moving through the water at speeds up to 30 mph), and to identify gaps in knowledge that require further investigation, we are using and developing encounter and evasion models. Encounter models have been used extensively in ecology to estimate predator-prey interactions of marine animals and to assess risk of predation mortality. Such models can also be used to predict rates of encounter of animals with renewable energy devices.

At SAMS we have developed a 3-dimensional encounter model to assess the relationship between animal size and encounter rate with tidal turbines, as well as the risk for individual species. Our model shows that encounter rate increases with body size, indicating greater risk to larger animals such as marine mammals. This is because bigger animals take up more space and also swim faster. Their population sizes and densities are smaller, and hence the risk is greater in terms of the proportion of the population that may be affected. Using the model we estimate that if, for example, 100 turbines, each with two blades and a radius of eight metres, were deployed on the west coast of Scotland, between 3.6% and 10.7% of the harbour porpoise population and 2% of the herring population may encounter some part of a turbine blade every year.

Marine vertebrates have the ability to avoid the area around a marine energy device – providing that they perceive it as a hazard and are able to take evasive action to avoid collision. Our encounter model has highlighted the need for more information on the abundance of animals at risk close to sites that are being considered for development, as well as on the sensory information that is available to animals to allow detection, avoidance or evasion. Other projects at SAMS are investigating

The EquiMar project is developing protocols to facilitate comparison of the many new marine energy devices, and their environmental impacts.

the background noise levels in tidal streams in order to asses the potential for turbines to be heard by animals as they approach.

Detailed studies of predator evasion by fish have shown how they respond to looming images (simulating a predator lunging toward them) and have allowed us to model their evasion capabilities.

The model predicts that fish will be able to avoid turbine blades at moderate speeds but not if they are on a collision course with the blade tip during peak tidal flow. This assumes that the turbine can be seen. Alternatively, animals may respond when they hear the sound of a predator rushing towards them, allowing evasion when visual cues are not available. The challenges that remain are to extend our modelling effort both to marine mammal behaviour and to predicting the potential for evasive responses of animals to the sound pressures emitted by turbine blades. Ultimately the hope is that monitoring effort can then be better targeted, so that we can test the model predictions and refine future assessment of environmental impact.

Further information

www.equimar.org

THE ECOSYSTEM APPROACH IN EUROPE'S SEAS

THE KNOWSEAS PROJECT MAKING MARINE SCIENCE COUNT

Dr Tim O'Higgins SAMS

Europe's regional seas have suffered severe environmental degradation. This damage not only affects the organisms living in the marine environment but also has impacts on the welfare of the human communities which are reliant on them.

The Ecosystem Approach to management, now being adopted by the EU, offers a means of sustainably managing our seas to optimize both ecological and social well being.

The one major obstacle is that nobody is quite sure how the Ecosystem Approach can be put into practice, and this is where the Knowledge-based Sustainable Management for Europe's Seas (KnowSeas) project comes in.

Over the course of European history human activities have had profound effects on our regional seas (North East Atlantic, Mediterranean, Black and Baltic). Unsustainable and damaging practices such as over-fishing, over-use of fertiliser, inadequate wastewater treatment, habitat destruction and the introduction of invasive species have all taken their toll on the health of our marine ecosystems. In turn the damaged marine ecosystems affect human welfare. For example, over-fishing leads to depletion of fish stocks with resulting losses to fishing communities; and eutrophication leads to reduced water quality, which damages marine organisms through hypoxia and reduces the value of ecosystems as recreational resources.

Today, new uses for the marine environment are emerging. The scramble for increased renewable energy capacity is resulting in the construction of wind farms in marine spaces, with unknown ecological consequences. At the same time, we are gaining new insights into marine ecology, for example our understanding of the extent and importance of deep sea coral reefs, is growing. These developments all occur within seas already subjected to altering conditions caused by climate change. The resulting novel policy dilemmas require robust and well informed decision making which must include both ecological and social considerations.

Since human activities have profound effects on our oceans, and the seas affect human welfare, successful management of these coupled systems needs to include both ecological and human aspects. The Ecosystem Approach, now an element of policy in the EU Marine Blue Book and mandated in legislation by the European Marine Strategy Framework Directive (MSFD), is a resource planning and management approach that recognises the connections between land, air and water and all living things, including people, their activities and institutions.

Despite the legislative mandate to implement the ecosystem approach and the sound theoretical basis for implementation, there is little hard information on how the approach should be put into practice. In particular, criteria for assessing costs and benefits of management actions are poorly developed in the complex marine environment where multiple uses and management conflicts are common. There is a strong need for a "joined up" systems approach between natural and social science, that delivers the knowledge base to support management for sustainable seas. This is what the KnowSeas project aims to deliver.

Implementing the Ecosystem Approach in Europe's seas requires expertise not only in ecology of marine ecosystems but also in the functioning of human, social systems and the ways in which they interact with the seas. Scientists from SAMS are leading an international team of researchers, which includes ecologists, economists, geographers and anthropologists. This team has been assembled with the aim of understanding how ecological, economic and social data can be brought together and effectively communicated to, and put into practice by, policy makers. Understanding the Ecosystem Approach requires a great deal of multidisciplinary thinking. Given the variety of backgrounds, knowledge-bases and skill-sets of project participants, the project has been carefully structured to allow an effective flow of information between different expert groups.

In the KnowSeas project, ecologists, economists, geographers and anthropologists from across Europe work together to develop a template for the implementation of the Ecosystem Approach to manage Europe's regional seas sustainably.

For example, the systems analysis subgroup is comprised of a think-tank of ecological modellers and economists. A diverse array of ecological modelling methods from statistical syntheses such as Integrated Ecosystem Assessment, to ecosystem models like Ecosim and the stochastic Bayesian Belief Network modelling, are being employed. These will be used to understand and predict how ecological processes and the ecosystem services they provide will flow to the people dependent on Europe's regional seas between now and the year 2050. The outputs of these ecological models will be flows of benefits obtained from the seas. These will be passed on to the economists in the subgroup. The economists will then translate the physical flows of benefits, modelled by the ecologists, into flows of economic benefits using the common currency of monetary values.

