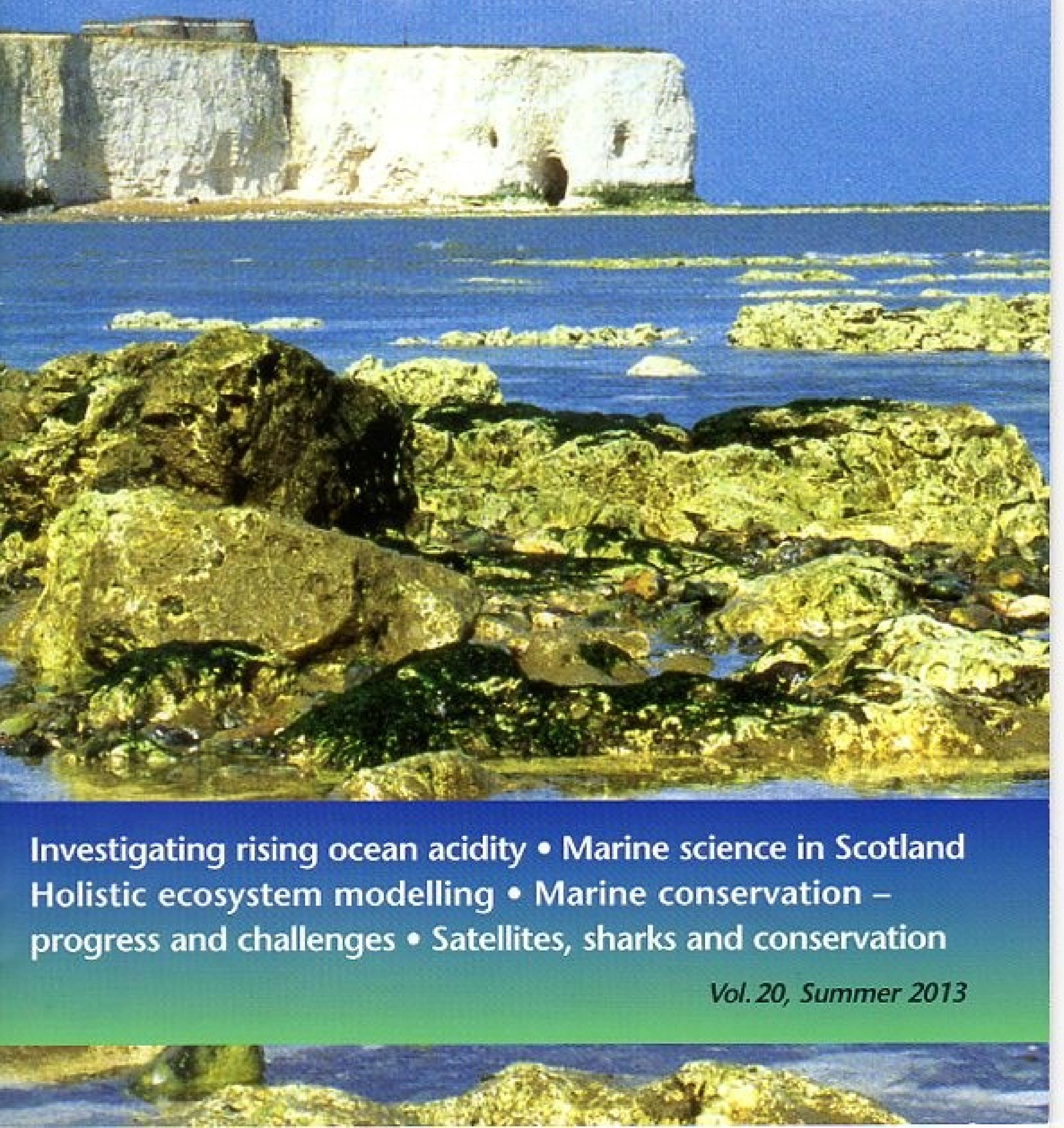
OCEAN

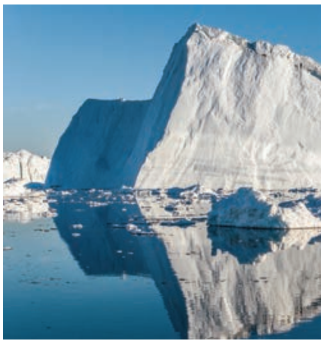
Challenge

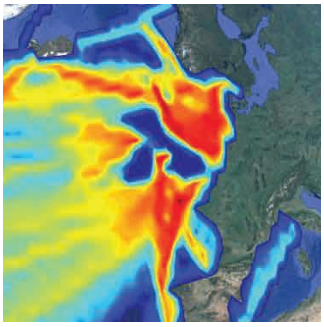
The Challenger Society for Marine Science

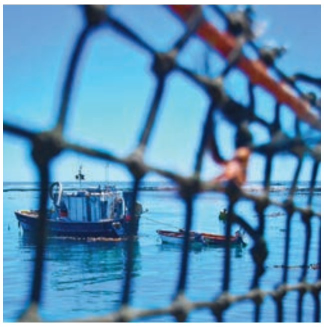


Investigating rising ocean acidity • Marine science in Scotland
Holistic ecosystem modelling • Marine conservation – progress and challenges • Satellites, sharks and conservation

Vol. 20, Summer 2013







CONTENTS

Message from the Editor

The first part of this issue relates to communication of our science. First, some encouragement for Challenger members to come together at the biennal conference in Plymouth and exchange ideas in various ways and formats. Then we have a tribute to *Ocean Challenge*'s Associate Editor, John Wright, who died earlier this year, and whose motto was 'Communication, not obfuscation!' This is followed by an interview with the Editor of *Nature Geoscience,* who has some good advice for those aiming to hone their communication skills. And If you have your eye on a prize at the Conference, do take note of the information below, and the tips for posters and presentations on page 4.

A topic that reccurs in later pages is the value of sustained observations and long time-series. There are also pieces on icebergs, aerosol in the Arctic, corals and coralline algae, and the challenges of conservation on both the local and the regional scale.

Angela Colling

Challenger Society Matters

The President's Photographic Competition

The President's Prize is given for the photograph judged by the President and President Elect to best convey a theme related to marine science. This year's theme will be

Interaction with marine science

Submitted photographs will be displayed in the poster hall at the conference. The owner of the winning entry will be awarded the prize at the conference dinner. To enter the competition, please submit your photograph in both paper and digital format. Paper versions should be submitted to the conference registration desk by Tuesday lunchtime, 9 September, or posted to:

Kate Brailsford, Challenger Photographs,
SAHFOS, The Laboratory, Citadel Hill, The Hoe, Plymouth, PL1 2PB

Your name and a title, relevant to the overall theme of 'Interaction with marine science', and a short description of what the photo portrays, should be written on the back of the photograph using soft pencil. In addition, please email a digital copy of your photo to csms@noc.ac.uk in a commonly accepted image format (jpg/tiff/bmp). All images are requested at high resolution but no more than 10 Mb due to email limits. Please attach your name to your image file (e.g. john_r_smith_1.jpeg) so that credit can be allocated when appropriate, and to avoid file-name duplication.

All entries must be taken by the person submitting the photograph and must not be overly post-processed (e.g. colours should be natural and objects should not be added or removed)

Black and white images are acceptable • The maximum size of the photograph should be A4

Entries will be judged anonymously

Entry to the competition constitutes agreement for the Challenger Society to use the photos (with attribution) in publicity material (but they will not otherwise be distributed).

Hilary Kennedy (President)

Can You Produce Winning Words?

As in many previous Challenger Society Conferences, a prize will be awarded for the best report of the meeting, which will be published in *Ocean Challenge*. The report should be your personal impression of the meeting – both science and social aspects, highlights and lowlights – rather than a blow-by-blow report. The emphasis should be on lively writing and good communication.

Entries should be sent to the Editor at AngelaMColling@gmail.com within three weeks of the end of the conference, and be about 1000 words long. The writer of the best report will receive a cheque for £75.

Challenger Conference for Marine Science

Held at Plymouth University, hosted by:

Programme themes

- Physical dynamics and connections of coastal oceans: from estuaries to the continental slope
- Observing and modelling the open ocean: from pole to pole and surface to seafloor
- Biogeochemical cycles
- Remote-sensing of the marine environment
- Modelling food-web dynamics and ecosystem functioning
- Modelling Interactions between hydrodynamics and the environment
- Exchanges at the air–sea interface: current status and future outlook
- Emerging technologies
- Marine time-series
- Marine microbes
- Marine biodiversity
- Deep-sea ecosystems
- Marine policy: challenges and tools for managing marine and coastal resources

Keynote speakers

Prof Jason Hall-Spencer: Ecosystem effects of ocean acidification
Prof Icarus Allen: Towards the next generation of marine ecosystem models
Dr Isabelle Rombouts: Pelagic biodiversity: from patterns to emerging processes
Dr Emily Shuckburgh: The polar oceans in a changing climate
Dr Adrian Glover: Environmental futures in the deep-sea mining frontier

To register for this event please visit:

http://www.2014.challenger-society.org.uk/

Some dos and don'ts for posters and presentations

There are two prizes to be won at the UK Oceanography Challenger Conference, in addition to that for the best entry to the President's Photographic Competition. These prizes honour Cath Allen and Norman Heaps. Cath Allen was a researcher in fluid dynamics at the University of Lancaster, who died in 1991. The Challenger Society introduced the prize to combat the idea that contributing to a conference poster session is a second best alternative to delivering a paper, even though a poster needs to be at least as well thought-out as a talk. Norman Heaps was a shelf-sea modeller who died in 1986. He was a particularly clear speaker, with an enthusiastic, lively and entertaining way of delivering a talk.

The Cath Allen Poster Prize

- A poster is a chance to use your skill in presentation of data, in layout, and in distilling the essence of your message. **It is not an abbreviated paper**.
- **A poster needs to be attractive**, with an interesting title that is visible from a distance. If a poster doesn't draw attention to itself, it could be overlooked, and all the work put into it could be wasted.
- **A poster needs to be easily readable**, and not just by someone standing really close to it. For the main text, take care to choose a clear type-face at sensible point size. Avoid long complex sentences.
- **Avoid large slabs of text** and overlong line-lengths; the optimal line-length for readability is considered to be 50–65 characters per line, including spaces. For consistent spacing between words, use unjustified text.
- **Ensure your diagrams are large enough** to be seen clearly, and that the line weights of graphs etc. aren't too spindly.
- **Ensure that you have explained your symbols and acronyms,** and have put scales on figures if necessary.
- **Try not to have more than about five figures** (diagrams and photos). Remember that a well-chosen picture can be worth a thousand words.
- **Diagrams need to be close to the text** that relates to them, **or very easily found**.
- **Make use of colour** to enliven the poster and help direct the reader where to look.
- **Don't be tempted into over-complicating the appearance of the poster**, and obscuring your message.
- **Try to convey why your research is so exciting**.
- **Be there by your poster to answer questions**.

The Norman Heaps Prize

- **Time your talk beforehand.** There is nothing more upsetting than having to leave the podium without getting to your conclusion.
- **Beware of overload**. It's not advisable to have more than about half-a-dozen pieces of 'hard' information (diagrams, maps, tables) per 15 mins of presentation. **That's still only 2.5. minutes per picture.** (This doesn't preclude any scene-setting photos.)
- Don't forget that **your time slot includes** 2–3 minutes for **questions.**
- Everyone uses their Powerpoint slides as memory prompts, but **try not to find youself just reading from them or you will lose spontaneity**.
- In particular, reading through introductory slides that show the title, the aims, methods, results and even conclusions, takes up valuable time and isn't necessary, as the Chair will have already introduced you, and the audience has the book of abstracts. **If you are determined to have an introductory slide, make it brief and interesting**.
- Your results may be fascinating, but that's irrelevant if they can't be read from further back than the first two rows. **Graphs and diagrams are easier for an audience to take in than tables**. If you do use tables, highlight the numbers you are talking about.
- **Make use of colour** to enliven your graphics and help convey your storyline.
- **Use variety – switch between text, diagrams and photos**. If you use visuals from a number of sources, ensure that they use the same conventions for symbols etc.
- **Remember who your audience are**. Challenger conferences are attended by marine scientists from all disciplines, each with their own vocabulary, so try to explain any specialist terms so that everyone can follow your talk.
- **Try to convey why your research is so exciting.**

A tribute to a great communicator

This is an unusual tribute, because it is written by the Editor of *Ocean Challenge* about the Associate Editor, John Wright, who died earlier this year. Without John there would be no *Ocean Challenge*, but John's contribution to the communication and dissemination of oceanography go far beyond this publication.

John was not an oceanographer. He began his working life as a geologist in the Kenya Geological Survey; after Kenya, he moved to New Zealand to work at the University of Otago. In 1967, he went to northern Nigeria to become the founding Head of the new Department of Geology at Ahmadu Bello University, Zaria – the first Geology Department in the vast area of northern Nigeria, and initially more or less a one-man department. While in Zaria, John combined running the department with both teaching and research, and was one of the first geologists to attempt to interpret the evolution of the Nigerian basement in terms of plate tectonics. The ability (or perhaps compulsion) to work like a demon, remained throughout his career.

After three years in Nigeria, John was invited by Ian Gass, the Head of the embryonic Department of Earth Sciences at the Open University, to join his small team of academics. Here he poured his enthusiasm into courses on geology and geochemistry. His writing, and his understanding of what students at a given academic level would be able to relate to, were major factors in shaping the first OU Earth Science courses and their successors. Most of the courses produced during the first 25 years of OU Earth Science teaching benefited from his experience and insight.

John was particularly passionate about courses concerning the Earth's physical resources. In his awareness of environmental issues, he was ahead of his time, and in the 1970s was involved in the building one of the first two solar houses in the UK.

The Open University Oceanography course

In the mid-1970s, Ian – who was an expert on ophiolites (ocean crust emplaced on land) – decided, with great foresight, that there should be a third-level Open University course on oceanography. Some of the course was to be written in house, but as the department did not at that time contain any oceanographers, a carefully chosen group of marine scientists at the University of East Anglia were asked to help out, and John was tasked with fashioning the text provided into OU course material. John was famously ruthless as an editor, with a keen eye for the essence of a story. As a result, some of the originators of the text were startled by the final result – but most came to see that it worked well.

This first OU oceanography course (which ran from 1978 until 1987) was probably the first UK oceanography course to deal with all aspects of the ocean – its physics, chemistry, geology and biology. However, it showed its origin in what was at that time essentially a geology department. When its updated successor was being planned, the oceanography team decided that only science that directly involved seawater would be covered, so magma chambers were out, but hydrothermal vents were in! This second version of the course sought to bring together all aspects of the ocean and show how they interacted with one another. John embraced this interdisciplinarity, and one of his favourite sayings was 'Everything in the ocean relates to everything else!'

The Oceanography course became one of the most successful and long-lived OU science courses, and its course books, published by Butterworth–Heinemann, sold well to students at conventional universities (they are still on recommended reading lists and are available online).

John was capable of achieving an international research standing in his own field, but his real love was communicating science – not just through writing, but also through lecturing, teaching at OU Summer School (where he was known as the White Rabbit), and presenting OU TV programmes. Whatever he was doing, his main concern was for those striving to learn.

John in his element during filming of an Open University TV programme

Ocean Challenge

Ocean Challenge was first thought of in 1987. It resulted from a 'meeting of minds' between certain Challenger Council members (notably Martin Angel, Peter Foxton and Anthony Laughton, then Challenger Society President), who were considering the possibility of a Challenger Society publication, and John and myself. The production phase of the second oceanography course was over and we were both missing the excitement of discovering new developments in oceanography and telling other people about them. We were therefore wondering how to set up an accessible, multidisciplinary oceanography publication. The Council, for their part, were keen to use the experience gained in making complex scientific material understandable for Open University students. A deal was struck!

John had extraordinary drive and energy. Many readers will recall him (in White Rabbit mode) rushing about Challenger Society conferences on the hunt for suitable *Ocean Challenge* authors. As well as commissioning articles, editing them and helping in all other aspects of production, John often wrote for *Ocean Challenge*. His writing conveyed his intellectual curiosity and sharpness, and his way of making links between different areas of science. His pieces were quirky, entertaining and sometimes mischievous, but very often had a serious message.

Angela Colling

An interview with the Editor of Nature Geoscience

Heike has headed the editorial team of *Nature Geoscience* since the launch phase in 2007, and before that was a Senior Editor at *Nature* handling manuscripts in the broad area of climate science. *Ocean Challenge* Editors first had the pleasure of meeting Heike when she won the prize for the best report of the Challenger Society Conference in 1996. Here she explains why you don't need to go to sea to have a satisfying career in Earth and ocean science.

How did your interest in marine science begin?

I have always liked the seaside, and the ocean, like most kids. But a more serious engagement and interest in the science of the sea started in 1990 when I worked as a summer student at Proudman Oceanographic Laboratory (POL), then located on Bidston Hill. At the time, I was a student in Marburg, Germany, and was looking for a more interesting way of using the maths degree I was working towards than banking or actuarial work. I loved the setting at POL as much as the more immediately relevant and practical problem of understanding ocean dynamics, compared to the very abstract world of pure maths. Seeing a few people with a maths degree at POL, and hearing of more mathematicians-turned-oceanographers elsewhere, greatly encouraged me that ocean science might actually be a potentially viable career path. So when I finished my degree two years later, I applied – successfully – for a Ph.D project in ocean modelling at the Institut für Meereskunde in Hamburg.

What prompted you to go into publishing?

Much as I loved trying to understand how the oceans work, and how climate change may be affecting them, I soon discovered that I completely lacked any passion for programming – something my degree had been extremely light on. (To illustrate the spirit in the Marburg maths department at the time: one of my professors once opined 'Why on Earth should I buy a computer? I might as well smoke marihuana.').

Yet with my maths background the natural employment for me was in numerical modelling. And even a change into observational oceanography was unlikely to allow me to escape: my sea-going colleagues were also spending more and more time using computers to handle large datasets. So I decided to try my luck elsewhere, and look for a field where I could spend more time thinking about the science, and less on the tedium of finding errors in my Fortran code. The position of an editor at Nature *was the perfect solution to that conundrum: henceforth all the most interesting ocean, atmosphere and climate science landed – ready-to-read – on my desk, and I could concentrate on selecting the most relevant and compelling work to appear in the journal.*

What are your thoughts on Open Access publishing?

The publishing industry has changed immensely since I started as a Ph.D student, and the rise of open access journals is one important aspect of that change. Personally, I think the future of academic journals will be two-pronged. On the one hand, online-only publishing has opened up a relatively low-cost way of disseminating any piece of research to the people who are interested enough to go and search for it. This development will support mega-journals that publish 'the long tail' of research: that vast number of studies that are of interest to only a small number of fellow investigators of the same phenomenon. Open Access publishing – financed by the authors and therefore not requiring a large number of readers for each piece – is well suited to this task. On the other hand, however, researchers still only have 24 hours per day, and have difficulty in keeping up with the literature even in their own field. Yet to stimulate ideas and keep up with the most recent developments, many still want to read papers that are at least slightly outside their direct area of interest. This is where I see the role of highly selective publications like Nature Geoscience*: we are hoping that our readers will come to us to browse, to learn about the bigger picture, and to think along unfamiliar tracks. We, as editors, read 160 papers per month, so that our readers can enjoy just the twelve or thirteen most pertinent ones – those that we, and our referees, think will make an interesting, compelling and worthwhile read for a broader audience.*

What is the most challenging aspect of your job?

As the Chief Editor of Nature Geoscience*, it is particularly important to me to ensure that all areas of the Earth and planetary sciences are represented fairly, and that our decisions on each submitted paper are as prompt, consistent and transparent as possible. With the large volume of submissions we receive, and the limited amount we can publish – for reasons explained in a recent editorial (http://www.nature.com/ngeo/journal/v7/n2/full/ngeo2090.html) – these three goals are not always easy to achieve at the same time. Of course, in addition to the research we publish, we also run a sizeable section of the journal with opinion pieces, overview articles and reports. Identifying the topics that will resonate most with our readers, and finding the scientists that are best placed to write on these topics, can take a lot of thought, too.*

Do you sometimes hanker after fieldwork or research?

Unfortunately I only once had the opportunity to go on a research cruise, during my Ph.D. This was just so that I could get an inkling of what real sea-going oceanography is like. From what I have heard about other cruises, it was a fairly easy and quiet one, a summer cruise in the German Bight and up to the Skagerrak. Nevertheless, I enjoyed my time on the ship immensely. Lots of opportunity to stare at the ocean, think about the ocean and, occasionally, fight with the ocean (or the winch). But during my week on the water, I felt quite underqualified among a team of people who had spent whole summers on research vessels, and I knew this was just a one-off.

I can't say I have ever regretted giving up numerical modelling. I always liked the end of a project best, when the results come together, and are ready to be written up and reported and discussed at conferences. Now I am much more involved with that final stage – even though the findings are not my own discoveries any more.

What advice would you give to someone thinking about a career in scientific publishing?

During my Ph.D and post-doc years, I always volunteered to critique my colleagues' texts – PhD theses, papers, or anything else – before they handed them in or sent them off. It was a very positive experience: I learned that I really enjoy improving the flow of the logic and language in a text, my colleagues were pleased (mostly) to get constructive criticism on their work, and I broadened my scientific horizon, too. This extensive practice later helped me to look at manuscripts critically – and to understand authors' reactions to a less flattering assessment.

The other essential ingredient in our line of business is an ability to get to the essence of a piece of research, and to be able to express it extremely concisely. So I would advise anyone aspiring to a career in scientific publishing to spend some time on writing a tweet-length summary – yes, that's 140 characters, including spaces – of any paper, thesis chapter or status report that they have written or are planning to write: a summary that distills the core message of the text.

The GEOTRACES Chemical Atlas

The cycles and concentrations of the ocean's nutrient elements have been relatively well understood for some time, but a clear global view of trace elements long remained elusive. March 2010 saw the launch of a major international research programme to remedy this. GEOTRACES is a decade-long investigation designed to improve understanding of biogeochemical cycles, and the large-scale distribution of trace elements and their isotopes, in all major ocean basins

The $300m project has involved researchers from 30 labs worldwide, gathering data on almost 30 cruises since 2010. They have collected nearly 30 000 water samples at various depths from 787 locations around the world. An international intercalibration effort took place during the initial phase of GEOTRACES to ensure that results from different cruises, and from different labs, could be compared in a meaningful way.

The researchers have measured more than 200 substances, both artificial and natural, and have produced detailed digital maps of important elements. These include: iron, which can fuel plankton blooms and influence how the ocean responds to climate change; lead, whose distribution reflects past pollution of the ocean as well as continuing contamination; and aluminium, which is used as a tracer of desert dust entering the ocean.