Translating ecological process into economic benefits is only one part of the Ecosystem Approach to management. Social and cultural differences between European peoples result in very different preferences, expectations and political cultures and these must all be accounted for if the Ecosystem Approach is to be practiced effectively. Politicians and ecologists often speak a different language. While the ecologist counts in numbers of individual animals, species or populations, the politician counts in numbers of jobs and votes. To this end the second subgroup will focus on integration. Conversion of the systems analysis information into practical guidance for real world situations will be achieved by means of stakeholder analysis, examining the cultural differences in attitudes and expectations of the seas. The project is also developing a suite of communication tools to allow the transfer of knowledge from the specialist systems analysis group to decision makers to facilitate adaptive management practices.

Supporting the work of the systems analysis and integration subgroups are groups of regional experts and stakeholders from each of the regional seas. The broad geographic scope of the expertise will provide inputs to regional case studies. These case studies include a geographically explicit examination of the interaction between trawl fisheries, climate change and the cold water coral *Lophelia pertusa* in the North East Atlantic; a study of the costs and benefits associated with the fishing of the critically endangered bluefin tuna *Thunnus thynnus* in the Mediterranean; a modelling study of the management dilemma caused by the destructive but lucrative fishery for the invasive whelk *Rapana venosa* in the Black Sea; and an examination of the social aspects of eutrophication in the Gulf of Finland. By carefully scrutinizing biological and social aspects of these issues the project will develop a template for the implementation of the Ecosystem Approach throughout Europe and this template will inform the way in which EU nations implement the Ecosystem Approach and the MSFD.

There has been intense interest in the project from within the Directorates General of the European Commission as well as other governmental groups: the International Council for the Exploration of the Seas (ICES), the European Environment Agency, regional seas commissions and non-governmental organisations such as WWF and the International Union for the Conservation of Nature (IUCN). The project is much more than an academic exercise. It has the potential to change the way in which people throughout Europe interact with the marine environment, and aims to achieve this through direct communication with the people who make the decisions.

Further information

www.knowseas.com

Title: Knowledge-based Sustainable Management for Europe's Seas (KnowSeas)
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Duration: 48 months
Consortium: 30 partners from 15 countries coordinated by SAMS
Project Coordinator: Professor Laurence Mee

MINIMISING THE MARINE IMPACTS OF MINING IN PAPUA NEW GUINEA

Dr Tracy Shimmield SAMS

The world's expanding population will continue to utilise the earth's resources and the environmental impacts of the extraction of non renewable resources such as oil and minerals are a constant source of public and scientific concern. In addition, the marine environment continues to be a repository for waste resulting from both land based and deep sea mining and oil extraction. In all cases there is an urgent need to identify and measure potential impacts so that these can be minimized and mitigated as far as possible.

Papua New Guinea (PNG) is a developing nation with rich mineral resources and an important mining sector. According to the statistics provided by the Bank of PNG, in 2007, 59% of PNG's export value came from copper and gold mining and another 23% from petroleum products. It is generally accepted that the amount derived from mining taxes and royalties is equivalent to the amount spent by the PNG government in the health and education sector.

However the social and environmental impacts of mining have been a controversial issue in the country for many years with the disposal of the waste slurry that results from the extraction of metals, known as mine tailings, being a major issue. PNG is located in the *Pacific Ring of Fire* which is an area where about 90% of the world's earthquakes occur and is home to approximately three quarters of the world's active volcanoes. Mines in PNG are located in areas of high and frequent seismic activity, with little appropriate land and a high risk of flooding due to high rainfall. This means that the long-term storage of tailings in ponds that are contained by engineered dams is an unsuitable method of dealing with the mine waste in the majority of cases.

Deep-Sea Tailings Placement (DSTP), the discharge of mine tailings via a pipeline into deep water, is an alternative disposal option that eliminates the risk of contamination to land or fresh water. However, there remains the potential for impacts on the marine environment. The PNG Government with the help of the European Union has therefore invested in research to better understand the potential impacts and to investigate how to reduce environmental risk to humans and marine resources.

In 2007, SAMS was contracted to carry out an *Independent Evaluation of Deep-Sea Mine Tailings Placement in Papua New Guinea*. The study entailed a rigorous scientific study of the impacts of mine tailings at two sites, Lihir Island, where an operational gold mine discharges approximately 4 million tonnes of tailings per year into the ocean, and Misima Island, where DSTP ceased

in 2004 after a total discharge of approximately 90 million tonnes. In addition, an environmental baseline study was carried out at the mainland site of Basamuk, a proposed discharge point for tailings from an inland nickel-cobalt mine currently under construction. These three contrasting sites offer the opportunity to establish the pre-impact baseline conditions at Basamuk, to identify and record any impacts of ongoing DSTP at Lihir, and to measure the degree of environmental recovery at Misima.

Exploitation of deep-ocean mineral resources is likely to increase throughout the 21st century, accompanied by pressure to use the deep seabed as a repository for waste

During October to December 2007, a six week-long research cruise went to Lihir Island in the Solomon Sea and Misima Island in the south-western Pacific. In September 2008 a similar cruise was undertaken in the Vitiaz Basin to survey the natural marine environment of Basamuk and the surrounding area. SAMS has a wealth of experience and a strong track record in multidisciplinary fieldwork in the deep sea, but these cruises nevertheless posed a significant logistical challenge.

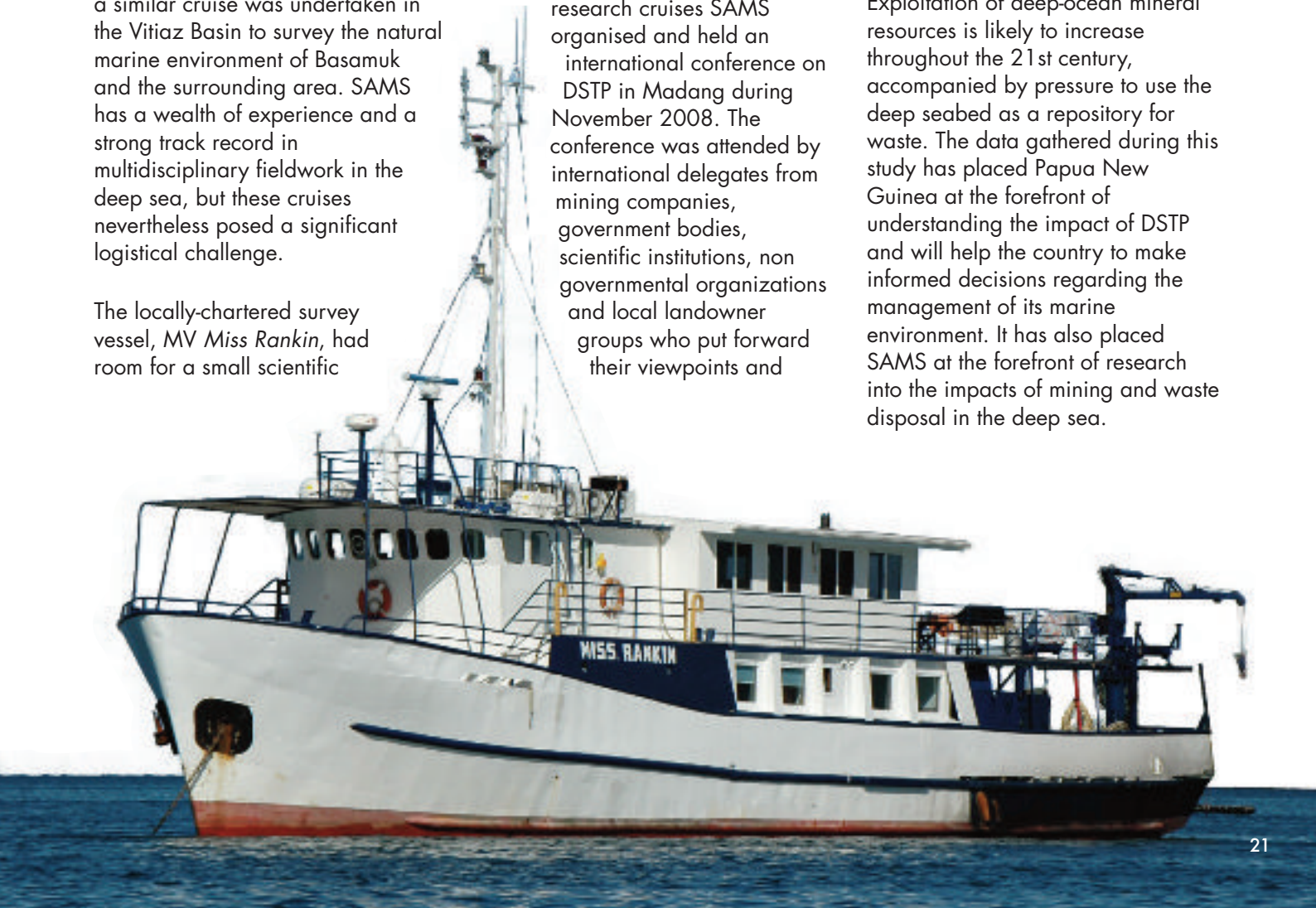
The locally-chartered survey vessel, MV *Miss Rankin*, had room for a small scientific team, and the crew and scientists had to learn how to deploy and recover the sampling equipment that was shipped out from Scotland. Operating in remote areas placed a premium on teamwork, flexibility and improvisation to overcome equipment failures, cyclones and other obstacles that inevitably confront all research cruises.

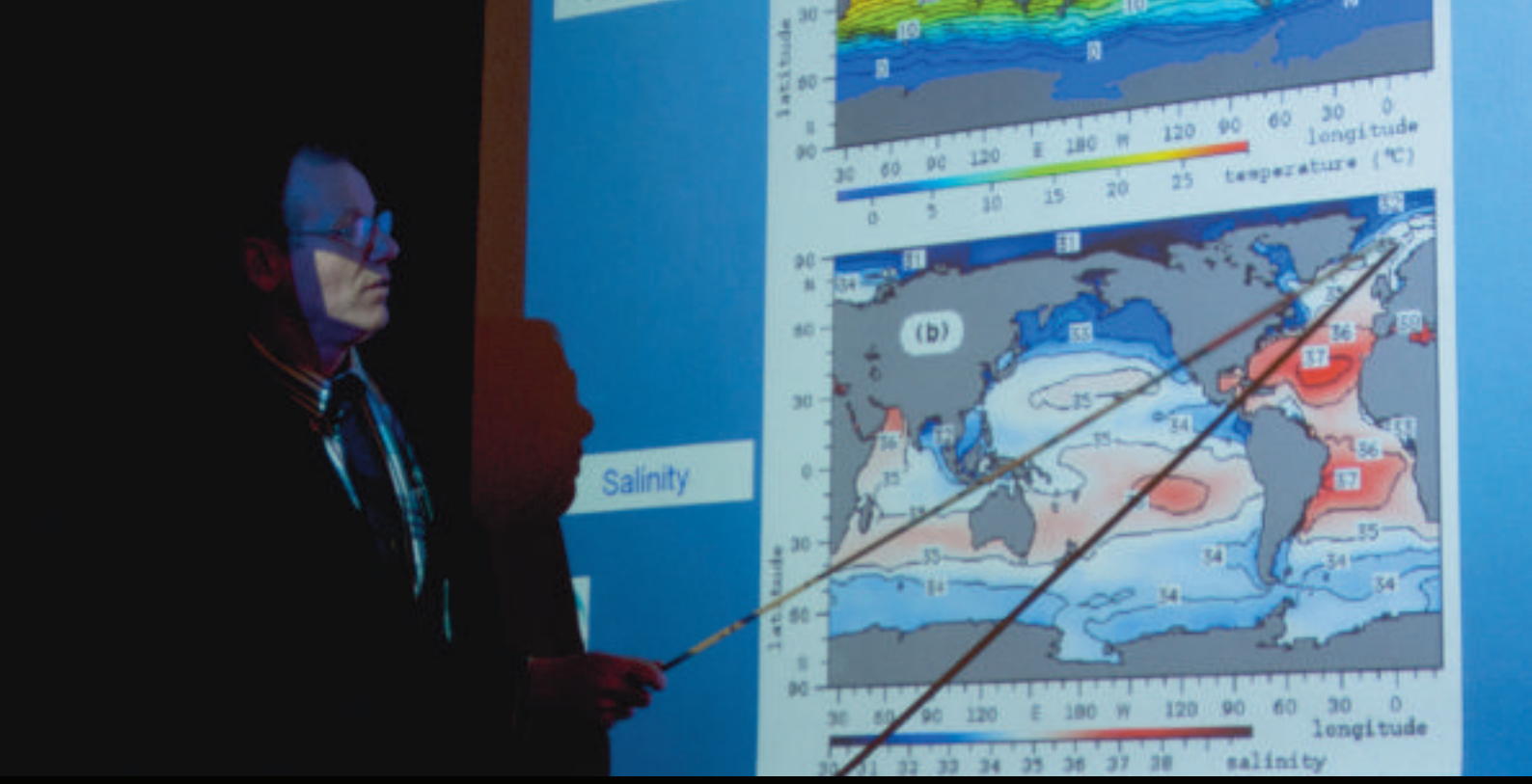
Both cruises were a great success and we gathered a large amount of data from core and water samples, seabed photographs and plankton hauls. The data is providing a solid environmental baseline for evaluation of any future effects of tailings discharge at Basamuk, increases the understanding of environmental effects of DSTP at Lihir and provides an assessment of any long-term environmental effects at Misima. Additionally, at Misima, we can assess the rate of environmental recovery after mine tailings discharge is discontinued.