UK-GEOTRACES has initially focussed on two sections in the Atlantic Ocean. These are to assess micronutrient cycling in a highly productive region and the calibration of critical paleoproxies (both in the South Atlantic), and the influence of metal input on biological processes, including nitrogen cycling (in the tropical Atlantic).

Much remains to be done, but a GEOTRACES 'atlas' is being constructed. This includes 3D digital maps and rotating images, providing a wealth of information, including the distribution of micronutrients, such as iron, zinc and cadmium.

For more information, see http://www.geotraces.org/ and http://www.ukgeotraces.com/

We hope to have a feature article about GEOTRACES in a future issue of *Ocean Challenge*.

An interview with the Technical Director of Partrac

Kevin Black describes the joys and challenges of working in the marine commercial sector

Partrac is a marine data-acquisition company specialising in oceanographic, environmental and geoscience surveys. Its headquarters are in Glasgow but it operates across the UK and in various countries around the globe.

How did your interest in marine science begin?

I grew up in Woodingdean to the east of Brighton, and we lived within walking distance of the beach there. I spent most of my summers on the beach, peeking into rock pools, building sandcastles, being rowdy with my friends, and swimming – lots of swimming. So I was a child of the beach really. From the age of about seven I joined a swimming club and swam competitively so I have always been confident around water.

As a child I watched all the Cousteau films on TV, and read about his exploits; and then there was the magnificent Victorian Brighton Aquarium, which at that time used to have dolphins in it. Whenever I went there I always made out it was my birthday so they would sing 'Happy Birthday' to me! When I look back I can see how all the pieces fit together. At 18 it was going to be either Oceanography or Medicine, and Oceanography sounded like much more fun!

What prompted you to start Partrac?

At the age of 37 I had done post-doc after post-doc, and there were no permanent jobs in academia. And so I went into commercial work by default really. I went to work for a firm on the west coast of Scotland, but the firm's owner turned out to be a rogue and so one day I simply left, wanting nothing more to do with that firm.

I wanted to stay in oceanography and there were still very few academic jobs on offer, so three of us from the old firm set up a new company, confident that we could do a better job. That was just over 10 years ago.

I went offshore as a Chief Scientist on the oil and gas SEA rounds (we mapped the sea-bed geology and biology of the north-east of Scotland and the Isles), which gave me some cash to work with. We also won a prestigious SMART:Scotland award to develop a novel geological tracer for use in contaminant and sediment transport studies, which is where our name comes from: Partrac = particle tracking.

What were the main challenges in developing the company?

Starting a company from scratch is almost a little mad! We were incredibly naïve at the outset in terms of commercial awareness, pricing, project management, cost control etc., all those things that are largely dislocated from the good parts – the science! And we had no reputation for delivering commercial projects. Early on, the three of us found the work (we were probably wildly cheap back then), did the work, and wrote the reports, all the while finding more work – an exhausting merry-go round. One of the biggest challenges is getting to the point of finding enough work to have other staff actually do the work (a survey team), to free up your time to build the company strategically. For any small business, employing the first staff is a nervous time. Then, of course, the pressure is on to keep the work coming in to keep those people fed and watered. Over our 10 years we have been through the worst recession in memory, which we really didn't need! However, one thing that was always a hallmark, and which I think our clients now recognise us for, is quality of work. More than anything, this has steered our ship through the stormy waters.

Over our history there have been a few times when we have really stuck our necks out and trusted our instincts. One of these was a £0.3 million investment in oceanographic monitoring equipment (ADCPs, wave buoys etc.) as the offshore wind industry picked up, and this certainly paid dividends. I don't know that everyone has such long and strong necks, but it certainly makes for an entertaining journey!

What are the best and worst parts of your job?

The best parts of my job are working with some great people on some really cool projects for some big clients. We have done studies for the US Geological Survey in Hawaii (tracking reef sediments), we have done all the monitoring of physical processes for one of the world's largest port construction projects, and we worked in the Florida Everglades for three successive summers to help inform planning their restoration. It ain't all bad! And the science – as the Technical Director in Partrac I am always on the sharp end of projects and responsible for technical delivery of projects.

Although we are a small company we actually do some highly unusual and innovative things. As present we have just been funded (with partners) by the Carbon Trust to undertake a huge project on turbulence for the tidal sector, which could be genuinely industry-changing.

I am hopeless with the more mundane but very necessary things, such as company finances, time-sheets, staff reviews, etc., and now I have twin boys all the travelling I used to do is less appealing. I now try to strike more of a work–life balance.

What does Partrac Consulting do?

We have in the company some specific expertise in coastal processes, environmental impact assessment (EIA), coastal geomorphology and geographic information systems (GIS), and therefore there was a time when it seemed a natural extension of the survey element to add consultancy to our list of services. While it remains a smaller component in terms of the company income we have nevertheless worked on a number of offshore wind projects and a proposed Scottish hovercraft crossing where we have written technical chapters for EIA and looked at issues such as scour and sea-bed mobility for clients. It's an interesting area of work where on technical quality we can compete with many of our rivals successfully.

What role do you see companies such as yours playing, in the context of climate change?

On a commercial level, where there are opportunities for Partrac to collect marine data to underpin these issues, then we should know about the work and bid for it. Secondly, I see us as having a role in educating people. As marine scientists involved in the industry, it is incumbent upon us to know as much as we can and to ensure that people are correctly informed – especially people who are higher up the policy or management tree and who make decisions which affect both us and the planet.

What do you consider would be the most sensible responses to problems like serious coastal erosion, and flooding of the Somerset levels, that occurred around the British Isles last winter?

As it happens, Partrac were the last people, in a contract with consultants Black & Veatch and the Environment Agency, to collect data on the flows and sediment budgets in the Parrett and Tone river systems and we therefore we know a thing or two about the sediments there, the siltation, and when dredging is necessary. The situation has been overtaken by politics, which isn't helpful.

If I could, I would suggest convening a forum, involving people from all sides, to review the situation and consider the options. I'd invite the media, appoint a forum co-ordinator and ensure that while sympathies lie with those flooded it is critical that a science-led, sustainable solution is found, even if that involves changing the management of the system at a policy level. And more importantly, get the solution delivered as quickly as possible, not five years hence. Let's get rid of all the reactionary, knee-jerk responses.

What is the future for Partrac?

Partrac now comprises a compact survey team and a small team of consultants (there are 12 of us now). We seem to have been successful at acquiring a good reputation and we are now a firm part of the commercial oceanography landscape in the UK. We have ambitions to head into oil and gas this year, and we have the technical expertise and assets to take on massive water quality monitoring programmes for the dredging industry, which we need to exploit. Partrac Consulting is very active in advising clients on long-term sea-bed mobility in connection with construction of Round 3 windfarms, a requirement for engineering design. Also, we offer particle-tracking services, predominantly in the USA, and this year we are focussing our efforts on the stormwater community. Finally, we now do hydrographic surveys, something we have long planned, and aim to expand into shallow marine geophysical surveys in time. There's lots going on. Here's to the next 10 years!

Finally, what does Partrac like to see in prospective employees?

We always welcome unsolicited CVs from any student; as you can see, we are principally concerned with physical oceanography and sedimentology, and don't get involved much in chemical or biological oceanography. We like to see students who work hard, have a 'can do' attitude, have a good grasp of field techniques and who can write clear scientific reports. Oh, and they must be numerate!

For more about Partrac, see http://www.partrac.com/

Deploying buoys at dawn

An hydrographer's tale: a tribute to Rear Admiral Steve Ritchie

In May 2012, the hydrographic community lost one of its most admired and celebrated personalities: Rear Admiral Steve Ritchie had made an immeasurable contribution to his profession, and was also held in high esteem amongst oceanographers. He was an Honorary member of the Challenger Society. Below is a belated tribute, which draws heavily on that published in the Hydrographic Society's publication, *Soundings*.

In an interview for *Hydro International* (May 2007), Steve explained how he became a hydrographer:

I was a naval cadet at Dartmouth Naval College from 1928 to 1931 and during the holidays one evening Admiral Sir Frederick Learmonth came to dinner. He was a former Hydrographer of the Navy currently serving on the Board of the Port of London Authority, of which my father was the secretary. When I was introduced to him as a Dartmouth cadet he realised he would have an attentive listener to his stories of navigating in treacherous currents through narrow channels in pulling boats [rowing boats] with sextants and lead and line. ...

Back at Dartmouth I asked those officers I could approach for details of the Surveying Service, but they knew little of the dozen or so survey ships working in many distant parts of the world. During my three years at sea as a midshipman I was always on the lookout for one such ship, but it was not until I became a Sub Lieutenant that [in 1936] I was able to join the ancient, coal-burning vessel Herald *as a temporary acting 4th Class assistant surveyor. My feet were on the first step of the long ladder.*

Prior to joining the survey ship *Herald*, Steve had been trying volunteer for the hydrographic service for some time. On leaving Dartmouth, he had joined the battleship *Valient*, whose captain actively tried to discourage his surveying ambitions. But during the pre-war Palestine crisis Ritchie was temporarily in command of the armed trawler *Lilac* off Haifa and found that he was in a position to recommend himself for surveying duties.

in 1939, following surveys off the coasts of Malaya and Borneo in the *Herald*, Steve came home to the *Jason*; within a few months he was transferred to the *Franklin*, for surveys off Labrador.

WWII and after

These surveys off Canada were cut short by the outbreak of war, and the *Franklin* returned to assist in the laying of the Channel Mine Barrage. Early in 1942, Steve was sent to join the *Endeavour* at Suez for surveys in the Red Sea and the Gulf of Suez, on an attachment to the Eighth Army. Ritchie and a colleague developed a technique for beach profiling (involving the use of folding two-man canoes) to identify suitable tank-landing sites behind enemy lines in North Africa. However his mission in the Bay of Bomba near Tobruk was almost scuppered before it had begun, by dozens of high-spirited Italian soldiers who chose to spend an afternoon relaxing close to where Ritchie was hiding in bushes, awaiting cover of darkness to start his work. Ultimately his survey was not used because the Eighth Army retreated to El Alamein, but young Lieutenant Ritchie was awarded the Distinguished Service Cross (DSC) for his show of courage and resourcefulness. After the Battle of Alamein, *Endeavour*'s surveyors were dispersed to Mobile Survey Units, surveying captured ports so they could be opened for shipping.

In 1944, Ritchie was in command of HMS *Scott* during both the rehearsals for D-Day and the invasion itself. The *Scott* was involved in mine clearance and the establishment of safe navigation channels using the new hyperbolic QM positioning system – a forerunner of Decca and Hi-Fix. *Scott*'s surveys along the coast of Normandy played an important part in the positioning of the Mulberry Harbour off Arromanches and in the landing of the Pluto cross-Channel fuel pipelines at Cherbourg. Port-opening work along the coast of northern Europe followed.

Early in 1946, Steve was appointed to stand by the conversion of the *Sharpshooter* for surveying, and on her commssioning went out to the Far East as her First Lieutenant. Returning from Borneo, Ritchie was appointed to the UK Hydrographic Office (UKHO) at Cricklewood as Officer in Charge of Notices to Mariners. Two years later, he was sent to Chatham to set up the Surveying Training Unit.

Commander to Captain

In 1949, Ritchie returned to sea in the newly completed *Owen*, for deployment to the Persian Gulf. In 1950 he was promoted Commander, with *Scott* as his first command. But before he had a chance to take up this appointment the orders were changed and instead he was flown out to Bermuda take over *Challenger* from the invalided Robin Bill. *Challenger* was undertaking a two-and-a-half-year voyage, making depth soundings in the three main oceans and the Mediterranean. Ritchie's experiences onboard *Challenger*, in the company of a small contingent of scientists from the Cambridge Department of Geodesy and Geophysics – including oceanographers Tom Gaskell and John Swallow – shaped his resolve that hydrography should adopt a broader oceanographic remit. *Challenger* was engaged in various research activities, and in 1951 a world record depth of 5940 fathoms (10 863 m) was identified in Challenger Deep at the southern end of the Marianas Trench – a highlight of the cruise.

Lieutenant Ritchie, Italy 1943

Ritchie left *Challenger* at the end of 1951 to become Superintendent of the Oceanographic Branch at Cricklewood. This lasted until 1954 when he was lent to the Royal New Zealand Navy for two years as commanding officer of HMNZS *Lachlan*, helping to establish the New Zealand Hydrographic service. He was promoted Captain while in New Zealand and came back to London in 1957 as Assistant Hydrographer.

In 1959, after two years in Whitehall, Steve returned to sea in command of HMS *Dalrymple*, for a survey of the Persian Gulf and then the north coast of Borneo, where the newly developed Two Range Decca positioning system was employed. This confirmed his belief in the importance of keeping up-to-date with technological developments.

In 1960, Ritchie returned to the UKHO, this time as Assistant Hydrographer, but three years later he undertook his final sea command, with the commissioning of HMS *Vidal*, a thoroughly modern survey vessel. Once again Steve found himself involved in the more scientific aspects of hydrography and the international NAVADO programme, which involved a fleet of international survey ships making geophysical profiles across the North Atlantic. During his final year of this command he was appointed ADC to Her Majesty before seeing the ship paid off at Chatham in August 1965.

Rear Admiral and Hydrographer

In January 1966 Ritchie was promoted to the rank of Rear Admiral and appointed as the 19th Hydrographer, a position he held until 1971. In 1967 he was made a Companion of the Bath (CB). During his time as Hydrographer, the UK Hydrographic Office underwent a period of radical change and technological advancement, coinciding with the department's consolidation at Taunton, which paved the way for contemporary charting and chart production. Steve oversaw the move from engraved plates to digital drafting, the use of four-colour printing for nautical charts and, perhaps most controversially, the metrication of depth measurements throughout the Admiralty's huge chart folio – something which the IHO had been advocating since its inception in 1921 but which had met with so much resistance that it saw the founding of the 'Friends of the Fathom'.

He was also at the helm during the advent of satellite navigation and digital echo-sounders and the introduction of computers and information technology to the department. Ritchie also eagerly, and once again contentiously, pursued the identification of designated shipping routes in the English Channel and Dover Straits – a move which eventually led to the adoption of the first mandatory traffic separation zones by the International Maritime Consultative Organisation (now the IMO). Ritchie retired from the Navy in 1971.

Work (and play) in Monaco

In 1967 Ritchie had led the UK delegation to the 9th International Hydrographic conference. In 1972, at the 10th conference, he was elected President of the Directing Committee of the International Hydrographic Bureau – the Secretariat of the IHO – and was subsequently re-elected in 1977. During his decade-long tenure, Steve oversaw the publication of the fifth edition of the GEBCO chart, in time for its use by UNCLOS (*United Nations Convention of the Law of the Sea*), and the establishment of the worldwide system of radio navigational warnings. He also actively encouraged the admission of both Russia and China to the IHO and successfully managed to steer the IHO on apolitical routes through both the Cold War and the Falklands conflict.

Much folklore surrounds Steve's time in Monaco. He is known to have frequented the infamous 'Rosie's Bar' where, it is alleged, more decisions were made by more admirals than were ever made at the IHO conferences themselves. He was also President of the 'Monte Carlo Club' – a group of fifty English-speaking gentlemen, who met once a month to enjoy a magnificent lunch in the Hermitage Hotel. It was in Monaco that Steve was introduced to the game of boules (or pétanque), which remained a passion. He would recall the occasion when he was enjoying an after-dinner discussion about the finer points of the game with Prince Rainier; the Prince broke off to write a declaration on the back of a menu card granting him permission to wash his boules in any fountain in Monaco!

The Hydrographic Society

Between retiring from the Navy and taking up his post in Monaco – aside from courses in bricklaying and decorating as part of the Navy's scheme to prepare him for civilian life – Steve spent some time as a Senior Research Fellow at the University of Southampton. Although he failed to complete his planned history of hydrography during this period, fruitful discussions with Alan Ingham (amongst others) ultimately led to the establishment of the Hydrographic Society in 1972, and to him becoming the first President.

Steve received many distinguished awards. These included the Royal Geographical Society's Founder's Medal, the Royal Institute of Navigation's Gold Medal and the Hydrographic Society's President's Prize. His achievements were honoured by the UKHO twice in recent years: first in 2004 when the new archive, opened by HRH the Duke of York, was named the Ritchie Building, and then two years later when he received the first Alexander Dalrymple Award, now presented annually in conjunction with World Hydrography Day.

As an Emeritus Member of the Hydrographic Society, Steve continued to support it energetically. His presence and ever-insightful and enthusiastic input were greatly appreciated.

Steve was a prolific writer, with an engaging style. He continued to write on both historic and topical affairs within the profession into his nineties, and wrote a regular 'As it Was' column for *Hydro International*. His books included *The Admiralty Chart* which ran to two editions, *Challenger – The Life of a Survey Ship,* and his highly popular autobiography, *No Day Too Long – An Hydrographer's Tale*.

Enjoying a Hydrographic Society conference

Steve had astonishing stamina and a zest for life – both professionally and socially – and made an immeasurable contribution to his profession. His friends and colleagues remember him as a great raconteur, a lover of music, a fanatical dancer, an ardent fan of Caribbean culture (particularly carnivals, steel bands and rum) and a boules enthusiast. He had his own sense of style (frequently sporting an elegant striped blazer and always red socks), and never lost the ability to surprise. Above all, he was always interested in everyone and everything.

Family was extremely important to Steve. He met his wife Disa onboard the SS *Ceramic* in 1942 and they married on arrival in Cape Town just weeks later. He is survived by two of their three sons and their daughter. He was immensely proud that his grandsons Francis and Allan decided to pursue careers in the Royal Navy and hydrographic surveying respectively.

Acknowledgements

Our thanks go to Helen Atkinson, the Editor of *Soundings*, where a longer version of this tribute can be found (Issue 58, October 2012) and more detailed acknowledgments. Other sources used for this piece include *Charts and Surveys in Peace and War* by Rear Admiral R.O. Morris (HMSO 1995) and Ritchie's own highly readable *Challenger – The Life of a Survey Ship.*

Ed.

Apps for the ocean and beyond

Paul Bell

Nowadays, many of us carry smart phones and regularly use apps. Here are some of the 'marine apps' that I find most useful when out and about, during both oceanographic work and sea-side leisure. The ones shown are free but most have added functionality that can be paid for. Other recommendations welcome!

anyTide UK

Available for IOS & Android platforms

anyTide UK is a mobile tidal prediction app that has been created by the National Oceanography Centre (NOC), and includes two types of tidal predictions:

- Predictions based on data from tide gauges located at sites around the British Isles
- Predictions based on computer models developed at NOC, Liverpool. This uses a model of the north-western European shelf on a 1.8 km grid and allows tidal predictions at any grid point around the coastline (and in major estuaries), filling in the gaps between tide gauges. It uses the same tried and tested system as the POLPRED package.

anyTide needs to have internet connection to create tide predictions (either via Wi-Fi or a cellular network). However, once a location is bookmarked, the tidal constituents for that point are stored and predictions for that location are available even when the device has no internet connection.

Met Office

Available for IOS, Android & Windows phones

Free 5-day forecasts from the trusty Met Office, with hourly predictions for two days ahead. I particularly like the map overlay of the UK's weather radars and rain forecasts for spotting incoming showers when planning a day out or even just a BBQ.

Ship Finder Free

Available for IOS & Android platforms

This uses live feeds from ship Automatic Identification System (AIS) receivers around the world to show you on a map the location, speed and heading of ships carrying AIS transponders. Different classes of vessels are assigned different colours, making ferries and cargo ships easy to differentiate, and you can bring up a vessel's name by tapping on its symbol on the live map. A great app for seeing where your ferry is when you're waiting at a port, or to identify a ship that's going past at the coast – or even track the ferry you are on and work out which bit of the coast you are looking at.

Sea Life Tracker

Available for IOS & Android platforms

The Sealife Tracker project aims to collect much-needed data on both invasive/non-native species and climate change indicator marine species around the UK coastline. It is the result of a unique partnership between the British Sub Aqua Club, the Marine Biological Association, the Environment Agency, Scottish Natural Heritage, the Scottish Environment Protection Agency, the University of Bristol and the Biological Records Centre. You don't have to be a diver or snorkeller to take part: the app features many species that you can find in rockpools and on the shoreline. Just don't drop your phone in a rock pool while you're using it! And, if you're lucky enough to own a boat, there's every chance you may encounter some pelagic warm-water species (e.g. sunfish) while out at sea, or find invasive species in marinas.

The team of developers has a range of apps to facilitate crowd sourcing of environmental data for a variety of topics, including freshwater invasive species, invasive plants, plant diseases, ladybirds and more. See http://naturelocator.org/ for more information.

MSW Surf Forecast

Available for IOS & Android platforms

This app provides wave, wind and pressure forecast charts from wave models that take feeds from a whole variety of measurements to keep them on track (the charts can be found in the 'more' section). I have used this app many times to anticipate the sort of wave conditions awaiting me on a trip to the coast. A great app that's not just for surfers!

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New insights into life as a baby turtle

Baby turtles communicate about when to leave the nest

Turtles have a special place in many people's hearts, but it seems we may have had misguided ideas about them. It was long assumed that they are mute, deaf, and solitary. However, recent evidence has shown that 47 different species of turtles are using sound to communicate, and this in turn suggests that turtles do not lead such solitary lives as we thought.

A recent study of leatherback turtles (*Dermochelys coriacea*) on Barra de La Cruz Beach in Oaxaca, Mexico, investigated sounds coming from 12 nests. Leatherback eggs incubate for about 65 days, and the recordings were begun after 51 days, when the embryos were well developed.

The sounds recorded were so distinctive that they could be classified into various types. There were short noisy sounds, and pulsing sounds (with a mean peak frequency of 960 Hz) that were associated with eggs, and may have been the result of the embryos rubbing body parts together, vibrating a body part in contact with some resonating chamber within the egg, or even discharging of gas bubbles. There were also harmonic sounds, with one note, or two separated by a short interval; these had ascending frequencies (ranging overall from 119 Hz to 24 000 Hz). The most complex sounds, recorded in nests that contained only unhatched eggs, were a combination of the harmonic sounds described above, and the pulsing sounds, with the latter following the former.

Although the less complex sounds could have been respiratory, or a kind of grunting, the researchers believe that the more complex hybrid tone in particular was produced by baby turtles for the purpose of coordinating synchronised hatching. Other animals whose embryos are known to emit sounds a few hours or days before hatching include giant South American river turtles (*Podocnemis expansa*), crocodiles and birds.

Unlike other species of sea turtle, leatherback females may change nesting beaches, though they tend to stay within the same region. They nest several times per season, with an average of 10 days between nestings. Although they do not come together in huge congregations (arribadas) like olive ridley turtles, it is still advantageous for the babies to hatch together. Communal digging could help the babies get to the surface more easily, and when there are hundreds of hatchlings heading to the sea at once, predators are overwhelmed, enabling a larger proportion of young to survive than would otherwise be the case.

Confirmation that sound is important to turtles has implications for turtle conservation. On many protected turtle nesting beaches, great care is taken not to confuse turtles with extraneous light sources, as turtles orient themselves on a beach by using the contrast between dark land (typically forested) and the brighter, often moonlit, sea: they head towards the dark for nesting, and then return to the light and the ocean. Now it's clear that noise pollution should also be of major concern; noise from motorised water vehicles could drown out communications between the turtle babies, and detrimentally affect the hatching process and the overall survival of the hatchlings.

Loggerhead hatchling

A hatchling's first journey is a formative experience

If a new-born turtle hatchling reaches the open sea, how does it know where to swim to? Juvenile whales and birds may learn migration routes by following their mothers or more experienced group members, but baby turtles are on their own – once the adult female has laid her eggs, her involvement in her offspring's development ends. What's more, hatchlings are very weak swimmers and are at the mercy of the currents.

In a study aiming to discover how adult turtles choose their feeding sites, researchers looked at what habitats the turtles would have encountered as juveniles. As hatchlings are too small to track with satellite tags, the researchers compared results of models of current flow past nesting sites (map below) with all the available satellite tracking data on adult turtles. For 42 nest sites around the world they compared ~45,000 model-generated Lagrangian hatchling drift scenarios with the migration routes of >400 satellite-tracked adults of five species of sea turtle (green, loggerhead, hawksbill, olive ridley and leatherback). The comparisons showed that adult sea turtle migrations to foraging sites were based on their experiences drifting as hatchlings.

It seems that if a hatchling drifts to a site that would provide good opportunities for feeding as an adult, they imprint on this location, and then later actively migrate there, presumably using an inbuilt compass/spatial sense. They may swim hundreds or even thousands of kilometres – some of the longest migrations in the animal kingdom. Hatchlings that don't drift to good feeding habitats grow to be adults that either do not migrate or forage in the sea in the vicinity of the breeding beach

Ed.

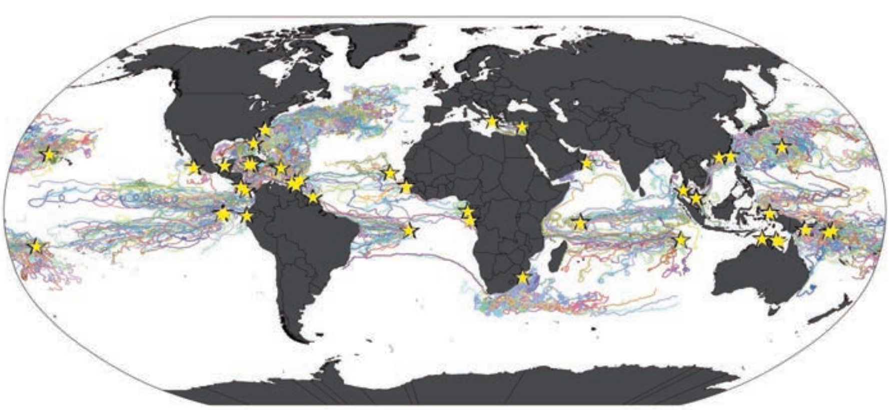
Further Reading

Ferrara, C.R., R.C. Vogt, M.R. Harfush, R.S. Sousa-Lima, E. Albavera, and A. Tavera (2014) *Chelonian Conservation and Biology*, **13**, No.1, 2014. http://www.chelonianjournals.org/doi/full/10.2744/CCB-1045.1

Scott, R., R. Marsh, and G.C. Hays (In press) *Ecology*. http://dx.doi.org/10.1890/13-2164.1

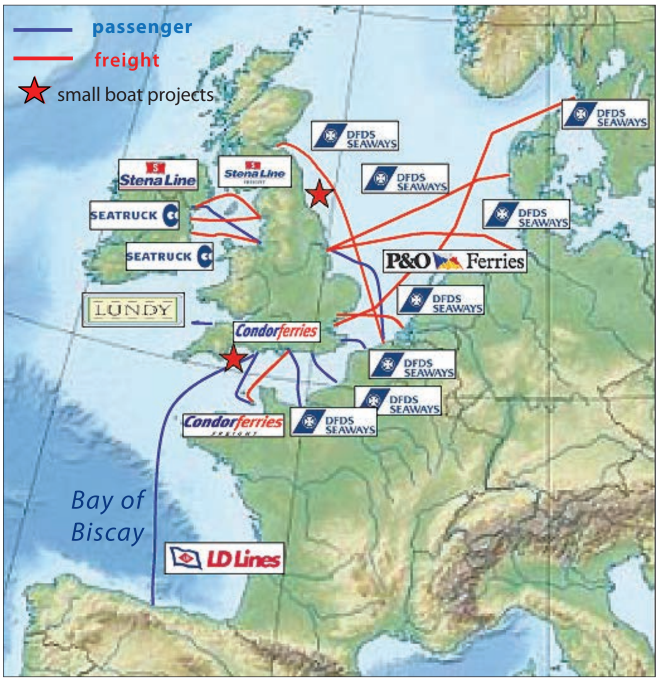
The map and photo are by courtesy of Rebecca Scott, Geomar.

Hatchling turtle drift routes from the breeding beaches (yellow stars) based on data from the NOAA-AOML satellite-tracked surface drifter buoys.



MARINElife: cost-effective conservation

James Speyer



Ferry and freight routes currently being used by MARINElife, and locations of surveys from small boats

In 1995, the Biscay Dolphin Research Programme (BDRP) was set up to utilise existing commercial ferry routes to carry out research into cetaceans and other wildlife in the Bay of Biscay area. Volunteers and programme staff members used the ferries as observation platforms to gather data on the distribution, abundance and population trends of numerous marine species. After much development, in 2005 the programme evolved into the charity MARINElife. Based in the UK, the charity still collects data in the Bay of Biscay but has also branched out to numerous other regions around the British Isles as well as Europe. The charity now undertakes research throughout the Channel, the North Sea and the North Atlantic, with the continued goal of monitoring species population changes.

The charity is currently sponsored to operate on seventeen ferry routes from ports all over the British Isles, travelling to a number of locations around Europe. Because of the fixed routes, researchers surveying from the same ferry many times throughout the year are able to track seasonal as well as annual changes in animal populations. Sightings are catalogued in great detail, with data collected including species, number of animals, GPS position and behaviour, along with environmental conditions at the time of sighting. This allows the charity to assess, year by year, the population trends of individual species in the surveyed regions. The information can be used to inform conservation and marine biodiversity policy, as well as designating and managing marine protected areas. Data collected through MARINElife's work is often used as evidence by government agencies for marine spatial planning and identifying areas that need protection.

Examples of the charity's research aiding conservation of cetaceans include the discovery of a decline in cold-water species (such as the northern bottlenose whale) and the increase in warm-water species (including the striped dolphin) in the Bay of Biscay. MARINElife has contributed irrefutable evidence of the effect that climate change is having on Europe's marine ecology. The charity is also responsible for documenting the recovery of harbour porpoise and minke whale populations in the Channel and monitoring the increased numbers of common dolphins immigrating into the Channel. Making this information available raises awareness of the increased risk of accidental snaring with fishing nets. These findings, as well as numerous others, highlight the importance of MARINElife's role in the protection of northern Europe's marine life.

MARINElife's chosen observation platforms – commercial ferries – provide researchers and surveyors with ample chance to view all manner of marine species. These sea-faring juggernauts not only provide long distance panoramic views for spotting cetaceans, but also offer safe travel and continued research opportunities in adverse weather conditions. Owing to the large number of passengers on board, ferries have also proved fantastic settings for educating the public about marine animals and their ecology, as well as raising awareness of conservation programmes. The recording of marine mammals from vessels of opportunity, such as ferries, has been widely undertaken across northern Europe with survey method protocols having been developed by the UK Mammal Society Cetacean Group/Sea Watch Foundation. Without the support it receives from private and commercial vessel operators, MARINElife would be unable to continue its vital work.

Along with the ferry monitoring network, MARINElife also operates from freight ships, cruise liners and smaller recreational boats as a cost-effective way to gather data in areas that are rarely surveyed. The charity coordinates and runs a number of other projects including targeted small vessel surveys, Passive Acoustic Monitoring (PAM) surveys and the North East Cetacean Project (NECP). MARINElife's work also includes the compilation of regional photographic identification catalogues, for such species as bottlenose and white-beaked dolphins, in order to better understand the distribution of individual populations.

The surveys are often rewarding, with a high percentage of voyages resulting in sightings of cetaceans. The charity relies heavily on the help of volunteers and supporters, offering training courses in wildlife identification and surveying throughout the year for those interested in getting involved. To see how you can help, please visit http//www.marine-life.org.uk/support-us where there is information about opportunities for volunteering (including boat surveys), fundraising and donating.

A bottlenose dolphin photographed by a MARINElife volunteer on a research trip

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At last – progress towards reducing sound pollution in the sea

In April 2014, after five years of intensive consultation, the United Nations International Maritime Organization (IMO) adopted a set of noise guidelines that, if followed by member nations, could decrease low-frequency shipping noise from commercial ships by 10dB (i.e. to one-tenth of the sound energy) in the next 30 years. This could effectively reverse the increase in shipping noise that has occurred over the last half-century with the expansion of international ocean-borne trade.

Public awareness of the dangers posed by sound to marine animals is driven by dramatic but rare events like whale beachings following sonar events. Continuous noise from shipping is a more insidious kind of pollution, and there are very few places left in the ocean where shipping noise doesn't dominate the low frequencies used by marine wildlife to socialise, hunt and navigate (*see map*).

Amongst the cetaceans affected are baleen whales, whose acoustic signals are drowned out by low-frequency noise (20–200 Hz) from large ships. Whales that were once able to communicate across entire ocean basins, on many days now find that their range is limited to mere kilometres. Whales respond to increased noise by moving away from their preferred habitat, changing their behaviour and altering the intensity, frequency and intervals of their calls.

It has been presumed that whales find 'noise harassment' very stressful. A dramatic demonstration that this is indeed the case occurred in the wake of the 9/11 disaster, when the US Government halted all shipping in and out of US ports for a week. Reduced ship traffic in the Bay of Fundy, Canada, resulted in a 6 dB decrease in underwater noise, with a significant reduction below 150 Hz. Associated with this noise reduction were decreased levels of stress-related hormone metabolites in the faeces of North Atlantic right whales, which under normal circumstances find it extremely difficult to communicate with one another. This was the first evidence that exposure to low-frequency ship noise could cause chronic stress in whales.

The IMO guidelines

The new guidelines are voluntary, not a mandatory code. but they are a great leap forward. The IMO offically recognises that shipping noise can have short-term and long-term impacts on marine life, especially marine mammals, and calls for measurement of shipping noise according to objective international standards. They also recognise the need for computational models to determine effective quieting measures, and to provide guidance for the design of quieter ships through, for example, hull design and the careful positioning of engines etc.

Although the greatest scope for reduction of underwater noise will be during the initial design of a ship, luckily much can be done to reduce noise from existing ships, especially by minimising the roar produced by ship propellers. Propeller cavitation is the formation and implosion of water vapour cavities (bubbles) resulting from the decrease and increase in pressure as water moves across a propeller blade. Cavitation causes both broadband noise and discrete peaks of sound at certain harmonics, but it can be reduced by polishing propellers to remove fouling and surface roughness.

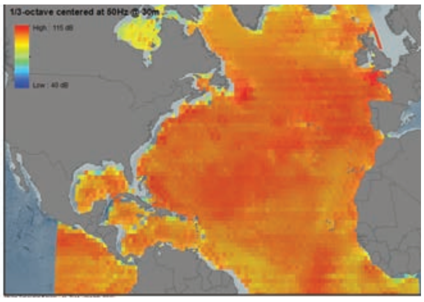


Figure 1 *NOAA map showing average noise levels at a depth of 30 m in the Atlantic Ocean: red represents sound at 115 decibels, around 60 decibels above natural ambient. The omnipresent noise is like a smog of sound, shrinking the sensory range of marine animals.*

The only positive thing that can be said about ocean noise pollution it is that once the noise stops, the pollution goes away. Would this were the case with other marine pollutants! Ed.

Global warming is good for (a few) penguins ...

We think of penguins as archetypal cold-water species, so how did they fare as the Earth came out of the last glacial period, during which Antarctic glaciers extended out over the shelf and winter sea-ice was much more extensive?

In fact, such conditions would not have suited those species of penguin that need ice-free ground to breed on, in addition to accessible areas of open sea to feed in. From about 30 000 ago, as Antarctica gradually warmed, three closely related penguin species – Chinstrap, Adélie and southern populations of Gentoo penguins – increased in numbers, while numbers of Gentoo penguins on the Falkland Islands, which were not affected by large changes in ice extent, were relatively stable.

This information comes from a recent study of changes in penguin genetic diversity over time, determined using DNA from feathers and blood samples from 537 penguin colonies around the Antarctic Peninsula. Using the rate of mutation of a region of mitochondrial DNA that evolves relatively quickly as a calibration tool, the researchers were able to chart how the size of certain penguin populations has varied over time.

Up to around 1000 years ago, most penguin populations were benefiting from retreating ice. Today, however, many penguin populations are struggling: Adélie and Chinstrap penguins around the Antarctic Peninsula are declining fast, probably because the krill they feed on (which overwinter under sea-ice) are less abundant. The winners are the Gentoo penguins, which don't rely on krill, and are expanding their range southward.

See Clucas *et al.* (2014) *Scientific Reports* **4**, Art. no. 5024 doi:10.1038/srep05024

Gentoo penguins: climate change winners *(Photo: Gemma Clucas)*

The role, value and future of sustained observations in the sea

John Huthnance

'A prospectus for UK marine sustained observations' – a joint meeting of the Challenger Society and UK-SCOR – was held at the Royal Society on 17 September 2013. At the event, early/mid-career scientists discussed how sustained observations contributed to research in their own field, what critical scientific problems long-term measurements can address, and their personal vision for future sustained observations.

The speakers and the areas of science they addressed were: Eleanor Frajka-Williams (University of Southampton): Physical oceanography related to climate; Nick Dunstone (Met Office Hadley Centre): Climate modelling and prediction; Stephanie Henson (NOC Southampton): Ocean-wide biogeochemistry; Nova Mieszkowska (MBA): Impacts of environmental change in marine food webs; Mark Tamisiea (NOC Liverpool): sea-level and geodesy; Povl Abrahamsen (BAS): The challenges (especially ice) in polar seas; Nicholas Bates (Bermuda): Seawater carbonate chemistry and trends; and Ian Mitchell (JNCC): Setting biodiversity indicators and targets, especially for policy.

The meeting began with Nick Owens (SAHFOS) giving a scene-setting overview; the two images are shown here are taken from his presentation.

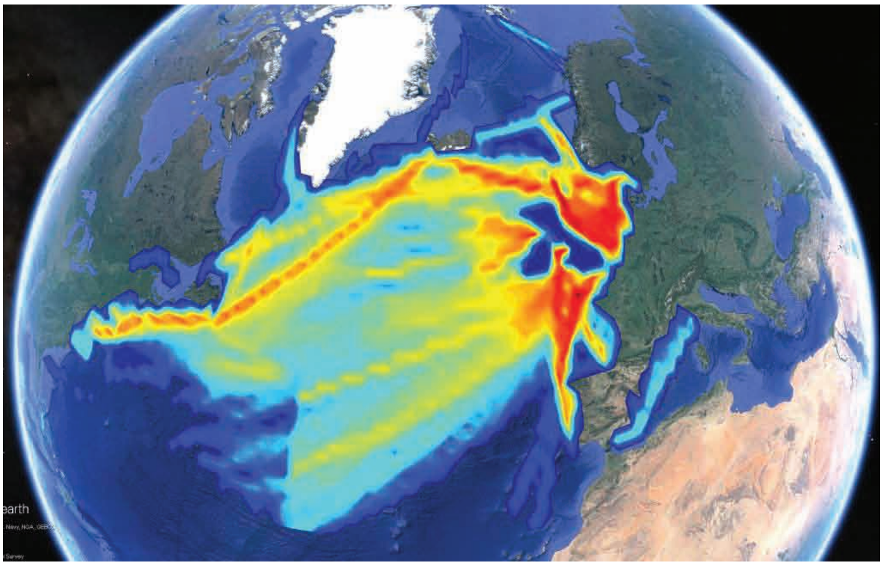
Benefits and challenges

Many benefits and challenges of sustained observations were highlighted in the presentations. Long time-series allow separation of anthropogenic and natural factors, and are useful for analysis of trophic dynamics. Development of models and their parameterisations, and validation of models, also benefit. Several forms of assimilated data (e.g. from Argo and altimetry) significantly improve model predictions.

One benefit of sustained observations – often an explicit aim – is improved understanding of ocean processes made possible by piggyback experiments and/or by the many 'degrees of freedom' provided by long time-series, multiple variables and locations; variability is needed to understand controls. Linkage of the state of the ocean to specific pressures helps in the choice of indicators and the development of management response. In turn, understanding of the processes involved helps to determine the need for (perhaps fewer) observations.

Benefits usually increase with the time over which the observations are continued, as variability on longer time-scales may be quantified and long-term trends (e.g. of sea level) can be estimated more precisely.

The longer observations are sustained, the greater their value is likely to be
Sampling effort of the Continuous Plankton Recorder Survey in the north-east Atlantic, from 1949 to 2012. Warm/hot colours (red/orange) represent more intense sampling than cooler colours (light blue). (© SAHFOS. Base map by Google Earth)



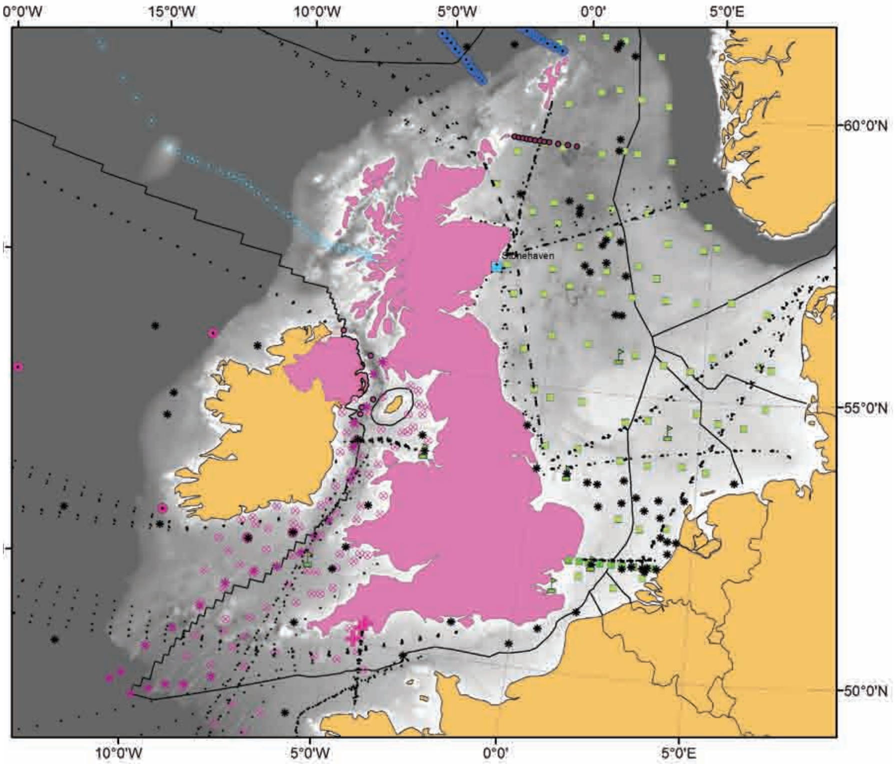
Sustained observations can be a focus for science community effort. Partly for this reason, the design of a programme of sustained observations may need to cater for multiple and changing user interests, although success depends on there being a clear vision of the purpose of the observations, and how they will be used. In this, oceanographers resemble the coastal communities – fishers and navigators – who, since pre-history, have watched the seas with particular purposes in mind.

Today, many international and national Acts (notably EU Directives) are compelling drivers. A variety of interests (science, policy, industry and the many sectors therein), and a long chain from observations to end-users, tends to lead to complexity; there may be many minority interests in the data but no one lead user (despite a strong combined case for funding). Many user interests concern changes relative to a 'baseline' which itself raises questions: e.g. are there baseline data, and do they represent a desired or an impacted state?

Users of data should credit the sources of data, although open-data policy tends to m ake tracking difficult; BODC is developing a digital object (doi) system to help keep track of where data originate and how they might have been modified. Due credit to the originators of data can help to make the case for sustained funding, because while benefits of observations might be difficult to quantify in monetary terms, practical impacts can be clearly demonstrated. Another way of obtaining recognition of the value of data is to engage 'citizen science', which can also broaden the coverage of sustained observations.

While the theme of the meeting was long-term observations, funding is typically short-term and often for 'blue-sky' research, involving testing of new hypotheses. It may be appropriate to test periodically the value of long-term data to counter perceptions of inertia, but suitable funding is needed to support this.

New technology can promise much to researchers, especially after repeated use has reduced risks and established accuracy. Technological advances have been allowing observation of more variables, wider coverage (e.g. under ice), more



The current status of the multiplicity of sustained marine observations (see above) carried out in UK waters by a wide range of contributors. *Not included, for the sake of clarity, are the extensive coastal measurements made by the UK Environment Agency, the UK Fisheries laboratories and the UK tidal stations. Solid lines are boundaries of exclusive economic zones. (By courtesy of Rodney Foster, CEFAS)*

efficient or cheaper observations, with finer space/time resolution (as is widely sought). For example, one SeaWiFS image yields more chlorophyll estimates than all samples collected from the ocean up until 1990. Analysis development is needed for new data forms (especially in the case of Lagrangian data) and new data + model combinations.

Question Time

The meeting concluded with a discussion in the style of BBC's 'Question Time', chaired by Nick Owens. Other members of the panel were Lawrence Mee (SAMS), Ed Hill (NOC), Karen Heywood (UEA) and David Mills (Cefas).

The session began with the panel being asked to choose three valuable indicators for monitoring the state of the seas around the UK. In responding, they described the recent development of a multi-species indicator for ecosystem health. In addition, they emphasised the need for an holistic view and of the use of observations to constrain and validate models.

The next question addressed by the panel was whether the time was right for a community-led joint-funded research programme to show the value of sustained observations. The panel felt that there should be more translation to applications to demonstrate the benefit of sustained observations and strengthen the case for funding; 'blue sky' funds should not be used for long-term measurements, bidding should be open to all (i.e. awards should be solely on the basis of merit), and collaboration should be encouraged.

When asked what criteria could be used to decide when to stop certain time-series and begin others, all panellists emphasised relevance – scientific rationale should be reviewed. Other criteria seen as important were integration, efficiency, reducing cost by using 'smarter' technology, and avoiding duplication. The criteria could depend on the motivation for the sustained observations, and the onus of funding might be transferred to the user(s) who benefit.