As well as carrying out the research cruises SAMS organised and held an international conference on DSTP in Madang during November 2008. The conference was attended by international delegates from mining companies, government bodies, scientific institutions, non governmental organizations and local landowner groups who put forward their viewpoints and discussed how best to minimise the environmental impacts of mining in PNG.

Lowering a sediment corer to collect seabed samples off PNG.

Exploitation of deep-ocean mineral resources is likely to increase throughout the 21st century, accompanied by pressure to use the deep seabed as a repository for waste. The data gathered during this study has placed Papua New Guinea at the forefront of understanding the impact of DSTP and will help the country to make informed decisions regarding the management of its marine environment. It has also placed SAMS at the forefront of research into the impacts of mining and waste disposal in the deep sea.





The Newth Lecture 2009 by Professor Toby Sherwin

CHARTING THE CIRCULATION OF THE NORTH ATLANTIC
THE LEGACY OF DAVID ELLETT 1934-2001

The warm surface current that flows northwards past the west coast of Scotland is an important arm of the global thermohaline (and Atlantic meridional) overturning circulation (the THC). It plays a significant role in moderating the climate of Scotland and north-west Europe, and its influence spreads throughout the globe from the Arctic to the Southern and Pacific Oceans. The relevance of the overturning circulation in the North Atlantic to the climate of northern Europe is well recognised by climate modellers investigating what would happen if the THC were to change in strength.

The northern North Atlantic and Nordic Seas are historically amongst the most measured of oceans, which is just as well as the circulation patterns here are not only complicated but also vary with time. Warm and salty surface waters move northwards and eastwards at the latitude of the British Isles under the forcing of a mean SW wind stress, a northwards internal pressure gradient caused by cooling in the Nordic Seas, and entrainment with the cold bottom water that cascades southwards across the Greenland - Scotland Ridge (see map - right). North of the ridge these surface waters sink and return south in bottom following currents. South of the ridge, on its western side, the Labrador Sea and Irminger Basin contain a great wind-forced circulating pool of water that is further driven by winter convection to great depths before making its way southwards and eastwards into the Atlantic Ocean as part of the global THC.

Many of these recirculating waters pass close to Britain's shores, and in the last 30 years the annual mean near surface temperatures of the Rockall Trough have seen a steady increase in temperature of about 1°C, significantly above the global mean warming rate of about 0.6°C over the last century. The reason for this excess warming is not obvious but is likely to be due to changes in the circulation patterns of both the North and South Atlantic. For example in the last decade the position of the surface front that separates cooler water to the west from the relatively warm water of the Rockall Trough has moved westward, as the sub-Polar Gyre has retreated and allowed more water to enter the Trough from the south.

We know this because of the dedication and foresight of SAMS' David Ellett, who recognised the importance of long term observations of the ocean and started a conductivity, temperature,

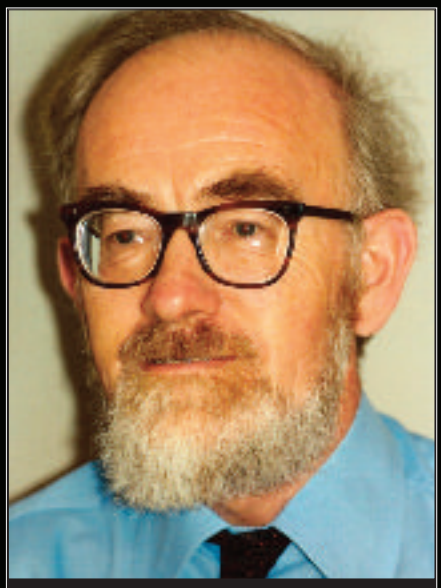
depth (CTD) section from Scotland to Rockall in 1975. This section, which in the 1990s was extended to Iceland when the National Oceanography Centre, Southampton became collaborators, has become a key 'National Capability' resource for the Natural Environment Research council (NERC).

The scientific legacy of the Extended Ellett Line is immense. Besides providing fundamental data for the analysis of the westward retreat of the sub-Polar Gyre, recent applications have also involved tracking the northward movement of water in the North Atlantic Current off the shores of north-west Europe, and investigations into the 'Great Salinity Anomaly' of the North Atlantic and the eastward migration of deep water from the Labrador Sea. Additional spin-offs include the development of national and international links, serendipitous research and student training, and the maintenance of technical skills.