The next question addressed what scope there might be for franchising by industry, given that industry already undertakes environmental impact assessments under licensing arrangements. Contract measurements could be problematic if the set-up was evolving along with the science question(s) but could be OK if a methodology has stabilised. Altimetry was cited as an example where the transition has been made over 30 years. The feeling was that the UK Integrated Marine Observing Network initiative (UK-IMON) should engage with industry.

The final question was whether research ships are becoming more or less important for oceanography in general and sustained observations in particular. All the panellists agreed that ships remain essential for some activities, for example measurements at great depth. However, the ever increasing expense associated with research cruises implies a need to plan transition away from them where practicable and to develop a wider range of sensors that can be mounted on other platforms.

The meeting was part of a broader plan by the Challenger Society to set out, in an open forum, new initiatives for marine science strategy and projects over rolling 5-year periods. In this, the event was highly successful. As well as providing an overview of the state of many areas of marine science, it highlighted both the value of, and the challenges associated with, sustained marine observations, which are collected for the benefit of science and policy-makers. The organisers, especially Clare Postlethwaite, Anna Hickman and Abigail McQuatters-Gollop, are to be congratulated.

John Huthnance is an Honorary Research Scientist at the National Oceanography Centre, Liverpool. jmh@noc.ac.uk

Prospectus for UK Marine Sustained Observations

Guest Editors: Anna Hickman, Clare Postlethwaite, Philip Woodworth, Abigail McQuatters-Gollop and Harry Bryden

This publication, arising from the meeting, will shortly be available as a special issue of *Philosophical Transactions of the Royal Society* (**372**, No. 2025). Individual articles will be online from 25 August 2014.

Printed copies will be available from 28 September, price £58, through Portland Customer Services: Sales@portland-services.com

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Eighty Years of the Permanent Service for Mean Sea Level

Phil Woodworth and Lesley Rickards

In September 2013, the Challenger Society held an important meeting at the Royal Society on the topic of Sustained Observations, i.e. the collection of long time-series of data (see previous report). Sea level is one oceanographic parameter that has been continuously observed for over a century, and on 28–29 October the Permanent Service for Mean Sea Level (PSMSL) held its own celebratory meeting.

The PSMSL is the global databank for long-term sea-level information from tide gauges, and operates under the International Council for Science (ICSU). Its data are used extensively in many branches of geophysics but most often these days they are used in studies of sea-level rise, such as in the research assessments of the Intergovernmental Panel on Climate Change (IPCC). However, it is important to note that, back in 1933, when the PSMSL was set up, the main topics of interest relating to sea level had nothing to do with sea-level rise or climate change. As far as planning of sustained observations is concerned, the lesson to be learned is that current measurements of basic ocean parameters will always find applications many years hence, even if they are not the applications we think are important now.

Some history

The PSMSL can be said to have been founded at the 1933 conference of the International Union of Geodesy and Geophysics (IUGG) in Lisbon, shortly after ICSU itself was founded in 1931. At that meeting were Professors Rolf Witting and Joseph Proudman who were national delegates from Finland and the UK, respectively (Figure 1). Witting was a distinguished Baltic oceanographer, and had founded the Finnish Institute of Marine Research in 1918. By 1933, he was also a politician and government cabinet minister, and he would go on to be Finnish Foreign Minister in the pro-German wartime government.

Witting appreciated the importance of sea-level measurements for understanding ocean circulation. In particular, he had an interest in determining the mean dynamic topography of the Baltic by measuring spatial differences between mean sea level recorded at many stations with respect to a common levelling datum (the geoid, in effect). To do that he had to make corrections for glacial isostatic adjustment (then known as post-glacial rebound), which meant that he had to collect time-series of relative sea–land levels using tide gauge data.

Proudman was nominated secretary of the IUGG Mean Sea Level Committee and set about collecting monthly and annual values of mean sea level using the international contacts of the International Hydrographic Bureau. 1933 was an important year for Proudman for another reason: he switched from being Professor of Applied Mathematics to being Professor of Oceanography, while remaining Director of the Liverpool Tidal Institute at Bidston Observatory which eventually became the Proudman Oceanographic Laboratory. By 1940 he had published the first comprehensive set of mean sea-level values in the *Publications scientifiques* series of the International Association for Physical Oceanography (IAPO, the IUGG predecessor of IAPSO).

Figure 1 *Pioneers of sea-level data collection: Rolf Witting* ***(left)*** *and Joseph Proudman* ***(right)****. ((a) By courtesy of the Finnish Geodetic Institute; (b) copyright NOC)*

How any analyst was supposed to use the data in those days is a bit of a mystery. Numbers were literally 'published' on paper so anyone interested would have had to plot them out again by hand. Only much later, in the late 1970s, after many issues of the *Publications scientifiques* had appeared, would data become available from the PSMSL on magnetic tape; later, data were provided on floppy disks, and then via the internet.

Nevertheless, it did not take long for someone to produce the first scientific paper on sea-level rise using PSMSL data. This was an enormous (52-page) effort by Beno Gutenburg in 1941, whose main interest was in glacial isostatic rebound, but who in addition suggested that 'average sea level' might be rising by ~ 1.1 mm yr^{-1}, an estimate for the period in question (late 19th–early 20th century) one would not disagree with today. Gutenberg was a German–American geologist and seismologist and a long-standing collaborator of Richter of earthquake magnitude fame.

The Mean Sea Level Committee of the IUGG metamorphosed into a 'Permanent Service' of ICSU in 1958 around the time of the International Geophysical Year, but the work remained the same. There have been only a small number of PSMSL Directors – Proudman, Corkan, Doodson, Rossiter (who devised the 'Revised Local Reference' jargon that users will be familiar with), Lennon, Pugh, Woodworth and Rickards – each remaining in post about a decade or so.

The PSMSL today

The PSMSL now holds over 64 000 station-years of information from around the world (Figure 2(a)) with more than 250 records 60 years or longer in the Revised Local Reference subset (stations with datum continuity, Figure 2(b)). The dataset is used by many scientists throughout geophysics, and the provision of those data to users remains the PSMSL's main role. PSMSL staff also produce their own papers, partly as a means of providing a high-level quality control to the dataset. As a snapshot, PSMSL data were used in 61 ISI-listed (i.e. high-impact) journal papers in 2012, and no doubt there were other articles. A large number of papers that made use of PSMSL data were referred to in the sea-level related chapters (Chapters 3 and 13) of the *IPCC Fifth Assessment Report (AR5)*. In addition, the PSMSL provided one lead author, one review editor and two contributing authors to these two chapters.

In recent years, considerable efforts have been put into providing a much improved website enabling users to find where in the world data exist and the properties of each time-series (trends, anomalies etc.). In addition, there are now links to other sea-level centres and to records of land movements obtained by GPS. The PSMSL has continued serving the wider sea-level community, providing training materials, organising training courses for developing countries and playing a major role in the completion of the Global Sea Level Observing System (GLOSS). Immediate plans include further improvements in all these areas and expansion into areas such as collection of data from bottom pressure gauge stations. For more details of these activities, see Holgate *et al*. in Further Reading.

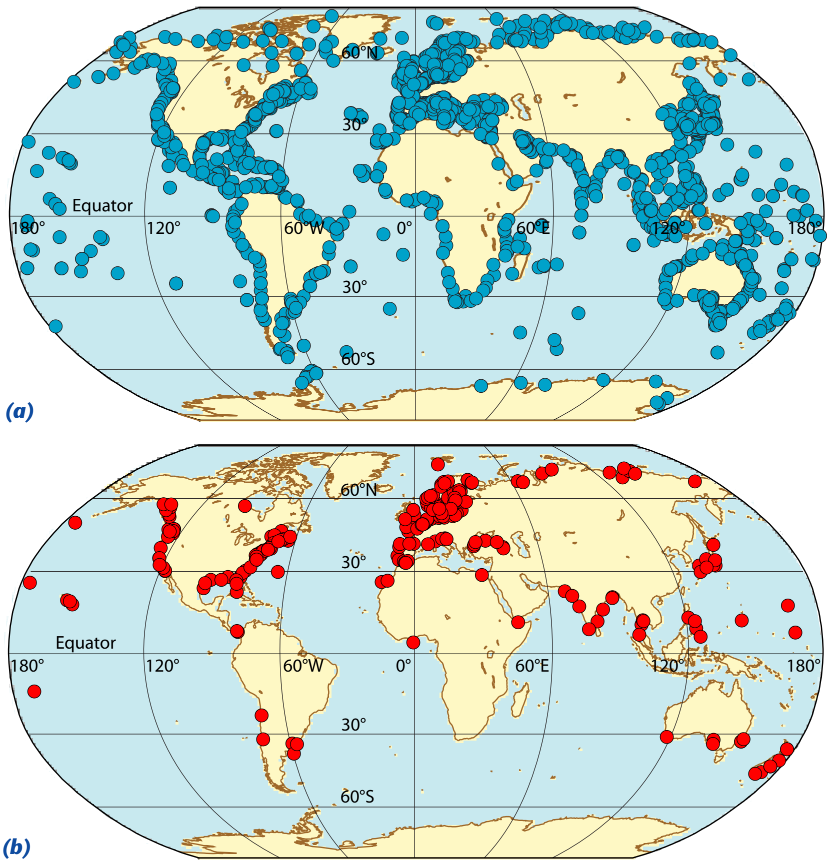


Figure 2 ***(a)*** *Locations with data in the PSMSL database,* ***(b)*** *stations with at least 60 years of data in the Revised Local Reference subset of the PSMSL. (Maps compiled by Andy Matthews)*

The 80th anniversary meeting

On 28 October 2013, as the south of England was being battered by the St Jude storm, 130 people gathered in the Victoria Gallery and Museum at Liverpool University for a workshop to celebrate the PSMSL's 80th birthday. Highlights included three hour-long talks by Anny Cazenave, Jonathan Gregory and Jonathan Bamber reviewing aspects of the *IPCC AR5*. These presentations, along with 13 others covering many aspects of regional variability in sea level and sea-level science in general, are available from www.psmsl.org, as are many of the over 40 posters presented at the workshop.

Earlier, over 20 people had braved the weather to attend a field trip to the salt marshes of the Dee estuary. The group discussed the ability of salt marshes to record long-term sea-level change. In addition, the field site provided an excellent setting for discussing the range of socio-economic impacts consequent upon rising sea levels.

The PSMSL workshop preceded the 13th GLOSS Group of Experts meeting held in Liverpool during 30 October–1 November. The presentations and documents associated with that meeting can be found on the Intergovernmental Oceanographic Commission website (www.ioc-goos.org Calendar pages).

Sustained ocean observations, including sea level, are important for many reasons. In particular, as the world continues to undertake the great global experiment of climate change, there is a satisfaction in providing information that has relevance to society. The work of the PSMSL will go on and we hope some of us will be around to see its 100th anniversary.

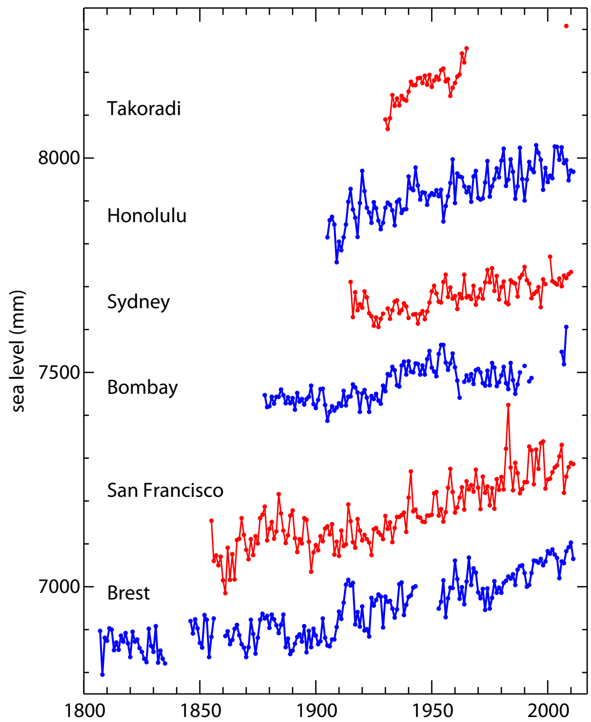


Figure 3 *Typical long PSMSL records from different regions of the world. The Takoradi (Ghana) record, one of the longest in Africa, has recently been restarted after many years. (Each record has an arbitrary offset for presentation purposes)*

NOC and BODC staff who contribute major parts of their time to the work of the PSMSL include Kathy Gordon, Svetlana Jevrejeva, Andy Matthews, Mark Tamisiea and Simon Williams (NOC Liverpool) and Liz Bradshaw (BODC).

PSMSL website:
www.psmsl.org

Further Reading

Holgate, S.J. and 10 others (2013) New data systems and products at the Permanent Service for Mean Sea Level. *Journal of Coastal Research*, **29**, 493–504, doi:10.2112/JCOASTRES-D-12-00175.1.

Nature Geoscience Editorial www.nature.com/ngeo/journal/v6/n12/full/ngeo2035.html.

Lesley Rickards (BODC) and **Philip Woodworth** (NOC Liverpool) are present and past Directors of the PSMSL.

Marine storytellers

Red coralline algae tell us how our environment is changing

Nicholas A. Kamenos

Marine time-series are important for understanding how Earth's climate has changed in the past, for determining whether current changes are extreme compared with past changes, and for understanding the response of marine ecosystems to historic changes. It is now becoming apparent that even changes at seasonal temporal scales can have significant effects on the climate system, as well as terrestrial and marine ecosystems. While we have instrumental records at sub-seasonal resolution going back over the past 1.5 centuries, climate reconstructions further back in time are usually of centennial resolution to decadal resolution. There is thus a need for seasonally and sub-seasonally resolved reconstructions of climate prior to the instrumental record, and for areas where instrumental data are sparse. Coralline algae – slow-growing algae forming calcareous deposits – are increasingly being used to provide such data, and of key importance is the high temporal resolution of data they can provide, in some cases up to fortnightly.

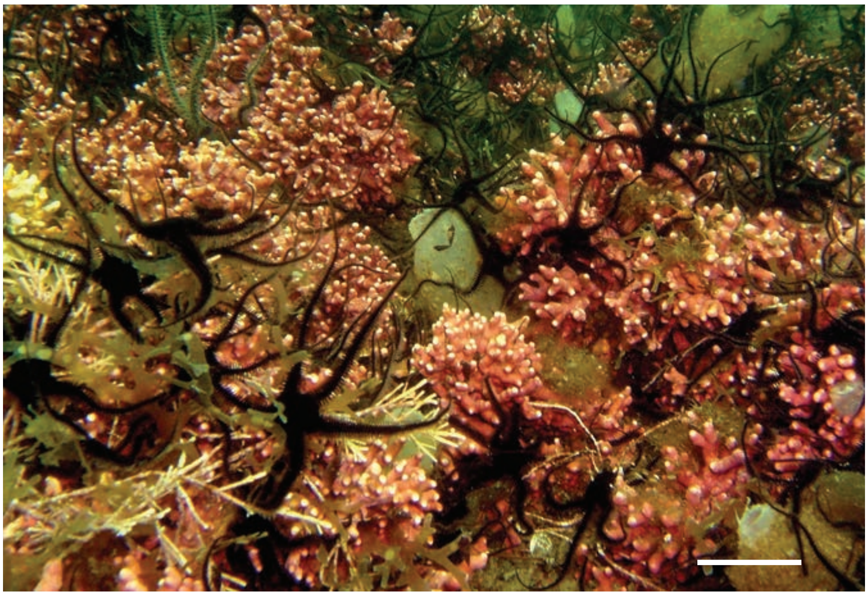
Coralline algae are typically pink or red, but some species are purple. They have a worldwide distribution in the photic zone, and can be found in varying depths of water, ranging from periodically exposed intertidal settings to water depths of ~250 m. Some species can even tolerate brackish or hypersaline waters.

The same species can occur either as unattached forms (rhodoliths or maerl) or encrusting forms. Accumulations of maerl-forming algae, caused when individuals grow on top of other individuals, are known as maerl beds (Figure 1). Due to their complex interwoven lattice structure, maerl deposits resist redistribution by currents, and are largely unaffected by bioturbation, maintaining their chronographical stratification.

An individual algal body – known as a thallus – can live for ~1000 years, and maerl deposits can reach up to ~20 kyr of age. Using growth bands of coralline algae to determine past environmental conditions is termed algochronology. Coralline algal banding is most commonly caused by reduced light availability and lower temperatures during winter. The bands are created by changes in the degree of cellular calcification, with less calcified cells being deposited in winter. Other causes of variations in widths of bands are changes in water movement, burial, monthly / lunar growth cycles driven by tidal patterns, and possibly large-scale climate patterns.

Strong relationships can often be found between the calcite density within the growth band and environmental conditions. For example, negative relationships between calcite density and both increasing temperature and increasing light availability have been observed in *Lithothamnion glaciale* from shallow seas around the Atlantic. Calcite density has been used to reconstruct cloud cover over the west coast of Scotland between 1910 and 2006, and indicates a modest rise in cloud cover over the 96 years!

Figure 1 *Red coralline algal thalli of* Lithothamnion glaciale*, forming a maerl bed in Loch Steen, western Scotland. The author collected specimens by SCUBA diving. Associated fauna include tunicates and brittlestars. Scale bar = 5 cm.*



The popularity of coralline algae as palaeoenvironmental recorders has increased because along with their banding patterns and structural aspects of the growth bands, there is also chemical information locked within the high-magnesium calcite skeleton. This has allowed reconstruction of marine temperature, salinity, upwelling events and ocean carbonate chemistry along with larger scale climatic parameters. Sea-surface temperature and *in situ* temperature have been reconstructed using the magnesium, lithium or oxygen isotopic content ($\delta^{18}O$) of a number of species of red coralline algae in Arctic, temperate and tropical regions. For example, the longest palaeoenvironmental reconstruction made using coralline algae (653 years long at fortnightly resolution) was made using magnesium from within *L. glaciale* on the west coast of Scotland: higher magnesium concentrations locked within algal skeletons indicate higher marine temperatures at the time of deposition (Figure 3(a)). Variations in upwelling frequency have been reconstructed using variations in the barium content of algae in Arctic and tropical areas, and seawater salinity has been reconstructed using barium or a combination of magnesium and $\delta^{18}O$ within growth bands in red coralline algal from the Arctic. In the North Pacific, concentrations of dissolved inorganic carbon in seawater have been reconstructed using ^{14}C deposited within the growth bands of encrusting coralline algae.

In addition, environmental reconstructions derived from coralline algae have been used to improve understanding of historic and future marine productivity. For example, in the shallow inshore waters of the north-west Atlantic, temperature (reconstructed using *L. glaciale*) was related to historic copepod abundance and, together with climate model data, was used to project copepod abundances over the next four decades. Also, growth increments in *Clathromorphum compactum* were used to reconstruct historic landings of Sockeye salmon, which

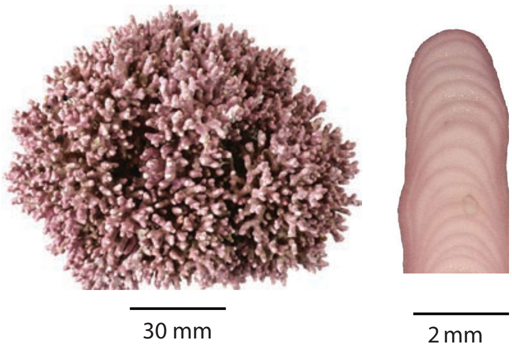


Figure 2 ***(a)*** *Thallus of* Lithothamnion glaciale *collected from Loch Steen* ***(b)*** *Annual growth bands in a transverse section of a polished maerl thallus branch.*

(Photos: Les Hill and Nick Kamenos)

support a major Canadian fishery, via the influence of cloud cover on plankton availability.

While their high-magnesium skeletons make coralline algae excellent palaeoclimatic proxies, the brittleness of the skeletons make them susceptible to damage and loss of the records they contain, especially given the slow growth rates (<1 mm yr^{-1}) . Fishing gear and trampling by tourists can destroy their physical structure, high sediment loads associated with land-use can smother them, while heavy metals and oil pollution disrupt enzyme systems and suppress reproduction. Recently, new threats are linked to rising atmospheric CO_2. The oceans are a key sink for anthropogenic CO_2 emissions; in the last 200 years they have absorbed half the anthropogenically released CO_2, leading to a 0.1 unit fall in their pH from a global mean of around 8 – a 30% increase in acidity. If these trends continue, oceanic pH is projected to fall by 0.5 pH units by 2100 leading to the lowest oceanic pH for the last few millennia (see Further Reading).

Critically, calcium carbonate dissolves at low pH with high-magnesium calcite thought to be the most susceptible to dissolution. Increased anthropogenic CO_2 absorption by the seas may further reduce marine pH putting the chemical composition and physical integrity of coralline algae at risk. At present there is inconclusive evidence about how coralline algae will respond to projected ocean acidification, with some studies showing detrimental effects but others showing an ability to acclimatise and possibly even adapt.

The ecosystems created by marine calcifiers provide significant services; for example, global tropical coral reefs, including their coralline algae, are estimated to provide goods and services worth up to £250 billion, and when the services provided by cold-water coralline algae are added in, the figure is likely to be substantially higher. Recent moves to protect red coralline algae (e.g. in the Lamlash Bay No-Take Zone off Arran in the Firth of Clyde, western Scotland) will be crucial to protect not only the services they provide but also the untapped palaeoclimatic records locked within contemporary coralline algal deposits.

Figure 3 *Algae-derived* in situ *temperature anomalies for summer and winter sea-surface temperatures.* ***(a)*** *Black line: molar Mg/Ca extracted from* L. glaciale *coralline algae on the west coast of Scotland; peaks represent maximum summer temperature and troughs mimimum winter temperature.* ***(b)*** *Red line and* ***(c)*** *blue line: extreme algae-derived summer and winter temperature anomalies (± 0.5°C) extracted from the fortnightly resolution subannual time-series. The black lines are 21-year moving averages. Note the temporal extent of the Little Ice Age (blue box). At bottom right are* ***(d)*** *the winter Atlantic Multidecadal Oscillation (AMO) index, and* ***(e)*** *the winter North Atlantic Oscillation (NAO) index.*

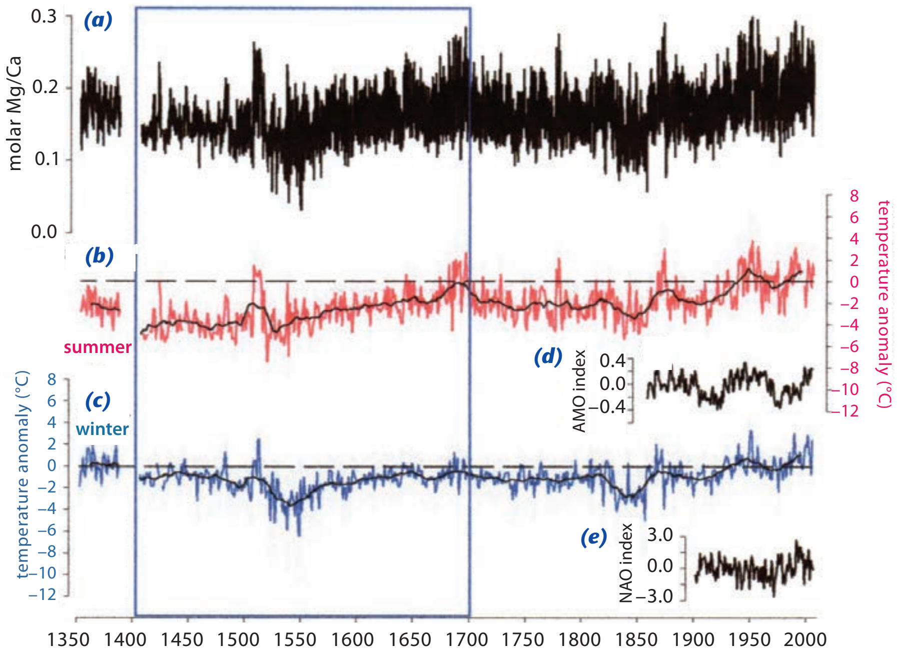


Figure 1 is from: Nicholas Kamenos (2010) North Atlantic summers have warmed more than winters since 1353, and the response of marine zooplankton, PNAS. www.pnas.org/content/107/52/22442.full.pdf

Further Reading

Hicks, N. (2013) Ocean acidification: much more than a hot research topic. *Ocean Challenge*, Vol. 20, Summer, 3–4.

Findlay, H., L. Wicks, F. Hopkins and M.P. Humphreys (2013) At sea with the UKOA: investigating the effects of rising ocean acidity. *Ocean Challenge*, Vol. 20, Summer, 5–8.

See also a group of articles on Ocean Acidification in *Ocean Challenge*, Vol.18, Winter 2011.

Burdett, H.L., N.A Kamenos and A. Law (2011) Using coralline algae to understand historic marine cloud cover. *Palaeogeog. palaeoclim. and palaeoecol*. **302**, 65–70.

Darrenougue, N., P. De Deckker, C. Payri, S. Eggins and S. Fallon (2013) Growth and chronology of the rhodolith-forming, coralline red alga *Sporolithon durum*. *Mar. Ecol. Prog. Ser.* **474**, 105–19. doi: 10.3354/Meps10085

Kamenos, N.A. (2010) North Atlantic summers have warmed more than winters since 1353, and the response of marine zooplankton. *Proc. Nat. Acad. Sci. USA (PNAS),* **107**, 22442–7. doi: http://dx.doi.org/10.1073/pnas.1006141107

Williams, B., J. Halfar, R.S. Steneck, U.G. Wortmann, S. Hetzinger, W. Adey, P. Lebednik and M. Joachimski (2011) Twentieth century δ^{13}C variability in surface water dissolved inorganic carbon recorded by coralline algae in the northern North Pacific Ocean and the Bering Sea. *Biogeosciences* **8**, 165–74. doi: 10.5194/bg-8-165-2011

Nick Kamenos is at the School of Geographical and Earth Sciences, University of Glasgow. He studies how the resources we obtain from the oceans are altered by the synergy between natural and anthropogenic change, while trying to determine the actual extent of global change. He conducts research in temperate, tropical and polar areas as well as in the laboratory.

How marine reserves can enhance resilience to climate change

There is general agreement that marine communities protected from human interference, particularly fishing, will be less seriously affected by climate change than communities that are fished. Empirical evidence of responses to climate change in marine reserves is limited, but analysis of a 20-year time-series of fish abundance from the Maria Island Marine Reserve off south-east Tasmania has provided valuable insights into how ecosystems in protected waters might be buffered from the effects of climate change, at least for a while.

The reserve is in temperate latitudes, but is affected by warm tropical waters carried in a branch of the East Australian Current, and this amplifies the effect of global warming regionally. The study, by researchers from Southampton and Tasmania, compared changes in the biodiversity and biological characteristics of reef-fish communities in the marine reserve with changes in nearby fished sites, over the last two decades of warming.

The researchers looked at changes in the fish community in reponse to both short- and long-term environmental variability. They obtained various measures of richness and diversity, including species richness (the number of species present), species diversity (the number of species present, and the extent to which the community is dominated by a small number of species) and functional richness. Functional richness reflects biological complexity, and relates to the variety of roles or functions that species play in the community.

In addition to global warming, between 1992 and 2012 the waters in question had been influenced by cyclical climate change associated with the Southern Oscillation. The effects of this cyclical variation on species diversity of fish within and outside of the reserve can be seen in Figure 1.

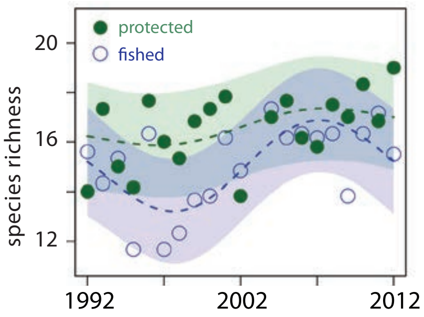


Figure 1 *Species richness increased over time in both the protected and fished communities, but for different reasons (see below). In addition, species richness varied over a 10-year cycle in both areas, but more so in the fished areas.*

While species richness varied over time in both fished and unfished areas, it fluctuated less in the unfished area, indicating that the ecosystem in the reserve was more resilient to these decadal-scale changes.

The study also found that species richness increased in both regions over the two decades (Figure 1), but for different reasons. In the fished community, warm-water species moved in from subtropical habitats, while in the protected commu nity there was a shift from smaller, more abundant fish, to fewer larger carnivorous fish like sharks and wrasse (Figure 2, right).

The number of herbivorous fish increased in both the protected and unprotected areas. This probably reflected a general extension in the ranges of herbivorous fish, which tend to favour warmer water because digestion of plant and algal material is more efficient at higher temperatures. This fact suggests that, in time, long-term warming off south-east Australia will lead to major changes in the structure and function of shallow reef-fish communities.

The number of warm-water fish species increased in both areas, but less so in the reserve. One likely reason for this was increased predation within the reserve, where the number of sharks etc. had increased; increased predation seems particularly likely as many of the invasive warm-water species were small and vulnerable to predation.

There were also indirect reasons for fewer warm-water arrivals in the protected area. For example, outside of the reserve, the sea-urchin *Centrostephanus rodgersii* had increased in abundance and had over-grazed patches of algae (Figure 2, left), leaving barren patches which warm-water fish seemed to favour. Within the reserve, the sea-urchins were kept under control by large lobsters.

Thus marine reserves have the potential to allow communities to build resilience through mechanisms that promote species and functional stability. More generally, the study showed that they have an important role to play in understanding how ecosystems evolve in the absence of fishing.

Ed.

Bates, A.E. *et al.* (2014) Resilience and signatures of tropicalization in protected reef-fish communitites. *Nature Climate Change*. doi 10.1038/NCLIMATE2062

Figure 2 Left *The voracious sea-urchin* C. rodgersii *was kept under contol in the reserve by a healthy lobster population.*
Right *Large-bodied species such as the blue-throated wrassse lead to greater community stability and resilience (By courtesy of Rick Stuart-Smith)*

Aerosol, clouds and climate in the Arctic

Rosie Chance, Lucy Carpenter, Ian Brooks, Theo Wilson, James Allan and Amelie Kirchgaessner

In 2013, atmospheric scientists took to the seas and skies of the Arctic to investigate processes controlling clouds and atmospheric aerosol – particles or droplets suspended in the atmosphere (Box 1). Climate in the Arctic is changing more rapidly than anywhere else on Earth, yet our ability to reproduce Arctic climate within numerical models, and predict how it will change in the future, suffers much greater uncertainties than for other regions. Improving our understanding of aerosol and cloud processes is key to reducing these uncertainties.

The challenge of clouds

One of the largest single sources of uncertainty in climate models is the representation of clouds; this is particularly so in the Arctic, where they are the dominant factor controlling the balance of incoming and outgoing energy at the Earth's surface. Arctic clouds affect the budgets of both incoming solar (shortwave) radiation reaching the Arctic during the boreal summer, and infra-red (longwave) radiation emitted from the Earth's surface throughout the year. The former is reflected by clouds, while the latter is both absorbed and emitted by clouds.

Low-level clouds also have a strong influence on turbulent mixing within the lower atmosphere, affecting exchange of heat and moisture with the surface, and the transport of material such as aerosol from surface sources up into the atmosphere. The thermodynamic and turbulent structure of the lower atmosphere in turn influences cloud properties, so that clouds, the lower atmosphere and the surface ocean together form a tightly coupled system.

Over most of the world, low-level clouds lead to surface cooling because they reflect more solar radiation than the darker water or land below (i.e. they have a higher albedo). Over the Arctic, however, the presence of highly reflective sea ice means that this effect has very little impact. Instead, the greenhouse effect of water droplets in clouds trapping infrared radiation below them becomes dominant, causing overall warming of the lower atmosphere and surface ocean. This is rarely accounted for in global climate models, which tend to represent cloud properties based on observations from lower latitudes.

The role of atmospheric aerosol

The way in which clouds interact with radiation depends upon the thickness of the cloud, and the number and size distribution of liquid water droplets and ice crystals within the cloud – Arctic clouds may contain either or both of these. The characteristics of the droplets or ice crystals are in turn dependent on the aerosol particles upon which cloud has formed – these are referred to as cloud condensation nuclei (CCN) and ice nuclei (IN). Only certain particles can act as CCN and/or IN, and their nature and identity is the subject of active research. Factors such as particle size, number and chemistry – particularly the ability to absorb water vapour (hygroscopicity) – contribute to the way aerosol particles affect clouds. For example, higher numbers of CCN create more numerous, smaller cloud drops, resulting in more reflective clouds. The Arctic is a very clean environment, and aerosol concentrations are often very low, resulting in low CCN concentrations and clouds that are optically thinner (i.e. allow more solar radiation through) than is commonly the case at lower latitudes.

The amount and type of aerosol observed in the Arctic show pronounced seasonal differences. In winter and spring, long-range transport brings anthropogenic aerosol particles to the Arctic atmosphere from industrialised mid-latitude continental regions. This results in persistent bands of brownish haze, noted by Inuit and early Arctic explorers, and named 'Arctic haze' in the 1940s. In summer, meteorological conditions change so that the Arctic atmosphere tends to become isolated from these distant aerosol sources and the near ubiquitous low cloud and fogs scavenge what aerosol there is very efficiently – in other words, aerosol particles that have not themselves acted as CCN or IN collide with and are incorporated into existing cloud droplets and may subsequently be removed from the atmosphere by precipitation as rain or snow. Combined, these factors result in very low particle numbers, sometimes as low as one particle per cm^3 of air – two to three orders of magnitude lower than typical concentrations in marine air masses at lower latitudes. The summertime high Arctic is therefore considered one of the cleanest regions of the global troposphere, and is expected to be very sensitive to local aerosol sources, specifically oceanic emissions. The ocean surface is both a direct and an indirect source of aerosol particles: sea spray containing salts and organic matter is ejected by bubble-bursting, and trace gases such as dimethyl sulphide (DMS) are released,

Figure 1 *Melting sea ice off the coast of Greenland, seen from the RRS* James Clark Ross *during the summer ACCACIA campaign; stratus clouds, dark land, bright ice, melt ponds on the ice, and dark channels of open water, all affect the overall albedo.*

and can form secondary aerosol following atmospheric processing. Surface ocean processes thus have potential to influence cloud properties in the Arctic, and hence affect climate.

The ACCACIA project

The Aerosol–Cloud Coupling And Climate Interactions in the Arctic (ACCACIA) project aims to improve our understanding of the processes controlling Arctic clouds, and the aerosol upon which they form, through a combination of field observations, laboratory experiments and computer modelling. The ACCACIA consortium is led by Ian Brooks at the University of Leeds, and involves scientists from the University of Manchester, the University of York, the University of East Anglia and the British Antarctic Survey, along with the Met Office and Hadley Centre, and project partners in the US and Europe. The four-year project formally started in April 2012, and included two field campaigns, in late winter/early spring (March–April) and high summer (July–August) 2013. The timing of the two ACCACIA field campaigns was designed to capture the two highly contrasting periods of cloud and aerosol behaviour. Both research ships and aircraft were utilised, and more than 50 scientists travelled north of the Arctic Circle.

ACCACIA is one of several projects funded by the NERC Arctic Research Programme (http://arp.arctic.ac.uk). It has close links with The Environment of the Arctic: Climate, Ocean and Sea Ice (TEA-COSI) project, which studies the energy and freshwater budget of the Arctic Ocean. The two projects have a mutual interest in surface energy exchange, and between them address the issue of closing the heat budget controlling Arctic sea ice.

The spring ship campaign

The first sea-going campaign, in March 2013, operated from the Norwegian research ship the RV *Lance*. The scientific party comprised teams from the universities of Manchester and York, who were making surface-based *in situ* measurements of marine aerosol composition and properties (see Box 1), and aerosol precursor gases such as DMS, volatile organic compounds and halocarbons (see Box 2). After steaming north from Tromsø to Svalbard, the RV *Lance* worked south along the sea-ice edge east of Greenland (blue track in Figure 2(a)). Days were alternately spent in open water and surrounded by sea ice, in order to compare these two environments. As the cruise took place in early spring, the ice was very changeable, and many different forms were encountered. On some days, the ice was no more than a near invisible film creeping over the water surface, while on others the RV *Lance* was surrounded by slushy grey platelets or a glittering flat crust, littered with bright white sculptures rising from turquoise pedestals.

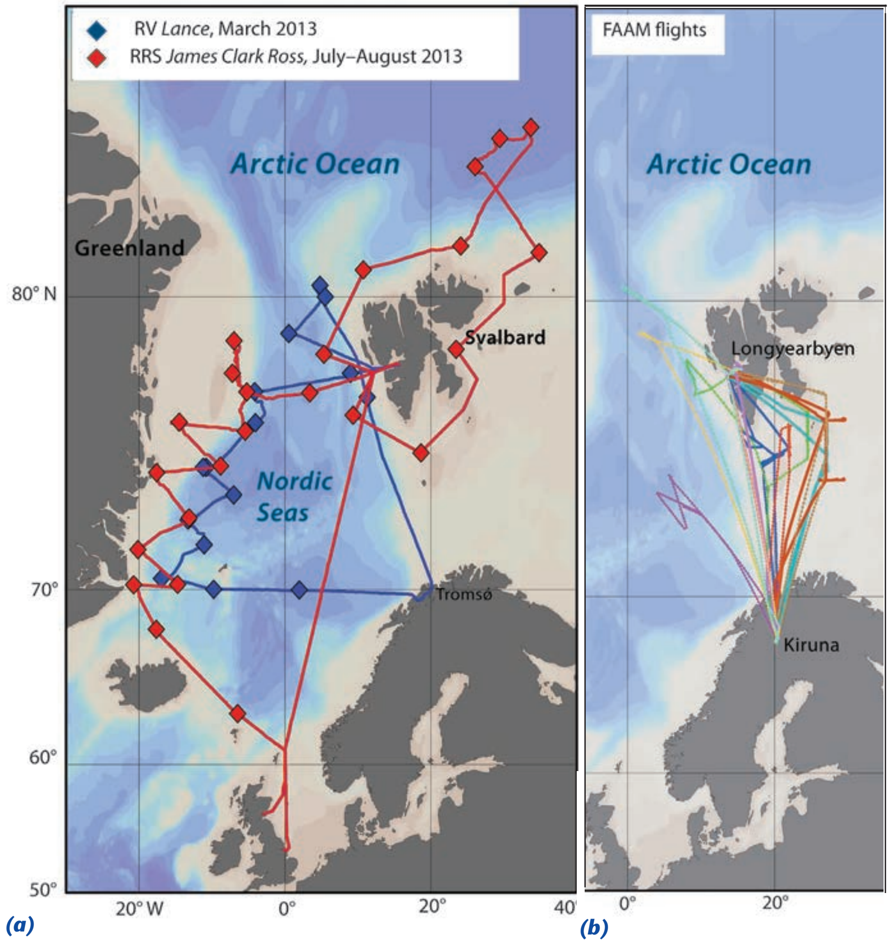


Figure 2 ***(a)*** *Ship cruise tracks and station positions. The zigzag tracks show where days in open water alternated with days surrounded by sea ice.* ***(b)*** *FAAM flight paths for the ACCACIA campaigns in March and July–August 2014. Background colours correspond to depth; pale brown shallowest, darkest blue deepest.*
(Produced using Ocean Data View (R. Schlitzer 2013; http://odv.awi.de))

Air-sampling lines were run from the crow's nest on the forward mast down to the scientific laboratories in the ice-strengthened bows (an ideal location for attempting to measure clean air uncontaminated by the ship's exhaust), and a container laboratory equipped with a suite of aerosol instrumentation was mounted on the foredeck (Figure 3, Box 1). A high volume aerosol sampler, which is not unlike a vacuum cleaner fitted with a filter inlet, was also set up on the top deck of the ship. In addition to atmospheric sampling, there were daily CTDs casts using a rosette of 12 ten-litre Niskin bottles; sub-sampling took place in a heated tent intended to prevent the CTD freezing up on deck when temperatures really plummeted (Figure 4).

The summer ship campaign

The summer ACCACIA cruise took place aboard the RRS *James Clark Ross*, and was divided into two legs (red track in Figure 2(a)). The first leg took a similar path to the spring cruise, zigzagging in and out of the sea ice off the coast of Greenland and reoccupying some of the same stations. Then, following a port-call at Longyearbyen (Svalbard) to exchange some members of the science team, the ship ventured into the ice north of Svalbard. In pursuit of the retreating ice edge, the RRS *James Clark Ross* reached her furthest north position ever (83°19'), and the science team were able to make measurements in a rarely studied area of the Arctic Ocean.

The very low aerosol concentrations in the Arctic summer mean that local aerosol sources, including primary marine aerosol from sea spray and bubble-bursting, and the formation of secondary aerosol from precursor gases, are important components of the ambient aerosol burden. As on the earlier cruise, atmospheric and oceanographic measurements were made

Box 1 Marine atmospheric aerosol

An aerosol is a suspension of solid or liquid particles in a gas, in this case the Earth's atmosphere. For simplicity, the term 'aerosol' is often used to refer to the particles alone, and we adopt this convention in this article. Primary aerosol is injected directly to the atmosphere, and includes both anthropogenic emissions such as soot, and natural materials such as wind-blown dust and sea spray. Secondary aerosol is formed in the atmosphere by the conversion of gaseous molecules to the particulate phase.

In order to study marine aerosol *in situ*, and investigate the processes by which primary marine aerosol can form, researchers from the University of Manchester took a customised laboratory container equipped with a suite of aerosol instrumentation on the two ACCACIA cruises. The resulting measurements will be used as input in cloud microphysical models, to investigate the influence of aerosol properties on aerosol–cloud feedbacks.

The container was located at the front of the ship during both cruises, to avoid contamination from the ship's exhaust. Real-time ambient aerosol measurements were made on air sampled through a dedicated inlet mounted on the container. In addition to counting aerosol particles, two complementary particle-size analysers (a Differential Mobility Particle Sizer, and a GRIMM dust monitor) were used to measure the aerosol size distribution down to 3 nm diameter particles. Numbers of cloud condensation nuclei were determined at different particle sizes and various degrees of water vapour supersaturation, allowing calculation of the fraction of particles that can form cloud droplets as a function of dry aerosol size distribution and degree of supersaturation; in addition, particle growth factors were measured across a range of relative humidities. Finally, two different instruments were used to measure aerosol black carbon, which is found in soot and is indicative of anthropogenic contamination.

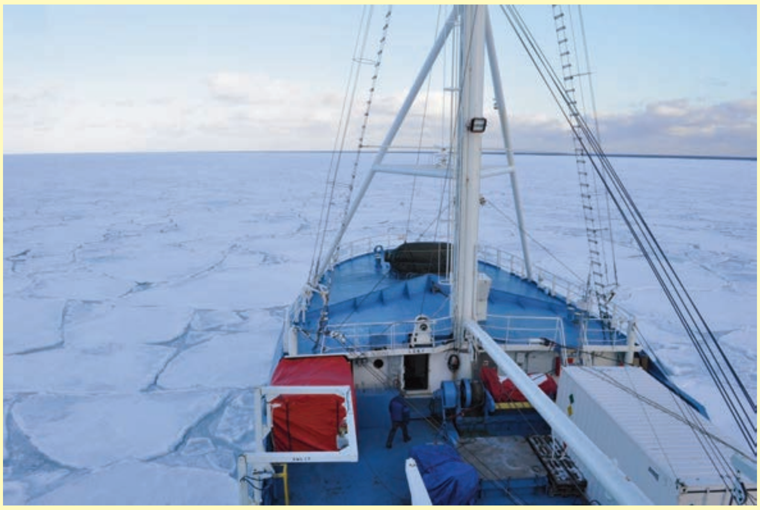


Figure 3 *The Norwegian research vessel the RV* Lance *during the spring ACCACIA campaign. The Manchester aerosol container lab is on the right.*

The chemical composition of aerosol particles was determined using a High Resolution Aerodyne Time of Flight Aerosol Mass Spectrometer (HR-ToF-AMS), and size segregated bulk samples were also collected on filters for additional chemical analysis back in the laboratory. The composition of organic matter isolated from marine aerosol and seawater samples, collected during the two ACCACIA cruises, will also be examined using high-resolution mass spectrometric techniques at the University of York. These powerful techniques will be used to compare the detailed 'fingerprints' of marine aerosol with those of organic material isolated from surface seawater, in order to investigate the direct contribution of oceanic material to local atmospheric aerosol.

In addition to atmospheric measurements, 'bubble tank' experiments were conducted to simulate the formation of primary aerosol particles at the sea-surface, with a view to seeing how biogenic materials in the seawater affect the properties of the particles. The tank consisted of a sealed enclosure that was partly filled with seawater (taken from the CTD Niskin sampler; Figure 4). The water was recirculated through a series of jets that dropped the water from a height onto the surface, simulating the action of waves breaking on the sea-surface and forming particles through the bursting of the resulting bubbles. The size distribution and properties of the aerosol generated in this way were measured by instruments sampling the tank's headspace, for comparison with similar experiments performed in the laboratory. The bubble tank results will be used to help quantitatively describe the sea-spray aerosol flux in models.