When David started the Ellett Line in 1975 he had ready access to RRS *Challenger*, the ocean going research ship that was based at Dunstaffnage, and with his dedication to the project he made up to four crossings of the Rockall Trough every year. This facility ended in 1996 with the sale of *Challenger* and since then the line has been occupied just once a year. The resulting lack of seasonal coverage has proved a challenge at a time when we need to quantify the natural variability of the ocean state in order to isolate the underlying trend.

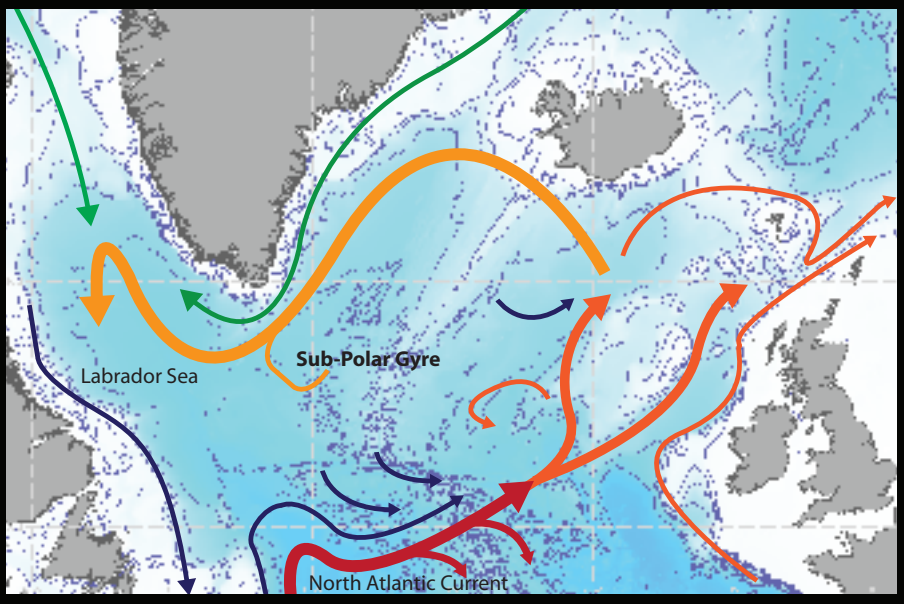
SAMS has risen to this challenge with innovative use of new technology such as marine gliders. On 12 Oct 2009 we deployed the first operational ocean glider mission in British waters from west of Tiree. Five days later *Talisker* crossed the shelf edge and began reporting ocean conditions down to 1000 m every six hours. By the end of her mission in March 2010 (see News page 8) she had performed 789 dives and produced a unique data set that is already providing insights into the circulation of the Rockall Trough. *Talisker* has thus demonstrated that gliders have the potential to replace ships for regular monitoring work.

With the ongoing assistance of our team of dedicated support scientists observational physical oceanography remains an exciting discipline at SAMS. Even though the present economic climate is uncertain, we look forward to building on the legacy of David Ellett.



David Ellett was the epitome of the physical oceanographer of his generation and his untimely death shortly after he retired has been a great loss. A gentle, modest, but highly respected scientist, the phrase 'perfect gentleman' springs to mind.

His research into, and knowledge of, the North Atlantic was immense and following in his shoes one is constantly led to suspect that David already knew all that we are (re)learning today. For example, David's analysis of historical winter temperatures in the Rockall Trough shows that there was an equivalent period of warming in the 1950s, which suggests that the recent warming may be due to natural variability.



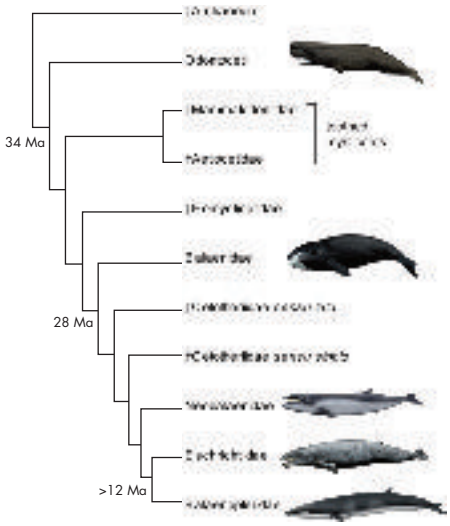
The recirculating surface currents of the sub-Polar Gyre

Further information

The Extended Ellett Line website at www.noc.soton.ac.uk gives a comprehensive overview of the Ellett Line. Also see: www.sams.ac.uk/ellett

SAMS first glider mission can be found at www.sams.ac.uk/glider

WEIRD AND WONDERFUL CETACEANS



by **Felix Marx**
University of Otago, New Zealand

All drawings by Carl Buell, Photo of *Janjucetus* skull by Rodney Start, Museum of Victoria (Australia)

More than 60 years ago, the famous palaeontologist George Gaylord Simpson described cetaceans (whales, dolphins and porpoises) as "on the whole the most peculiar and aberrant of mammals". A great deal of research, carried out by those who followed in his footsteps, has since helped to shed some light on the origins and evolution of these 'aberrant' creatures. We are now (reasonably) certain that cetaceans are close relatives of even-toed mammals – cows, sheep, camels and, most importantly, hippos. We also know that cetaceans most likely originated in the Tethys, an ancient sea bordering what is now India and Pakistan; that they are descended from dog-sized land-living ancestors; and that they are really quite old, with the earliest fossils ever found clocking up an impressive 53 million years. However, there are also a lot of things palaeontologists still have little or no clue about. For example, we are still not really sure how baleen whales, maybe the most conspicuous members of the cetacean family, are related amongst each other. This is a real problem, not just for people who are interested in their evolution, but also for conservation scientists with a view more centred on the present day. How can we assess how evolutionarily unique the living baleen whales are, or how they reacted in the past to environmental changes similar to those they face today, if we are not even sure how they are related, or when and how the living lineages first appeared?