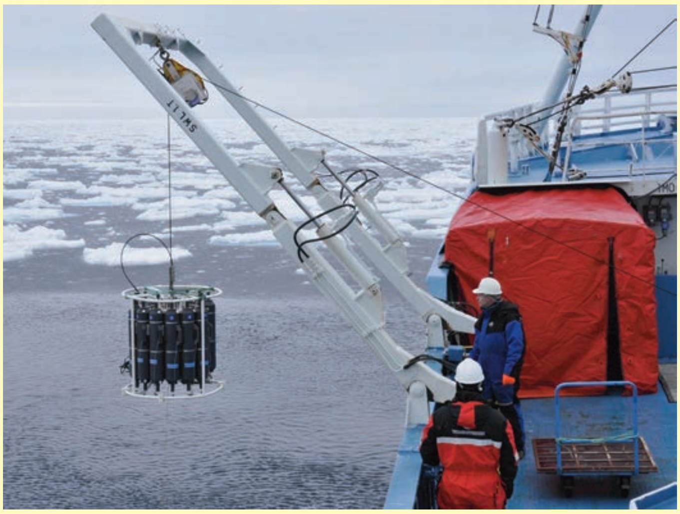


Figure 4 *CTD operations aboard the RV* Lance *during the spring ACCACIA campaign; the red heated tent can be seen close by.*

to characterise ambient aerosol, and investigate how biological and chemical processes in waters at the ice edge affect the atmosphere above. To this end, similar sets of instruments were deployed during both cruises (see Boxes 1 and 2). The science teams from the March cruise were joined by additional collaborators with interests highly complementary to the ACCACIA objectives. The mixture of atmospheric scientists, physical oceanographers and biogeochemists made for an exceptionally multidisciplinary and stimulating cruise, with measurements on board ranging from the physical properties of atmospheric particles to phytoplankton physiology. Linking together the diverse range of measurements to build a picture of the air–sea interactions in the Arctic is one of the exciting challenges of the ACCACIA project.

Links to the TEA-COSI project

As part of the NERC-funded TEA-COSI consortium project, during the second ACCACIA cruise researchers from Bangor University measured ocean microstructure using a vertical microstructure profiler (VMP 500). The vertical profiles of turbulent ocean mixing collected on the cruise will provide a baseline against which to compare future changes in Arctic Ocean mixing rates, as well as improving our understanding of the dominant processes that generate mixing across the Arctic Ocean and adjacent shelf seas. Understanding these processes is crucial to

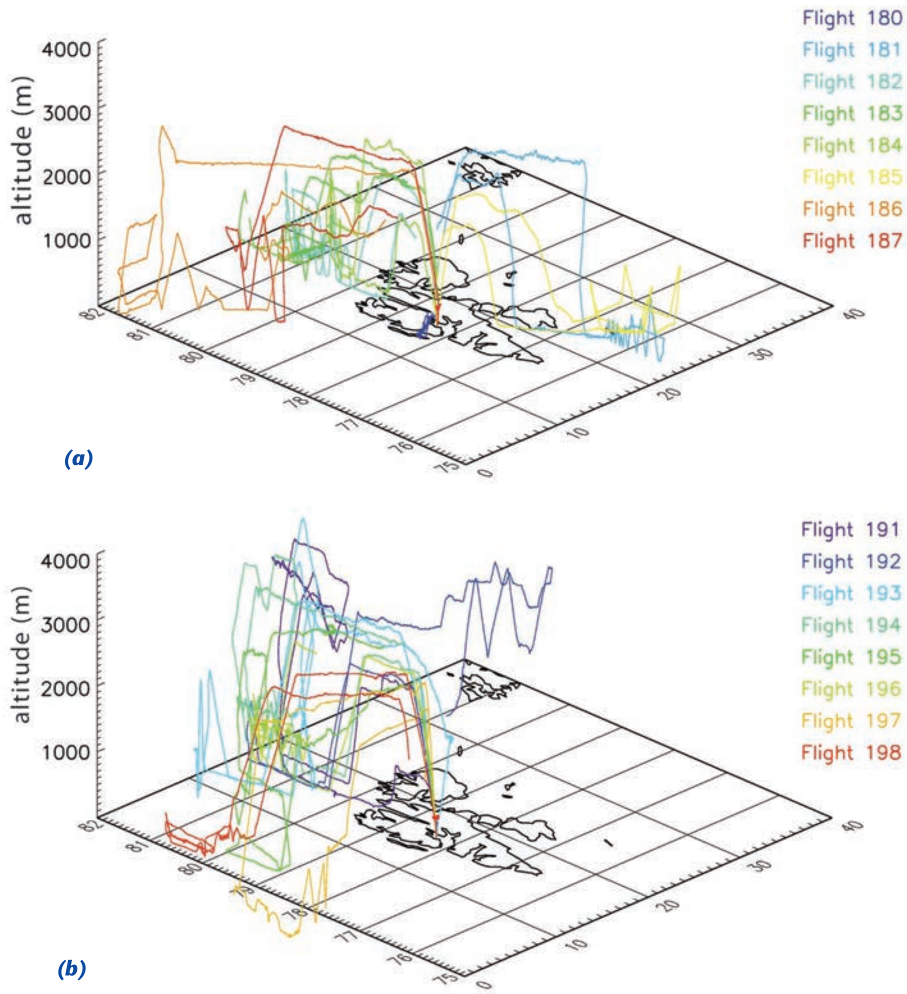


Figure 5 *3D flight paths for the BAS MASIN aircraft operating out of Longyearbyen, Svalbard, in* ***(a)*** *spring 2013 and* ***(b)*** *summer 2013. (See also Figure 6.)*

Box 2 Surface ocean biogeochemistry and the production of atmospherically active trace gases

The low background aerosol encountered in the Arctic during summer means there is a high tendency for condensable trace gases, produced via atmospheric processing of oceanic gaseous emissions, to form new aerosol particles rather than condense onto pre-existing particles. One of the aims of the ACCACIA cruises was to constrain fluxes of these natural secondary aerosol sources, and investigate potential biological controls on the production of the gases involved.

Atmospherically active trace gases, including DMS, isoprene and halocarbons, were measured during both cruises. Near-simultaneous air and water measurements were made using a pair of gas chromatograph mass spectrometers, operated by researchers from the Chemistry Department at the University of York. Sea-to-air fluxes calculated from these measurements will be used to constrain secondary aerosol sources in atmospheric chemistry models, and the DMS measurements will also be incorporated into an ice–ecosystem model, with the aim of improving estimates of how biogenic gas production will change as sea ice declines.

Haloperoxidase enzyme activity, which has been found in a range of marine organisms, including phytoplankton, and has been implicated in the production of halocarbon gases, was investigated during both cruises by researchers from the Environment Department at the University of York. Assays were conducted on size-segregated samples and will be linked to size-segregated chlorophyll-*a*, in order to probe how haloperoxidase activity varies according to phytoplankton community.

During the second ACCACIA cruise, a team from the University of Oxford made detailed measurements of phytoplankton physiological status, and of the taxonomic structure of the phytoplankton communitiy. These measurements will help us to understand phytoplankton community structure in the Arctic under varying sea-ice conditions, predict how it may change, and aid in developing remote sensing techniques for marine productivity. They will also be invaluable in helping to interpret biological controls on primary and secondary marine aerosol sources. The ecological role of DMS in grazing interactions between phytoplankton, microzooplankton and copepods was also investigated during the second cruise. As part of a NERC-funded project entitled 'The role of DMS in pelagic tri-trophic interactions', a team from the University of Essex and Plymouth Marine Laboratory conducted on-board experiments to measure grazing rates, DMS production and change in the dynamics and intracellular concentrations of its precursor dimethylsulfoniopropionate (DMSP).

predicting how changes in the Arctic will affect global climate: a seasonally ice-free Arctic Ocean will be exposed to wind forcing, increasing the transfer of momentum and strengthening the ocean's turbulent mixing. This will change rates of deep-water formation, altering the thermohaline circulation and affecting climates much further afield, including that of the UK.

Airborne measurements

Concurrent with the two seagoing campaigns, other members of the ACCACIA consortium were flying above the Arctic Ocean in specially equipped research aircraft (Figure 2). The flights surveyed the boundary layer (the region of the atmosphere closest to the Earth's surface, typically 500–1000 m thick), from daringly close to the sea or ice surface, to above the cloud tops. There is a close two-way interaction between the boundary layer clouds and the ocean surface, mediated by turbulent atmospheric mixing and radiative energy transfer. In addition to studying aerosol and cloud properties, the flights aimed to make observations of these processes across a range of ocean surfaces, from open water to full ice coverage.

Figure 6 *The British Antarctic Survey MASIN Twin Otter aircraft surveying an area of broken ice during the summer ACCACIA campaign.*

Two research aircraft were used in the ACCACIA campaigns: the UK Facility for Airborne Atmospheric Measurement (FAAM) BAe-146, operating out of Kiruna in northern Sweden with refuelling stops in Longyearbyen (Figure 5), and the British Antarctic Survey MASIN Twin Otter (MASIN = Meteorological Airborne Science Instrumentation), operating out of Longyearbyen (Figure 6). The FAAM aircraft was heavily instrumented for *in situ* measurements of aerosol and cloud properties; for example a range of instruments were used to determine the size distributions and shapes of aerosol particles, cloud liquid droplets and cloud ice crystals, across a range of different size fractions and particle types. Some gas phase chemical measurements were also made, and aerosol samples were collected for compositional analysis back on the ground. Other instruments on the FAAM aircraft measured turbulent fluxes of momentum, heat and moisture, and the thermodynamic structure of the boundary layer. Lidar, which uses lasers to image remote objects in a manner analogous to radar, was used to map clouds. MASIN's instrumentation measures general meteorological conditions, turbulent fluxes of

Box 3 ICE-ACCACIA: Is the Arctic sea-surface a source of ice nuclei for Arctic stratus clouds?

Some aerosol particles can catalyse the formation of ice in clouds, and so are called ice nuclei (IN). Various types of particle are able to act as ice nuclei including mineral dusts, soot and biological material (e.g. certain bacteria, fungi and pollens), but there is very little information on ice nuclei sources in remote marine environments, and they have been neglected in global climate studies. However, evidence is now mounting to suggest that biological particles associated with sea spray may make a significant contribution to ice nuclei populations in remote marine regions.

The presence of IN allows the formation of ice crystals at higher temperatures than would be possible in the absence of such particles, and affects precipitation as well as the optical properties and lifetime of clouds. Low-level stratus clouds, which are ubiquitous in the Arctic region, are composed of a mixture of supercooled water droplets and ice particles. In the presence of sufficient ice nuclei, clouds formed below 0 °C can freeze – as the growth of ice particles causes them to precipitate out, this is expected to shorten cloud lifetime. However, Arctic stratus persist for many days despite clear signs of ice formation, a phenomenon that cannot currently be explained. A key area where understanding needs to be improved is the identity and source of the IN that form ice particles in these clouds.

Running alongside the main ACCACIA project, the ICE-ACCACIA project aims to investigate Arctic aerosols with respect to their properties as ice nuclei, and to evaluate the sea-surface microlayer as a source of ice nuclei. The sea-surface microlayer is an accumulation of organic material at the surface of the ocean that originates from biological activity such as excretion by phytoplankton. Sea spray aerosol generated by bubble-bursting is thought to be enriched in organic material like that found in the sea-surface microlayer. Aerosol particles generated in this way can be lofted by updrafts to cloud altitude where they could act as IN.

During the second ACCACIA cruise, researchers from the University of Leeds sampled the sea-surface microlayer using a remotely controlled vessel equipped with a PTFE-coated rotating drum and skimmer (Figure 4), in order to measure the concentration of IN present. The material collected from the sea-surface microlayer and bulk seawater were analysed on the ship by measuring the freezing temperature of small droplets deposited on to an electrically operated cold stage. Analysing fresh material has the advantage that it ensures that no changes have occurred to the composition of samples during storage.

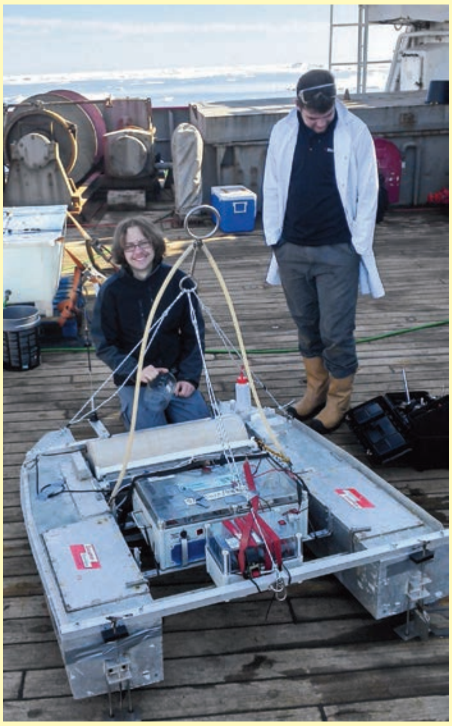


Figure 7 *The Leeds IN team with their craft; the drum is at the 'bow' end. See also Figure 8 overleaf. (By courtesy of Ben Lincoln)*

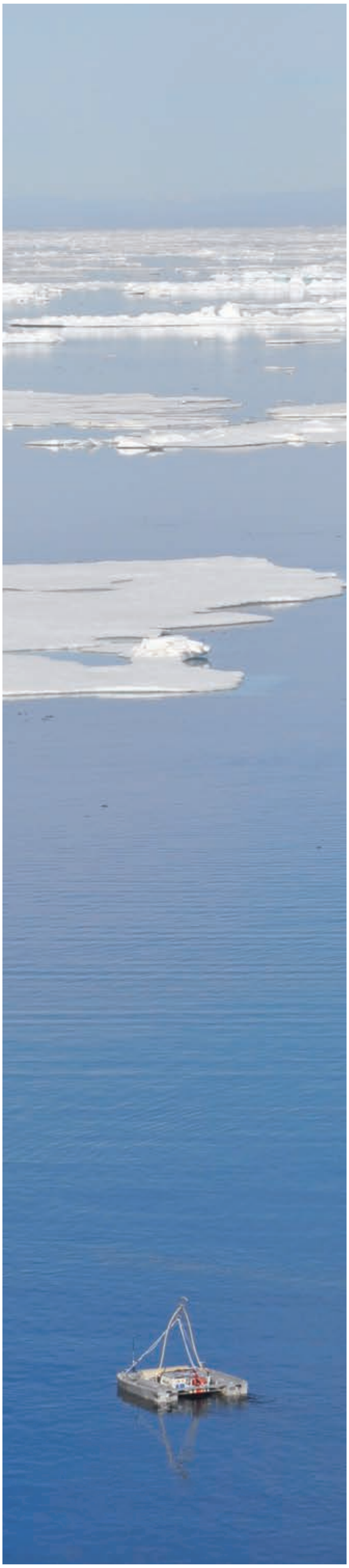


Figure 8 *The sea-surface microlayer sampler in action (By courtesy of Steve Andrews)*

momentum, heat, moisture and carbon dioxide, upward and downward fluxes of solar and infrared radiation, surface temperature, sea-ice roughness and the number, size distribution and phase of cloud particles (droplets and ice crystals) and aerosols. During ACCACIA, filter samples were also collected from the MASIN aircraft, and in-flight experiments were done to investigate aerosol volatility.

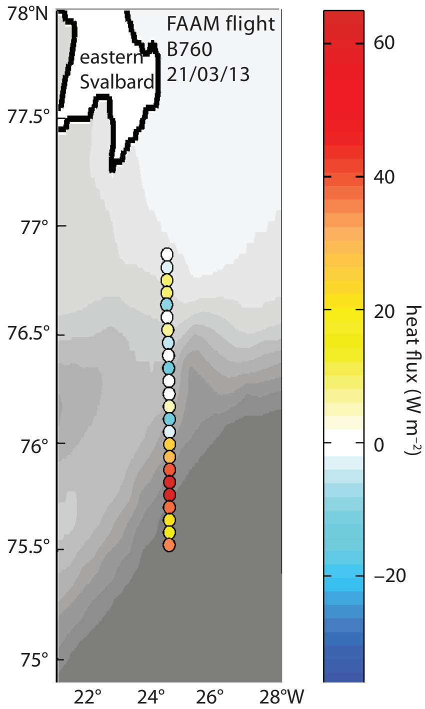
During the spring campaign, FAAM focussed on measurements of cloud and aerosol while MASIN focussed on characterising the atmospheric boundary layer around the ice edge, where the contrast between ice and water temperature leads to large surface heat fluxes of up to several hundred W m^{-2} (Figure 9). Only the MASIN aircraft operated during the summer campaign, splitting its time between boundary-layer dynamics and cloud measurements. The air and sea ACCACIA campaigns were loosely coordinated with each other, a particularly challenging undertaking when working in a very remote environment at the limits of the aircraft range. The location of the marginal ice zone during the campaigns, and logistical limitations, precluded a more closely coordinated sampling strategy, but the aircraft were able to make a 'fly-by' of the research ships during each campaign for intercomparison of results.

An urgent challenge

Recent rapid changes in Arctic climate, and particularly the reduction in sea-ice extent, serve to increase the urgency with which uncertainties in Arctic climate predictions need to be addressed. In 2013, the annual Arctic sea-ice minimum was the sixth lowest in the satellite record and continued the long-term downward trend of about 12% loss per decade. A notable change in 2013 was the large reduction in sea ice off the east coast of Greenland, south of Fram Strait (a region surveyed in both ACCACIA cruises), even compared with the record low sea-ice extent of 2012. Increasing industrial activity in the Arctic will also have unprecedented impacts on atmospheric chemistry and aerosol processes, which there is an urgent need to understand.

Now the field-going ACCACIA personnel have their feet back on dry land, their datasets are being worked up and used to inform modelling efforts by other members of the consortium. It is hoped the results from the ACCACIA project will help us to better represent Arctic clouds in global climate models. This will in turn allow us to better understand the

Figure 9 *Variation in estimated sensible heat flux (W m^{-2}) from the ocean surface, from open water (dark grey) across the ice edge to high sea-ice cover (white = 100% sea-ice). Note the higher fluxes toward open water, and the peak at the ice edge. Heat fluxes were estimated using the eddy covariance method, and sea-ice concentration is from the OSTIA satellite-based analysis. (By courtesy of Ian Renfrew/Andy Elvidge, University of East Anglia)*



rapid changes occurring in the Arctic and fully quantify the impact anthropogenic emissions are having on this unique and beautiful environment.

Acknowledgements

The ACCACIA teams would like to thank the officers, crew and technical support on the RV *Lance* and the RRS *James Clark* Ross during the two cruises, and the pilots and flight crew on board the FAAM and MASIN aircraft.

Further reading

Hodson, D., S. Keeley, A. West, J. Ridley, H. Hewitt and E. Hawkins (2010) *Identifying Uncertainties in Arctic Climate Predictions.* NERC/Met Office Report to NERC Arctic TAP.

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Lucy Carpenter (University of York) leads on surface sources of aerosol precursor gases; **Rosie Chance** (University of York) studies organic aerosol composition; **Theo Wilson** (University of Leeds) works on ice nucleation; **James Allan** (University of Manchester/ National Centre for Atmospheric Science) works on aerosol properties; **Amélie Kirchgaessner** (British Antarctic Survey) works on the ACCACIA aircraft measurements.

Piracy off East and West Africa: the current state of affairs

Martin Ewence

Much has been written about piracy since its rise to prominence off Somalia from 2008 onwards. Here, Martin Ewence, Chair of the Maritime Security and Safety Group (MSSG), outlines the origins and impact of piracy off East Africa and its growing prominence in West Africa, and describes areas in which providers of both security and equipment can continue to assist. Martin's last appointment in the Royal Navy was in 2011 when he was Chief of Staff to NATO's counter-piracy squadron, onboard in the Dutch Flagship and on patrol in the Somali Basin.

Causes of piracy off East Africa

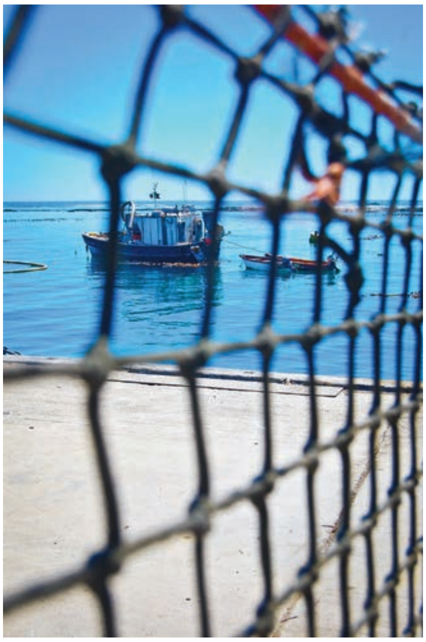
Those sympathetic to the Somali pirates will argue that they were forced into this way of life through necessity. Illegal fishing on an industrial scale had been happening since the overthrow of Somalia's ruler, Said Barre, in 1991, and industrial waste, in some cases reputed to be nuclear, was being dumped off their coast. The lack of any form of domestic jurisdiction since 1991, on land or sea, left no alternative but to find local solutions: fishermen needed to protect their rightful fishing zones and began by capturing the foreign vessels involved and demanding ransoms.

From capturing fishing vessels, Somali coastal people moved on to capturing merchant ships and to demanding higher ransoms. From thousands of dollars in 2005, ransom demands had risen to over $10 million per ship and crew in early 2011 when more than 700 seafarers in 30 ships were held off the Somali coast. The pirates appeared to have all in their favour: there was no jurisdiction on the high seas or in Somali coastal waters, merchant ships were unable to defend themselves and the international community appeared powerless to take effective policing action.

East Africa solved?

By mid-2011, however, the tide had turned against the pirates. Triggered by a more proactive stance by the NATO squadron that April, other squadrons followed suit and found greater 'flexibility' in their rules of engagement. More merchant ships were using their own protective measures as recommended in the industry's own Best Management Practices (BMP, now on version 4) and more were employing private armed security guards: usually a team of three or four former Royal Marines or soldiers. Additionally, the pirates themselves were being hounded out of the coastal communities: their excesses (alcohol, drugs, prostitutes and the spread of AIDS) were too much for the local culture.

In an unusual twist, former Somali pirates are now reported to be employed as private security guards aboard vessels fishing illegally in Somali waters. According to a recent UN report, 'Local fishermen from different communities along the Puntland coast have confirmed that the private security teams on board such vessels are normally provided from pools of demobilised Somali pirates and coordinated by a ring of pirate leaders and associated businessmen operating in Puntland, Somaliland, the UAE, Oman, Yemen and Iran.'



Threats to artisanal fishing off Somalia sowed the seeds of piracy

30 merchant ships were attacked during the peak of pirate activity in early 2011, but currently no merchant ships are being held by pirates off Somalia

British companies have made a significant contribution to the fall in the number of attacks and successful hijackings in the Indian Ocean. There are said to be over 200 private armed security companies (PASCs) operating in the region and an estimated 75% are British led and manned. But their competition is huge: many foreign firms, some of which have very doubtful managerial and financial credentials, are operating with less qualified operatives and at far cheaper prices. In equipment terms, many technical counter-piracy methods originate from the UK, such as emergency communications, power hoses, flares and even portable citadels – secure cabins, to which the crew can retreat until help arrives. A key factor has been better exchange and analysis of information: all naval forces communicate and share via a dedicated, privileged access net, whose information is being monitored constantly by the naval force HQs.

The general consensus is that we have reached equilibrium in the Indian Ocean and Gulf of Aden: piracy is contained – for now. The raising of the maritime security threat by the Department of Transport on 6 August 2013 for British-flagged ships operating off the Yemeni coast is terrorist related, but pirate attacks are down to their lowest levels for over five years and no ship has been hijacked since May 2012. British PASCs continue to dominate the market, and British technology firms continue to devise new deterrent methods for the ships themselves. It may be that technology will eventually be able to replace armed guards, but there is a way to go yet.

The growing threat off West Africa

The situation in the Gulf of Guinea is far more complicated, and not helped, ironically, by the fact that there are functioning governments, and all with navies and coastguards. And the seaborne threat is more diverse: there are mercenaries in armed speedboats navigating with their lights off; pirate boats with no form of identification; illegal fishermen; oil, weapons, drugs and human traffickers.

Whereas off East Africa the pirates' operating model is Kidnap and Ransom (K&R – holding the ship for months until a high enough ransom is paid), in the Gulf of Guinea it is more smash and grab: pirates will board a vessel, steal money and other valuables, then leave. The recent worrying trend, however, is for some crew members, particularly western officers, to be taken ashore and held for ransom. Although ransoms are generally paid and captives released quickly, this growth in K&R is a significant concern for seafarers. According to the International Maritime Bureau, 966 seafarers were attacked by pirates off West Africa in 2012 and over 200 of them were taken hostage.

Raising the stakes ever higher is the extraordinary wealth created through oil theft. Barges filled with stolen crude taken directly from the main trunk lines will rendezvous with ships that will then take it out to larger ships or further along the coast for sale at a discounted price. In the Niger Delta alone, an estimated $7 billion of revenue per year is lost to the Nigerian exchequer. At this rate, the Niger Delta thieves constitute the 12th largest oil-producing group in Africa, generating revenue that exceeds the gross domestic product of 15 different African countries.*

In June 2013 the oil tanker MT *Adour* was attacked off the coast of Togo and taken to Nigerian waters. The assailants – a dozen men with Kalashnikovs – were not able to siphon off the oil (the tanks were empty) so settled for the fuel the boat was using but also took the captain hostage along with his second in command. Both were released a few days later.

In August 2013, the Ghanaian Navy reported that it had intercepted the MT *Mustard* off the coast from Ghana's Saltpond offshore oil facility, claiming it had been hired to rendezvous with another tanker, the MT *Cotton*, which had been pirated in Gabonese waters in mid-July. That incident marked the first reported hijacking in Gabonese territorial waters in five years. According to the authorities, the pirates had used the *Mustard* to siphon some 3500 tonnes of fuel from the *Cotton* before sailing it to Ghana to sell the stolen fuel. This suggests the existence of a well-organised network with links across the region, able to exploit information about the tanker's whereabouts, to the point of specifically hiring a vessel to meet with it.

An emerging threat is to ships which are conducting ship to ship (STS) transfers, whether legal or illegal. A recent report stated that a tanker had been offered the opportunity to take on crude oil illegally offshore, but an alternative view is that this was a ploy to entice the ship into a position where its cargo could have been stolen. Most worrying for security analysts was that the caller had access to the ship's movements and that these had probably come from a legitimate source.

The solution off West Africa?

Regional navies, marine police and coastguards will insist that they are capable of providing the required security in their own waters but often lack the capability or training to be able to react quickly enough to prevent an attack. Another problem is that the regional governments whose sea areas are most affected by this crime (Cameroon, Nigeria, Benin, Togo and Ghana) will not permit private security guards to bear arms within their territorial waters. Complicated (and more costly) arrangements have to be made with regional armed forces whereby they provide the armed security aboard vessels, but are 'mentored' by private security personnel.

Off West Africa, international navies are not present in the same numbers or in

**Financial Times* Special Report on Nigeria, 28 November 2012.

Of the estimated 200+ private armed security companies operating in the Indian Ocean, over 75% are British manned and led

as coordinated a fashion as they are off East Africa. Why should they be? Fewer seafaring countries have a major stake in safe passage to and from West Africa: shipping movements are dwarfed by the volume passing through the Gulf of Aden. The most dedicated presence in the Gulf of Guinea appears to be from the US Navy: it has a ship permanently placed off Nigeria as part of a training programme and conducts frequent visits. The French Navy has a frigate on patrol off the eastern Niger Delta as reassurance to its maritime interests (the oil company Total has a presence) and the Royal Navy pays occasional visits when en route to or from the South Atlantic. But, politically, there is not the same determination to establish permanent patrols; more to encourage the regional navies to cooperate through training and mentoring.

Merchant ships must continue to work hard to improve their self-defence systems

Scanning the horizon: where will future threats come from?

Off East Africa the situation is stable and contained, but the strong suspicion is that the pirates are using this time to regroup and re-equip. Should one of the four 'containment factors' – more proactive navies, better BMP, private armed security and internal pressure – disappear, the pirates could re-emerge. Western navies' budgets are reducing, BMP adherence can be patchy and, while there is still a strong demand for it, intense competition in private armed security is driving down the prices and, in many cases, standards. An immediate solution is that private security and technology companies should work together to devise methods of better early warning (surveillance and reporting) and deterrence (non-lethal weapons). Live fire should only be used as a last resort.

Off West Africa, the firm assessment is that the situation will continue to deteriorate until regional navies' capabilities, and their ability to work together, improve. But when so many – reputedly senior politicians, high ranking military and local communities – are gaining so much from the proceeds of piracy and oil theft, it is difficult to see that anything will change in the near to medium term. The will is not there. This leaves an opening for PASC but there are complications to operating as an expat private security company. There are certain companies who already have a foothold in key West African states: they have generally developed a good relationship with the standing armed forces and are able to work with them to provide maritime security in coastal and offshore waters.

Again, there is enormous potential for technology companies to develop improvements in surveillance and reporting, as well as in information collection, analysis and storage. The lessons from East Africa show us that only when knowledge is improved, shared and acted upon, can there be marked improvements in the situation.

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Japan's Scientific Whaling isn't Scientific

Earlier this year, the UN International Court of Justice ruled that Japan's whaling operation around Antarctica is not for scientific purposes, and must therefore stop.

In a vote of 12 to 4, the Court ruled that aspects of Japan's whaling programme cast doubt 'on its characterization as a programme for purposes of scientific research'. Those factors include: the fact Japan did not consider using non-lethal methods; the scale of Japan's programme and number of whales taken; the open-ended time-frame of the programme; and Japan's lack of cooperation with other international research programmes in the Southern Ocean.

Perhaps the most telling indicator was that since 2005 the programme has produced only two peer-reviewed scientific papers (on seven minke whales), neither of which addressed Japan's stated goal of studying the size, structure, feeding and competition of minke, fin and humpback whale populations.

Japan has said that it will abide by the decision, but some believe that it will leave the International Whaling Commssion (IWC) in response to public pressure.

B31 – a giant iceberg in the Southern Ocean

Grant Bigg, Bob Marsh and David Wilton and Vladimir Ivchenko

During July–November 2013 a giant iceberg calved from the Pine Island Glacier in Ellsworth Land, West Antarctica, into the Amundsen Sea. The iceberg was initially ~ 720 km^2 in area – roughly the size of the island of Singapore (Figure 1). The calving of this iceberg had been anticipated for more than two years, after a long crack was seen in the glacier in October 2011 during flights for Operation IceBridge, NASA's 6-year study of polar ice. The rift gradually widened until, in June 2013, it extended across the entire glacier. However, it wasn't until austral summer began to approach that the iceberg actually calved and moved into open water in Pine Island Bay.

This was ideal timing for us, as we had just started a NERC Urgency Grant on 1 November, gained in response to the July separation, to track and model the trajectory of this iceberg, now named B31 (see Box). While B31 is a very large iceberg, calving of similar or even larger icebergs from Antarctica occurs irregularly but not infrequently. At any one time there are generally 30–40 icebergs in the Southern Ocean larger than 18 km (10 nautical miles) along one axis, the minimum size required for an iceberg to be categorized as 'giant'. Over the 11 years 2003–2013, 286 icebergs larger than 500 km^2 calved from Antarctica, with at least half a dozen larger than B31. What merits more attention than usual for this iceberg is its possible trajectory. Icebergs calved from many regions of the Antarctic follow relatively predictable paths, if not with predictable speed, as they are normally entrained into the Antarctic Coastal Current, with most of those that survive entering the Southern Ocean proper through the cyclonic circulation of the Weddell Gyre (Figure 2). Past icebergs calved from the Amundsen Sea sector of Antarctica, however, have followed one of two radically different trajectories, either the 'normal' one within the eastward-flowing Coastal Current, or one where the iceberg is quickly carried out into the Southern Ocean enough to travel eastward, eventually towards Drake Passage. The latter pathway would mean that the giant iceberg, or a field of icebergs if it breaks into several pieces along route, could be a threat to shipping routes through the Drake Passage, and into the South Atlantic.

Naming giant icebergs

Why 'B31'? For icebergs greater than 10 nautical miles in any one horizontal direction, the US National Ice Center uses a naming convention which relates to the sector of Antarctica from which the iceberg calved. The iceberg retains its label even if it drifts into another sector, and if it fractures into two or more pieces above the length threshold then these are given secondary labels. Thus, the Pine Island iceberg was the 31st giant iceberg to be calved from sector B (essentially West Antarctica) since regular observation from satellite became possible the early 1990s. If it splits into two substantial pieces then these will be labelled B31a and B31b. These large icebergs cease to be monitored once they are not sighted for 30 days, or their size drops below the threshold.

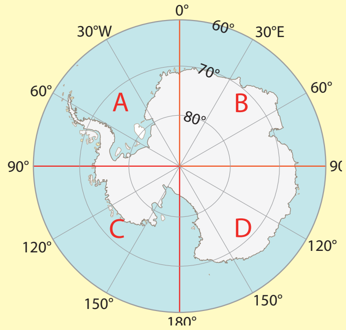
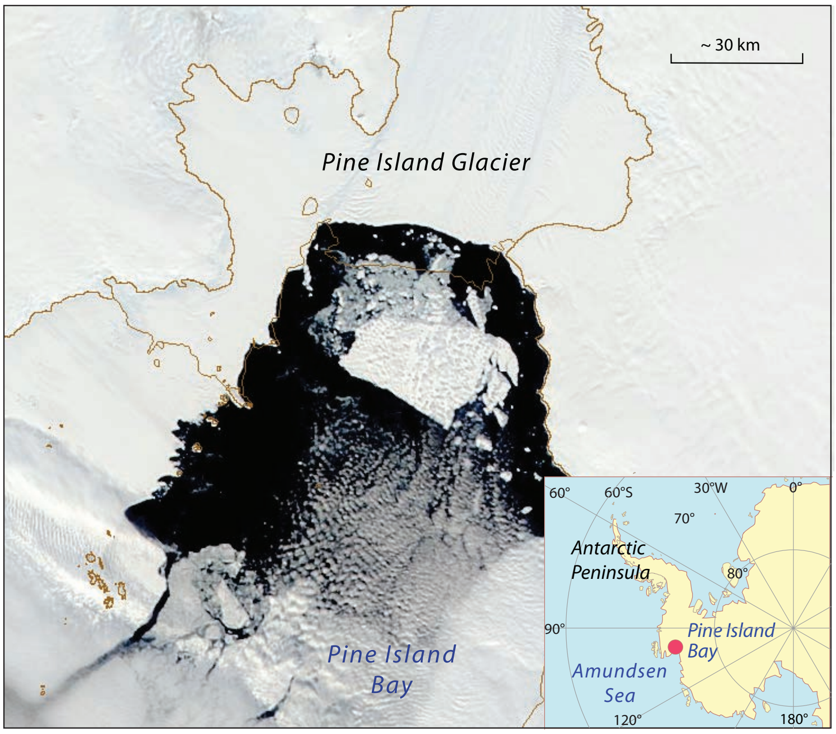


Figure 1 *Satellite image (visible light) of B31 soon after release, when it was ~ 30 km along its long side. Note the initial break-up of ice from the south-east corner of the iceberg, closest to the Pine Island Glacier, and the moderately sized icebergs breaking off from the west side.*



Iceberg tracking

Icebergs can be tracked in a range of ways. GPS trackers can be placed on the iceberg and their position monitored in virtual real time through satellite. BAS deployed two ADIOS trackers on Pine Island Glacier seaward of the crack in 2012, but unfortunately they ceased to transmit a few days after the calving event. In the first few days of the iceberg's life it lost approximately a third of its mass as the ice between the original calving crack and a secondary, seaward, crack fractured and largely disintegrated. Smaller icebergs also broke off from some of the sides in response to the changes in internal and external stresses following calving. It is likely the trackers were a casualty of this initial phase.

Icebergs can also be tracked through various types of satellite-based instruments, all with advantages and disadvantages. Long-term monitoring of giant Southern Ocean icebergs has been carried out by NASA and Brigham Young University using microwave scatterometer data since 1992. This dataset is revised several times a month but, due to the relatively coarse footprint of the various scatterometers used over the years, only a position is given. Smaller icebergs can be recorded using the much smaller footprint of an altimeter, with a minimum size of 400–500 m being typical, and a measure of length becoming possible. Even better resolution is achievable with satellite-borne Synthetic Aperture Radar (SAR) instruments, from 400 m down to sub-50 m, depending on the specifications of the SAR product. However, the large volume of data produced by SAR imagery means that the instruments are not always switched to record mode, especially over the open ocean, and interpretation can be difficult, especially in areas with sea-ice or rough seas. Larger icebergs are also seen with the various resolutions of visible imagery, although cloud and light conditions need to be suitable. We are using a range of approaches to track B31 and its change in orientation and size over time.

At the time of writing B31 has only been adrift for a few months, but some interesting variation in its trajectory and size, and evidence of iceberg–ocean interaction, has been seen (Figure 3). B31 initially moved down the centre of the fjord, but break-up of a large part of its south-east corner led to initiation of a clockwise rotation. This caused the berg to move closer to the fast ice on the western side of the Bay, an interaction that caused it to move quickly offshore again, and then resume its clockwise rotation. Near the mouth of the fjord B31 essentially came to a halt for around two weeks before resuming its outward motion and clockwise rotation. As of mid-January B31 has rotated through roughly 180° since it began this behaviour in late November. Whether these motions are due to ocean or atmospheric forcing is not yet clear. The smaller icebergs that have broken off along-route are behaving rather differently and are more clearly responding to circulation within the fjord. As can be seen from Figures 1 and 3, B31 was large enough to be a major obstacle to circulation in the fjord, and its movement is likely to be caused by a combination of down-glacier katabatic air flow, existing fjord circulation, and interaction of the iceberg movement with the surrounding ocean and land/ice. With B31 moving into the main part of Pine Island Bay we expect larger scale ocean circulation to begin to have a major effect on its motion over the next few months.

Iceberg modelling

Modelling iceberg motion at local to regional scale has been possible since the 1980s, and is used routinely by the US Coast Guard's International Ice Patrol to monitor iceberg movement in the Labrador Sea, to assist in the ice warning service they provide to shipping in the north-west Atlantic. However, it is only since 1996 that is has been possible to model the movements of melting icebergs over entire hemispheres, and only since the mid to late 2000s that such models have been coupled to first ocean and then climate models. We are using a recent implementation of iceberg modelling in the Nucleus for European Modelling of the Ocean (NEMO) modelling structure to study the likely motion of B31 in the months to years ahead.

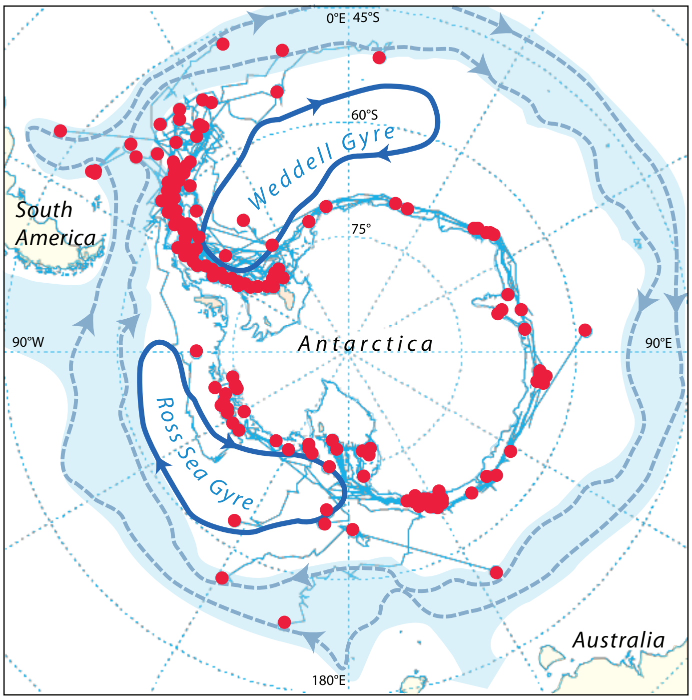
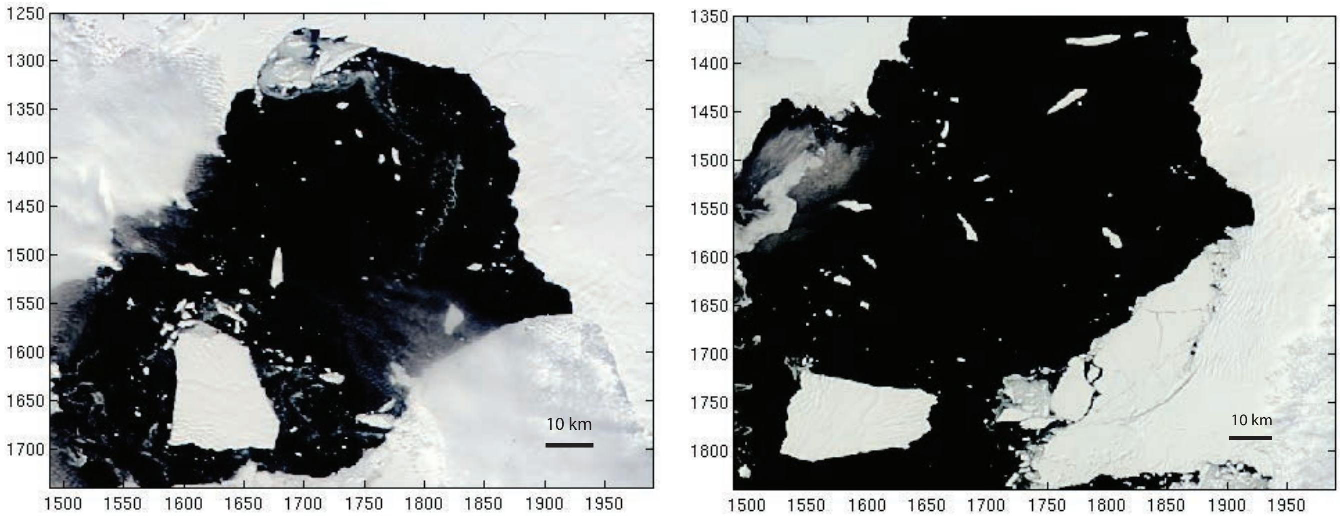


Figure 2 *Trajectories of giant icebergs as tracked by the National Ice Center, 1987–2003. Red dots mark the track ends. The pale blue band is the Antarctic Circumpolar Current, and the dashed blue lines are average positions of more intense current within it.*

Iceberg data reproduced with permission from T.A.M. da Silva

Figure 3 *Two B31 satellite images, from 10 December 2013 and 18 January 2014, showing the clockwise rotation. The coordinate system of both images is relative to the same origin, and is in pixels of size 250 m.*



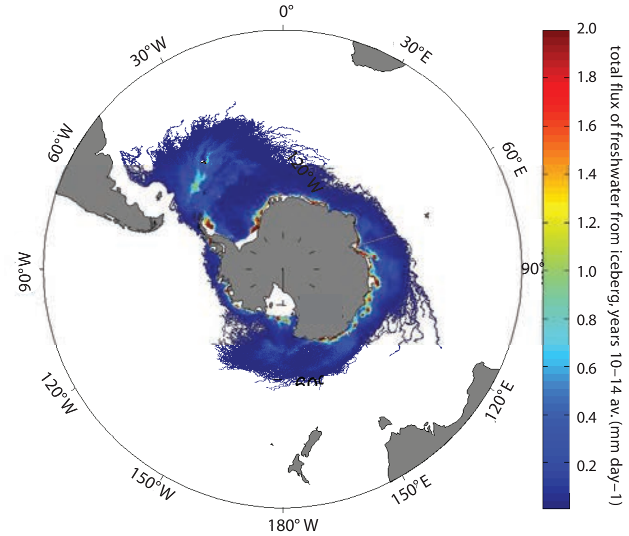


***Figure 4** Average freshwater flux from Antarctic icebergs, according to the ORCA025 model (which has 0.25° resolution) (averages for years 10–14 of the simulation)*

The icebergs are modelled as a sequence of releases of a range of size classes, the maximum depending on the estimated or observed calving flux of each marine-terminating glacier or ice stream. These are forced by a combination of physical drivers of the iceberg motion – water, wind and sea-ice drag, Coriolis force, sea-surface pressure gradient and waves – and thermodynamic drivers of iceberg size-change including basal melting, wave erosion, buoyant convection and several smaller terms relating to snowfall and the surface radiation balance. The icebergs can roll over when dynamically unstable, ground and re-float. From the model trajectories both the iceberg density and their meltwater contribution to the ocean surface can be found. In significant parts of the Southern Ocean, particularly near the coasts and in the South Atlantic, the annual iceberg meltwater input to the ocean is as large, or larger, than the local precipitation–evaporation balance (Figure 4).