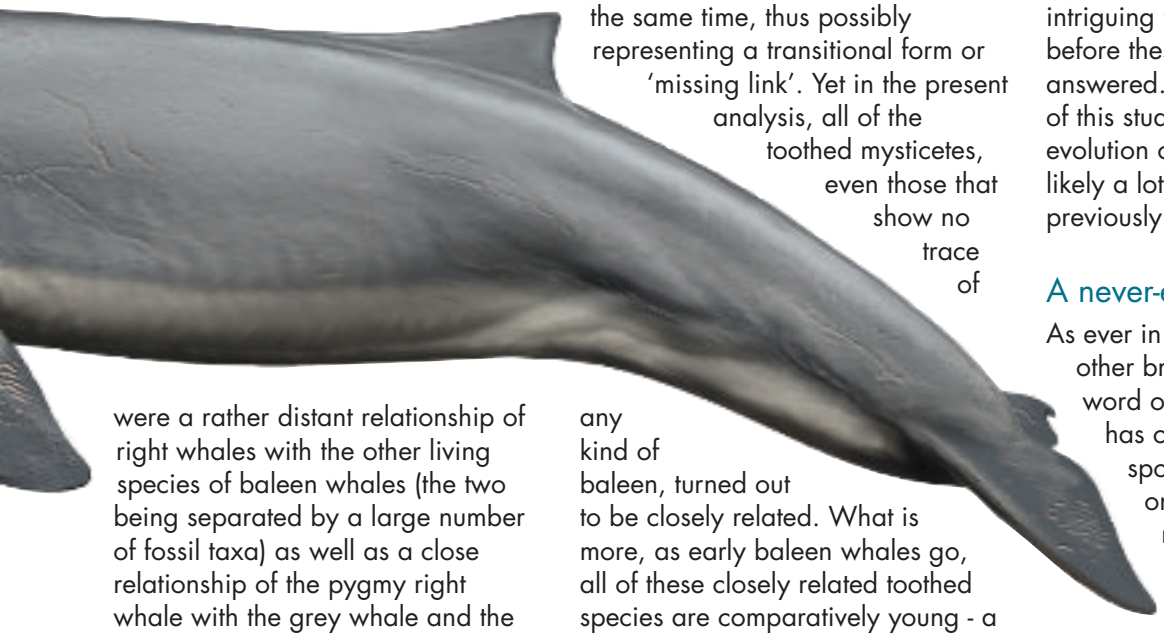
The problem of sorting out evolutionary relationships

Many studies have tried to use morphological and molecular data to reconstruct the mysticete tree of life. Yet, surprisingly, the results of these analyses have a tendency to contradict each other quite markedly. For example, morphological analyses generally tend to favour a close relationship of the pygmy right whale (family Neobalaenidae) with the right and bowhead whales (family Balaenidae). By contrast, many, albeit not all, molecular studies usually group it together with rorquals (family Balaenopteridae) and the grey whale (family Eschrichtiidae). The relationships of the latter are also frequently the subject of debate, and the grey whale has variously been included and excluded from the rorquals, and, on occasions, even been allied to right whales.

More data, new methods, better results?

The present study, which was based on morphological data, aimed to shed some new light on baleen whale evolution by looking at the relationships between a much larger number (53, to be exact) of both living and extinct baleen whale species than had been done in any previous analysis. The idea was that more data should provide more stable results. The data were analysed using three different phylogenetic analysis techniques, two based on the principle of parsimony and one based on Bayesian methods. Encouragingly, all three analyses yielded rather similar, well-structured and, most

importantly, well-supported results. Amongst the more intriguing findings were a rather distant relationship of right whales with the other living species of baleen whales (the two being separated by a large number of fossil taxa) as well as a close relationship of the pygmy right whale with the grey whale and the rorquals. The former result is important, as it underlines the evolutionary uniqueness of the right whale lineage, which is separated from the other extant lineages by at least 28 million years of evolution (as indicated by the presence of fossils of that age); the latter, because it represents the first time ever that this relationship has been identified in a morphological study. Given that analyses based on DNA also seem relatively consistent in grouping the pygmy right whale with rorquals and the grey whale, the findings of this study may be a first step toward a reconciliation of the often contradictory phylogenetic signals obtained from molecular and morphological data.



Mysterious mysticetes – with teeth

This analysis also yielded some results that are rather interesting from an evolutionary perspective. One of the more important concerns a very early group of 'baleen' whales that possessed teeth. At first sight this should not be too surprising, since baleen whales must surely have evolved from a tooth-bearing mammalian ancestor. Indeed, some previous analyses even hypothesised that some of the extinct toothed species that were included in this study (the Aetiocetidae) may have possessed both baleen and teeth at the same time, thus possibly representing a transitional form or 'missing link'. Yet in the present analysis, all of the toothed mysticetes, even those that show no trace of any kind of baleen, turned out to be closely related. What is more, as early baleen whales go, all of these closely related toothed species are comparatively young - a mere 25 million years or so – and thus existed 5 -10 million years after *Llanocetus denticrenatus*, the oldest baleen whale fossil ever found. Most surprisingly, although it did possess a set of widely-spaced teeth, *Llanocetus* also shows reasonably clear signs of baleen in the form of long grooves on the top of its mouth, which may have contained blood vessels supplying (proto-)baleen racks on either side of its jaw. In this, *Llanocetus* differs from aetiocetids, for which the potential evidence of baleen is somewhat less apparent, and thus potentially represents one of the best examples of a genuinely transitional cetacean species yet identified. (Note, however, that *Llanocetus* has not yet been fully described, and hence was not included in this study.) Why, then, did aetiocetids and their other toothed relatives still retain teeth so long after the origin of baleen whales, and indeed most likely of baleen itself? Did they represent an early and archaic sister branch of all other baleen whales that radiated 25-30 million years ago, and then came to a sudden end as the climate underwent a major shift? Or might some of these toothed 'baleen' whales have been derived from baleen-bearing ancestors, and indeed lost their baleen again as they adapted to a different mode of feeding or specialised on a certain type of prey? More work on these intriguing fossils will be needed before these questions can be answered. It is clear from the results of this study, though, that the early evolution of baleen whales was most likely a lot more dynamic than previously assumed.

A never-ending story

As ever in cladistics, and indeed any other branch of science, the last word on mysticete relationships has certainly not yet been spoken, and the work goes on. The evolutionary relationships proposed here will be subjected to the test of time, and indeed will most likely change as yet more data, more fossils, a better understanding of baleen whale morphology, and maybe even more living species are added to the mix. Bryde's whales, for example, seem particularly good candidates for a new round of species splitting, as cetacean biologists are currently mulling over no fewer than four potential species arising out of what, ten years ago, would have been considered a single, living taxon. Nonetheless, the agreement between some of the results of this study and many molecular analyses, as well as the relatively high support for many of the relationships identified here, may be reason to hope that, if nothing else, this analysis will be a step in the right direction.

Acknowledgments

I would like to thank SAMS for supporting this study with a research bursary that enabled me to travel to a number of museums, in particular the Smithsonian Institution in Washington, DC, where much of the fossil and extant material I had to investigate for this project was stored.

Jill McColl SAMS UHI student

ARCTIC EXPERIENCE FOR AN UNDERGRADUATE

On the 7th of August 2009, I left Scotland for a semester at the University Centre on Svalbard (UNIS). It is the world's northernmost higher education institution, located at 78°N. I arrived at half eleven at night, the sun was still shinning and there were lots of mountains with no trees on them at all - very different from Oban!

Student accommodation was in old mining barracks: these were amazingly sociable. On my floor were three Swedes, three Norwegians and three Germans. We hit it off immediately and became close friends. In fact, meeting new people from all over the world was one of the best parts of the experience.

The first week on Svalbard included a two day safety course: we had to jump into the fjord (thankfully wearing a survival suit), learn first aid, how to set up camps, and finally received rifle training.

This included how to load, aim and fire in case we were ever in a situation with a polar bear. Polar bears are common in Svalbard and rifles are used as a standard safety precaution. If you see a polar bear, firstly you must try to scare it off using a flare gun; the rifle is a last resort.

Our term started with "Arctic Hydrology and Climate Change" and "Arctic Pollution". I really enjoyed both, and in particular my project on the effects of shipping in the Arctic. Shipping is predicted to increase as Arctic sea ice extent decreases, expanding access and opening a short route from Asia to Europe. My project focussed on the effects of antifouling paint on organisms. (Several gastropod species exhibited "imposex", when female organisms display male sexual characteristics).

The courses concentrated a lot on team work, which was fun and a different way to learn, teaching me a lot about my strengths and weaknesses. There was also a lot of field work. During "Arctic Hydrology and Climate Change" we went to Kap Kinne to look at hydrological structures in the area. We got there by speed boat, passing many "ghost towns" abandoned from the old mining days, looking run down due to the harsh weather.

During "Arctic Pollution" we had a trip to Svea, a small mining village. We took a small plane there, which was brilliant as the plane flew quite low and everyone had a window seat – and a bird's eye view of the beautiful mountains and glaciers. We worked all day doing experiments on oil spills, putting different types of oil down on the beach and recording how long each took to disperse, the viscous oils taking the longest. We took turns on polar bear watch as there were three in the area at that time. I was awful at this as I forgot to load the rifle or even take bullets with me, so if we had seen one I would have been useless! We did see a polar bear from a safe distance, on the hill behind where we were staying. Although it was just a white dot in the distance without binoculars, it was still an amazing experience to see a polar bear.

Not only the courses were filled with enjoyment; the social life in Longyear was brilliant. Every week we had "Friday Gathering", the perfect way to finish off the week. As I was the only Scottish person there, I tried to teach people how to Ceilidh dance by playing Scottish music through an ipod but this usually turned into a disaster after a few drinks.

Just as my time on Svalbard was coming to an end, I finally saw the Northern Lights. This experience made my trip, and I wish I could have shared it with my family and friends from Oban as it was amazing. The lights were moving pretty fast across the sky, bright green in colour. The whole setting was incredible as there was a glacier in the background and snow all over the mountains.

Going to Svalbard was an experience that will stay with me forever. The environment was so different from any other I have experienced: when I arrived it was 24 hours of sunlight and when I left it was 24 hours of darkness. It was also very cold in winter, but these reasons are what made my trip to Svalbard special.

Further information

Jill's full blog at: www.sams.ac.uk/expedition-blogs/students-in-the-Arctic/jill-mccolls-blog
www.unis.no

David Meldrum SAMS Marine Technology Group

Sea ice has an important effect on the heat balance of the planet because it reflects solar energy back into space. For this reason alone, when there is a lot of sea ice the planet will tend to be cooler than when there is no sea ice. At the moment the planet is warming and sea ice, especially in the summer Arctic, is disappearing: this will accelerate the warming trend.

Unfortunately climate models do not accurately describe the changes we are seeing in the Arctic, and this is affecting the quality of their predictions. The reason the models are struggling is that we do not properly understand how sea ice grows and decays throughout the year, and in different parts of the globe.

In February this year, I joined RRS *Ernest Shackleton* in the Antarctic to set up an experiment on the sea ice. The object of the experiment was to improve our understanding of sea ice dynamics, and so to make the models better. We deployed a number of sensor chains through small holes in the sea ice.

The chains comprise 120 tiny sensors which measure temperature changes in the ice as it grows and decays, as well as in the sea under the ice, and in the snow and air above it.

The measurements are sent back as emails to our lab in Scotland by tiny satellite transmitters. We hope that the equipment will work for at least one year before it melts out into the Southern Ocean.

We also deployed eight drifting buoys as part of a global effort to populate the world's oceans with barometers and sea surface temperature sensors. The buoys are attached to a sea anchor, both to slow their drift and to give an accurate estimate of the surface current, and should last for at least a year. The data are used in near real time by weather forecasting centres all round the world, and in delayed mode for climate studies, oceanography and satellite sensor validation.

Further information

See the latest data sent from the sea ice sensor chains at:
http://dalriada.sams.ac.uk/asbo/

See the latest drifting buoy map at Data Buoy Cooperation Panel site:
www.jcommops.org/dbcp

OBITUARY

MARGARET BARNES DSc FRSE FIBiol 1919-2009

Robin N Gibson SAMS Honorary Research Fellow

Early days

Margaret Barnes was born in Manchester on 26 August 1919. After a brief period in Wales her family moved back to England where she continued her education in Devon and in 1939 was awarded a BSc from the University of London. Her further education was partly interrupted by the outbreak of World War II and she went to work in industry where she spent the following six years using her training as a chemist to investigate colloidal graphite lubricants. During this time, and with characteristic determination, she used her spare time to study for an MSc which she was awarded in 1945 at the end of the war.

Husband and wife team

She had met her future husband Harold while at college and they married in 1945. Harold was also a chemist but in 1943 had been seconded to the Scottish Marine Biological Association's (SMBA) Marine Station at Millport in the Firth of Clyde where he was involved in the development of antifouling paints. After their marriage Margaret joined him in Millport and it was there that their lifelong partnership in science began.

Barnacle research

Harold's early work was varied, but he had developed an interest in barnacles during his antifouling work and began publishing on the group in the early 1950s. Margaret acted as his assistant, officially designated by the Marine Station in the SMBA's restrictive practices of the time as an 'unpaid permanent visiting worker'. It is remarkable that in all the years she was associated with SMBA/SAMS her employer never offered her a salaried permanent position. Their first joint paper appeared in 1953, albeit on *Calanus finmarchicus*.

Their barnacle papers then came on stream covering a very wide range of topics including general biology, morphology, distribution, reproduction and development, settlement, biochemistry, physiology and metabolism.

In 1967 the SMBA opened its new laboratory in Oban and Harold and Margaret moved there from Millport to continue their barnacle studies.

An editor's life

Before moving, however, in 1963 Harold had started the review series *Oceanography and Marine Biology: An Annual Review*. The husband and wife team, now becoming recognised as world authorities in barnacle biology, continued their partnership in editing 'The Review', as they called it. Not content with starting one journal, and with Margaret's continuing support, Harold followed *Oceanography and Marine Biology* four years later in 1967 with the *Journal of Experimental Marine Biology and Ecology* (JEMBE). The first issue of JEMBE was published in September of that year and it is significant that the first paper in the issue was co-authored by Harold and Margaret. Margaret was an integral, experienced and tireless other half of the editorial team on both periodicals, so that on his sudden and untimely death in early 1978 it was natural for her to assume the editorship of both publications and so ensure their smooth continuation. The year following Harold's death was a difficult one for Margaret but she showed little outward signs of her grief and buried herself in writing up unfinished manuscripts and in the considerable amount of editorial work the two journals entailed. She also had to be involved in the painful task of discussing with the publishers her future role. Fortunately, Aberdeen University Press (AUP) were aware of her contribution to the regular appearance of past volumes of *Oceanography and Marine Biology* and were content to allow her to continue as Editor. The transition for JEMBE was not as smooth and Elsevier insisted that others joined her on the editorial team. Although Margaret was not initially happy with this arrangement she realised it was for the best, because one person could not have managed the burden of editing both journals single-handed. In the late 1980s she invited colleagues to become Assistant Editors on *Oceanography and Marine Biology* to share the load. In 1998, and approaching her 80th

birthday, she decided it was time to take a back seat in the editorial team and Alan Ansell took over the reins as Managing Editor. Prior to this, however, in 1993 AUP collapsed as a result of what was known at the time as the 'Maxwell affair' and the rights were bought by University College London Press. Another change of publisher took place in 1998 (to Taylor & Francis) and Margaret continued as co-Editor until Volume 40 was published in 2002 when she decided to stand down, having retired from JEMBE in 1999, thus ending a 57 year contribution to marine science.

Her long standing contribution was publicly recognized in 1972 when the University of London awarded her a DSc for her cirripede studies and in 1976 when she was elected a Fellow of the Royal Society of Edinburgh.

Subsequently she was made a SAMS Honorary Research Fellow in 1978 and the Institute of Biology invited her to become a Fellow in 1980.

She was a meticulous editor with a fine eye for detail, who insisted on high standards of English and spent many hours improving the texts both of authors whose first language was not English and many whose it was. She dealt diplomatically but firmly with tardy or recalcitrant authors and I well remember her patience when meticulously compiling the indexes for early volumes of *Oceanography and Marine Biology* from entries on scraps of paper which were then sorted and typed out by hand, a task now done in a fraction of the time by computer. She brought to both publications standards that few others could match.

Margaret and Harold travelled extensively in the course of their barnacle work and they were founder members of the European Marine Biology Symposium. In 1988 Margaret was elected for a term as President. She was intimately involved with the two Symposia that were held in Oban in 1974 and 1989 and was instigator, organiser and Senior Editor of the Proceedings of the latter meeting. In later years when she no longer felt able to attend the Symposia, I was frequently asked by participants "How's Margaret?" and to pass on their regards. At the EMBS and during her visits to numerous laboratories throughout Europe and the US she made contact with people the world over and many of these contacts developed into lasting friendships. She was always encouraging to young scientists, especially young women. As one of them explained to me, "Although she was a very traditional woman in many respects, she did buck the trends of the time by being very successful in her own right and by demonstrating intellectual independence from her husband and I believe she was very proud of her DSc, a public acknowledgment of her contribution to science. She told me she had to strongly argue the point and explain why several of her publications had Harold as first author when in fact she had done the work." This comment sums up Margaret's attitude to her work. She was an independent and determined woman largely overshadowed by her husband and her true scientific and editorial abilities only really became apparent after his death.

Outside interests

She was a gentle, modest, courteous and charming person, a good listener and had a terrific sense of humour. In her younger days she was very active as a keen cross-country skier, mountaineer and long term member of the Austrian Alpine Club. She remained sprightly until her death, working in her garden throughout the year and we had numerous conversations about hill walking and the state of her crops. She was also a keen sports fan and could talk knowledgeably about tennis, rugby and snooker. However, I suspect that many will particularly remember her for her coffee mornings and dinner parties. They were deservedly famous for their wide ranging and relaxed conversation and their cuisine, and it gave her great pleasure to entertain students and visiting scientists of all ages and nationalities at her home overlooking the sea.

Margaret died peacefully in Oban on 30 October 2009, leaving the legacy of a considerable and longstanding contribution to the scientific output and social life of the SMBA/SAMS Laboratories. She will be greatly missed by all who were privileged to call her friend or colleague.

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