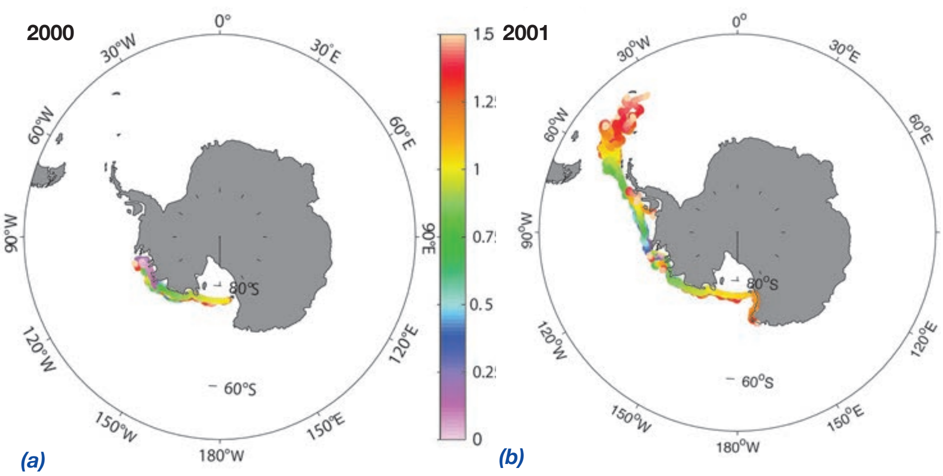
While there is a range of both dynamic and thermodynamic factors affecting iceberg motion, the water drag is normally the most important force on the iceberg, so simple particle tracking is a useful way to gauge the range of possible iceberg paths over a wide range of forcings. Just comparing two successive years shows the chaotic nature of the iceberg dispersion from the Pine Island area – particle releases into NEMO for 2000 went west, towards the Ross Sea, while those for 2001 went east, towards Drake Passage (Figure 5).

Navigational hazard

Icebergs are fascinating in their own right as expressions of abrupt natural change, examples of the interplay between land, ocean and atmosphere, and as modifiers of climate, both locally and, in mass, at larger scales. However, it is because they pose a potentially lethal navigational hazard that they have greatest potential for short-term impact. The sinking of the RMS *Titanic* in the north-west Atlantic in April 1912 after collision with an iceberg was not an exceptional event (for more on this, see pp. 42–7). In the late 19th century an average of more than one vessel a year in the North Atlantic was lost, with several times this number damaged, through iceberg collision. There are still occasional iceberg–ship collisions, with a cruise ship, MV *Explorer*, sinking in the Bransfield Strait, just north of the Weddell Sea, as recently as November 2007.

There is a distinct iceberg stream spreading north-east in the Weddell Gyre from east of the northern tip of the Antarctic Peninsula. The crew of ships entering this area will be used to monitoring ice warning services in the region. However, if B31 follows the eastward path it, and its fragments from any fracturing, may reach the Drake Passage and so pose a hazard to shipping in a region normally iceberg-free. It won't be known for a year or more whether this eventuates but using the NEMO iceberg model we can attempt a prediction. At the time of writing (February 2014) our work is still at a preliminary stage, and the iceberg has not yet moved very far, but before next austral summer we will have a prediction ready.

***Figure 5** Passive drift with ORCA025 hindcast currents at 47 m, for 38 particles released in Pine Island Bay every 5 days from November to May (sea ice-free season) of **(a)** 2000 and **(b)** 2001. Particle position is plotted daily for 1.5 years and colour-coded for time (years) since calving.*



Further Reading

BYU database: http://www.scp.byu.edu/data/iceberg/database1.html

Bigg, G. R., M.R. Wadley, D.P. Stevens and J.A. Johnson (1997) Modelling the dynamics and thermodynamics of icebergs. *Cold Regions Science and Technology* **26**, 113–35.

Levine, R.C.and G.R. Bigg (2008) The sensitivity of the glacial ocean to Heinrich events from different sources, as modeled by a coupled atmosphere–iceberg–ocean model. *Paleoceanography* **23**, PA4213, doi:10.1029/2008PA001613.

Silva, T.A.M. (2006) *Quantifying Antarctic icebergs and their melting in the ocean.* Ph.D. Thesis, University of Sheffield.

Grant Bigg and **David Wilton** are in the Department of Geography at the University of Sheffield; **Bob Marsh** and **Vladimir Ivchenko** are in the School of Ocean and Earth Sciences of the University of Southampton.

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Does local marine conservation work? A case study of bait collection in the UK

Gordon Watson

Bait collection – the harvesting of organisms for use as bait for sea angling – has been an integral part of coastal life for generations. There are an estimated one million UK anglers fishing in the sea and tens of millions worldwide, all of whom rely on bait for fishing, with the vast majority collecting bait from the wild. In recent years, bait collection has become a highly contentious issue, often polarising anglers, local communities and those managing marine coastal resources; it has even led to incidents of intimidation and violence. Marine ecosystems face increasing threats from human activities and it is now recognised that management of bait collection is a high priority in coastal marine protected areas. This article looks at our current research on this topic and discusses how successful local management has been in meeting its objectives. Locally driven approaches also have high relevance for a diverse range of human impacts on the coast, from recreational activities to fishing. As the marine conservationists' management toolbox is under ever-increasing financial pressure these types of schemes are likely to be increasingly used as they are often relatively cheap to implement and run.

Although some aquaculture companies have been able to carve a niche out of the bait market, the majority of bait organisms will be collected from the wild. Indeed many anglers prefer wild caught bait due to its greater 'wriggle ability', superior colour and smell – all essential in making your next big catch! A bait collector might be an occasional angler who needs to collect some bait for a weekend fishing trip or a match angler who is fishing several times per week and might collect a considerable quantity (several kilograms) and then store it. There are also commercial diggers who collect bait to sell to tackle shops or online, and often move around the country in organised groups.

In recent years bait collection has become a highly contentious issue. In the UK, ragworms (e.g. *Nereis virens*) and lugworms (e.g. *Arenicola marina*) (see Figure 1) are the two major groups collected, but many other species, such as soft-shelled shore crabs (*Carcinus maenas*), razor shells (*Ensis* spp.) and cat worms (*Nephtys* spp.),

Figure 1 Left *The king ragworm (*Nereis virens*), the most collected species in the UK.* ***Right*** *The lugworm (*Arenicola marina*). King ragworms are typically 10–50 cm long, and lugworms 5–20 cm long.*

Ragworms and lugworms – both polychaetes – are an ecologically important part of the marine benthic community

are also used, depending on season, personal preference and the species of fish to be caught. *N. virens* is the most commonly exploited species in the UK and is collected by manual turning of the sediment with a garden fork, usually to a depth of 30 cm. Experienced collectors can identify burrow entrances and then target-dig worms, but the more usual approach is to dig a trench and remove exposed worms. Some species such as the black lug (*A. defodiens*) live in burrows up to 1 m deep, and collecting these involves using a bait pump. A bait pump is a stainless steel tube with a plunger: the tube is inserted into the sediment and pulling the plunger removes a core of sand, which will (hopefully) include the worm. Bait dragging, which involves dragging rakes (30–40 cm long) behind a boat at high water, is another method for collecting *N. virens*. This method is unique to Poole Harbour on the south coast of the UK, due to the unusual conditions found there – the exceptionally soft sediment makes access difficult, and the double high water and small tidal range mean that it is only exposed for a short period of time.

Ecological impacts

The impacts of bait collection have received considerable attention over the last 30 years. Physical characteristics of the shore are altered, with the production of mounds and troughs being the most obvious result (Figure 2). These topographic changes redistribute organic material, which accumulates in the depressions, and there is a loss of the finer grained particles as they are resuspended in the water column. Not surprisingly, bait collection also results in significant changes in the size/age structure of exploited populations, but in a somewhat counterintuitive way. Dug sites have significantly higher densities of *N. virens* than unexploited sites, but individuals here are smaller. This is because although *N. virens* feeds on a wide range of other invertebrates it also has cannibalistic tendencies, and removal of the larger individuals from the sediment allows more of the smaller ones to survive.

By contrast, other long-lived, larger and less abundant invertebrate species suffer significant and long lasting reductions; these include cockles (*Cerastoderma edule*), burrowing sea urchins (*Echinocardium cordatum*) and other polychaetes (e.g. *Neoamphitrite figulus* and its associated scale worm, *Harmothoë glabra*). Our recent work has also shown that areas dug repeatedly have a different macrofaunal community structure at the hectare scale, as shown by the clear separation of points corresponding to 'dug' and 'undug' points in Figure 3 (*opposite*). For example, an increase in the abundance of *Hydrobia ulvae* is associated with undug areas on the mid shore, while increasing relative abundances of nematodes are associated with both dug and undug areas on the mid shore and dug areas on the low shore.

There is also some evidence that wading bird populations are disturbed by the presence of diggers on the shore and are affected indirectly by a reduction in prey densities. Bait collection can also adversely affect many shore users. Unfilled holes are a hazard, whilst moorings, jetties and boats can be damaged or undermined.

Conflict with coastal conservation?

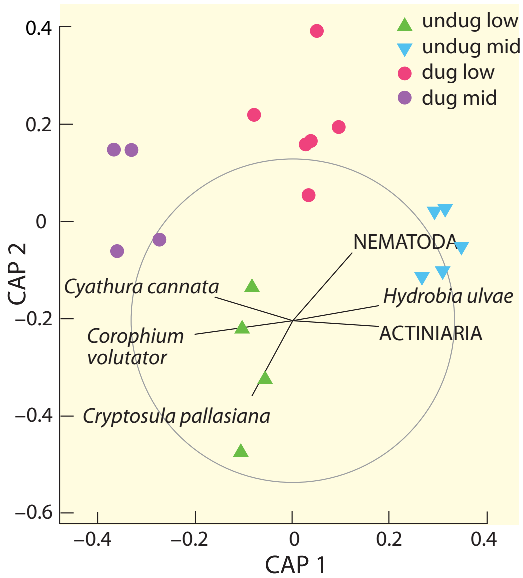
European Marine Sites (EMS) were set up to manage marine and coastal resources in a sustainable way. They include internationally important marine sites designated under the EU *Habitats Directive* and *Birds Directive,* i.e. Special Areas of Conservation (SACs) and Special Protection Areas (SPAs). SACs provide increased protection to a variety of wild animals, plants and habitats, as part of efforts to conserve global biodiversity,

Figure 2 *Intertidal sediment in Poole Harbour showing the topographic changes caused by bait collection.*

Bait collection produces mounds and troughs in which organic material collects

Figure 3 *CAP (Canonical Analysis for Principal Components) plot for square-root transformed macrofauna community data (abundance and diversity of all recorded species) from low and mid shore cores taken from Dell Quay. CAP is a way of finding axes through the multivariate cloud of data points (macrofaunal abundance data collected from sediment cores taken from the sites) that have the strongest correlation with variables, in this case, height on shore and presence/absence of digging. The axes are linear combinations of the orthonormal principal components axes. The community differs between dug and undug sites, but there are also differences between low and mid shore areas (shown by the groupings).*

A visually exploratory vector overlay of macrofaunal species (higher taxonomic levels in capitals) is overlaid (only vectors with length > 0.4 are shown; the circle has radius = 1.0). The length and direction of each vector indicates the strength and sign, respectively, of the relationship between that variable and the axes.



The abundance and diversity of the various macrofauna living on the shoreline depend on the height of the site on the shore, and whether or not it has been dug

and SPAs have been identified as of international importance for the breeding, feeding, wintering or migration of rare and vulnerable species of birds found within the EU. However, as EMSs have been established in areas where many human activities were already occurring, the aim was not to exclude these activities, but to ensure that they are undertaken in ways that do not threaten the nature conservation interest,

In the Solent, extensive harbour and estuary systems that include soft sediment shores, combined with up to 60 000 active sea anglers, allows great scope for bait collection (and for stakeholder disputes that are hard to resolve). In fact, it is difficult to find an easily accessible area of mud supporting high numbers of the target species that is untouched. However, the Solent EMS (as well as many other areas around the UK) contains a number SACs and SPAs as well as Ramsar* sites, SSSIs and local nature reserves (cf. Figure 4 overleaf). Intertidal mud flats, sand flats and estuaries are key habitats for the SACs, and many sites are also SPAs as they are internationally important for overwintering wildfowl and wading birds; intertidal mud flats are highlighted in the EU Directives as being important habitats for feeding. More generally, those areas, features and species listed in *Annex 1* of the relevant directives are required to be conserved and protected.

In other countries, intertidal activities such as clam-digging have been banned or controlled. After extensive legal discussions and a number of public enquiries, bait collection in the UK remains a public right and so cannot be extinguished, but it can be regulated indirectly by a variety of local authority, public health, conservation, fisheries and harbour authority byelaws. This public right only extends to the collection for personal use as there is no legal right to take worms commercially, without the permission of the landowner.

Effective conservation management is integrally linked to well designed monitoring and evaluation systems. It must have clear objectives, community and scientific involvement from the beginning, and the schemes must be founded on up-to-date and locally based science, which performance can be set against. Unfortunately, many conservation schemes have serendipitous origins, taking advantage of politically expedient opportunities. Management of bait collection in the UK has been at a local level and this has resulted in the implementation of a range of site-specific management strategies that, in places like the Solent, can run concurrently and are in close proximity to each other. Their implementation has been a significant step forward, but any scheme must be evaluated in relation to how well it meets its primary objective. My research group based at the Institute of Marine Sciences of the University of Portsmouth has focussed on the efficacy of these management strategies as, to date, there has been no quantitative evaluation in the UK.

Management methods

Zonation

Marine Protected Areas (MPAs) are defined as areas in which certain uses are regulated to protect natural resources, biodiversity, or human livelihoods, and they have become a major focus of marine conservation. Their establishment, positioning and extent of coverage are currently hot topics of scientific and conservation debate as the UK grapples with establishing a coherent network of Marine Conservation Zones through the *Marine and Coastal Access Act* (2009). MPAs that use zonation – the exclusion of an activity from a site or for a particular period of time – are one of the most popular methods, gaining worldwide usage since the first marine reserves were established. Two sites in the Solent, which have

*Ramsar sites are wetlands of international importance, designated under the *Convention on Wetlands of International Importance, especially as Waterfowl Habitat*, signed at Ramsar in Iran in 1971.

An area such as the Solent may contain several different kinds of marine protected areas, perhaps with various serendipitous origins

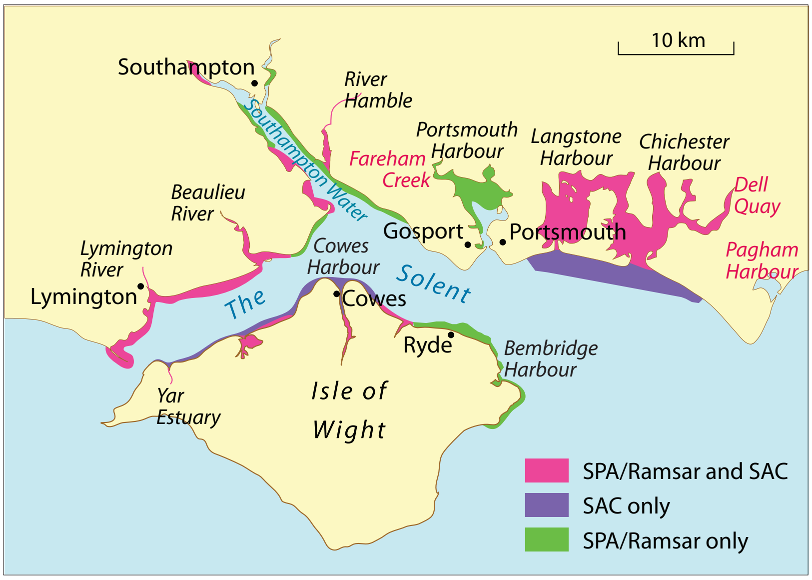


Figure 4 *Map of the Solent area with the names of the three study sites discussed in this article shown in red. (For explanations of SCAs, SPAs and Ramsar sites see* *p. 37.)*

spatial zonation at the core of their bait collection management, were used as case studies. These were Fareham Creek and Dell Quay (labelled in red in Figure 4). At Fareham Creek, a key collection area in Portsmouth Harbour, a Special Nature Conservation Order (SNCO) was established in 2003–4 to prevent commercial digging. The aim was to protect core parts of an intertidal area deemed unique to its SPA status using Natural Habitats regulations. At Dell Quay in Chichester Harbour (Figure 5), a byelaw prohibiting bait collection within 15 m of any mooring, or 6 m of any structure, was established by Chichester Harbour Conservancy Council with the aim of minimising damage and risk of injury to people.

At Dell Quay bait collectors respected the official exclusion zones

Although data show that Dell Quay is a very popular site for bait collection (with up to 14 collectors present on one tide), very few diggers were observed within the protected zones (Figure 6); these observations were supported by mapping of the biotopes (areas of distinct habitat supporting specific communities of species), which showed that areas of dug sediment were nearly always located in unprotected areas (Figures 5 and 6).

Figure 5 *Location of sediment areas of Dell Quay identified during the biotope survey as having been dug over for bait collection (red) along with the 15 m radius exclusion zones around moorings (purple circles) and 6 m exclusion zones adjacent to jetties/quays (yellow), established using the byelaw.*

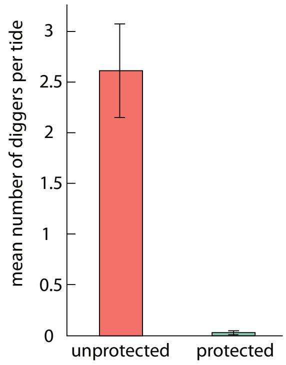


Figure 6 *Mean number of diggers per tide (± standard error of the mean) recorded on video within unprotected and protected areas (i.e. exclusion zones) at Dell Quay. Data are from two camera deployments (51 day and night tides in total), and show a statistically significant difference.*

Cameras are a cost-effective way of monitoring protected areas of shoreline

Figure 7 *Examples of deployment locations for CCTV cameras used at Pagham Harbour to record bait collection activity. Cameras run using leisure batteries or mains electricity.*

Fareham Creek was not as popular as Dell Quay, but still had significant levels of digging activity recorded inside and outside the area covered by the SNCO. This mirrors the patchy nature of areas which the biotope survey of the site showed were dug. It is theoretically possible that all digging within the SNCO area was for personal use only, but the CCTV video observations (Figure 6), history of the site and our own observations make this highly unlikely, suggesting a disregard for the relevant byelaw and, therefore, failure of the spatial zonation approach.

For our third case study we chose Pagham Harbour (Figure 4), a site located at the east end of the Solent, approximately 10 km from Chichester. This site is not within the Solent EMS, but is a local nature reserve and has SPA status. It was not possible to assess the effectiveness of the management methods as no diggers were observed from over 30 tidal cycles of recordings and only a very small amount of dug sediment was mapped during the biotope survey. Bait collection at this site is controlled by enacting National Nature Reserve byelaws through a combination of temporal and spatial zonation. Collection is restricted to two areas with alternate 6-month access to each to protect soft-sediment habitats and wading birds for the SPA status.

At Dell Quay, the regular and sustained 'unofficial' enforcement by officers of Chichester Harbour Conservancy is likely to contribute greatly to the success of the byelaw at this site, helped by the obvious nature of the protected structures (moorings, jetties etc.). This is in clear contrast to a lack of enforcement at Fareham Creek, combined with the difficulties of having merely a line on a map. In addition, even though the police and agencies were regularly contacted by the public to enforce the SNCO they have been unable to act on these reports due to the difficulties of separating commercial digging from personal use. In Pagham Harbour, rather than indicating a successful zonation system, the lack of activity is more likely to be because of the distance of the harbour from conurbations, and the distance from the car park to the digging areas.

Education

Education via stakeholder involvement is seen as a critical tool for the communication and promotion of conservation aims, because it stimulates support, and encourages a sense of ownership and buy-in to a conservation project. Understanding how people think about issues, their knowledge, beliefs, attitudes and values is crucial in the search for coastal management solutions. Education aimed at increasing awareness, reducing impacts and increasing sustainability, can be either active or passve: stakeholders can become involved through (say) workshops or focus groups, or may simply respond to signage or leaflets. In response to the commercial collection occurring at Fareham Creek a voluntary code of conduct was developed by stakeholders (conservation agencies, bait diggers and other local NGOs). The code, which is set out in a leaflet, includes ten points of which only five (cf. Table 1) relate directly to bait collection. The others cover general shore and countryside awareness and safety. The production of 42 000 leaflets distributed within the Solent region, and posters for information boards, were used to maximise exposure.

Table 1 *The key statements relating to reducing the impacts of bait collection, as set out in the Bait Collectors' Code*

- **Observe local byelaws; only dig in permitted areas**
- **Collect bait in a sustainable fashion**
  Avoid damaging other animals, take only what is necessary
  Do not take spawning worms
  Store bait to minimise mortality
  Return unused bait to similar areas
- **Back-fill holes, for safety and to maintin intertidal habitat**
- **Avoid disturbing wildlife (Including birds and marine mammals) and marine heritage**
- **Do not dig near moorings, slipways or sea walls**

Survey responses collected during visits to fishing tackle shops initially indicated that the Bait Collectors' Code seemed to be working well, with the majority of respondents having heard of it and saying that they follow the code. However, nearly all of the bait-specific points in the code are standard practice for most experienced diggers. For example, diggers routinely collect only what is needed, select larger worms, but avoid spawning ragworms as they do not remain intact on a hook. The fact that the code largely describes what people do already is likely to explain why the majority of the respondents said they follow the code.

Back-filling of holes has always been promoted as best environmental practice, but was also thought of as a way to turnover sediment with minimal effort. It was, therefore, a surprise to see the data show that 100% of observed diggers were disregarding this part of the code.

Our research therefore shows that the voluntary code has had little demonstrable positive impact on changing behaviour, as diggers were already doing many of those things recommended in the code, but were not persuaded to do anything new. These issues, combined with the code's influence being severely limited by the inability to reach all diggers, have meant this passive educational approach to management has not been successful. Education must also have 'teeth' to move stakeholders towards change.

Licences and quotas

As part of the management system for Pagham Harbour, approximately 18 permits to fish and collect bait were issued in the early 1990s. Although the permitting system has now been rescinded in this harbour, it is commonly used elsewhere, e.g. in the case of freshwater rod licences issued by the Environment Agency. Even bait collection on the east coast of the USA has a licensing programme, with approximately 1000 licensed diggers who can dig a range of invertebrates including clams and worms. Licences for bait collection in the UK have some support from the industry and from anglers. A licensing system has the benefit of being a method to rapidly assess the number of people performing an activity and also control who does it. However, numbers of licences do not accurately represent actual levels of bait-collecting activity on the shore. For example, CCTV recordings show that some diggers spend only a few minutes digging, but others are often present for over three hours. The frequency of visits is also dependent on need: a match angler may go a number of times a week, whilst an occasional angler may only go once every few months. In addition, it is not easy to assess scientifically what a sustainable level of digging might be for a particular vulnerable habitat. For these reasons, matching the number of issued licenses to the 'correct' level of activity would be impossible.

Often associated with licensing and permitting is the issuing of bag limits; Pagham Harbour also had a limit of 0.5 kg per visit as a condition of the licence. The variability in digging effort between sites, dates and individual diggers, and the fact that *N. virens* can be stored for several weeks using just a fridge, some coral sand and seawater, make any limit unrepresentative of the full spectrum of fishing. The question of what an appropriate bag limit mighe be also suffers similar problems to how many licences can be issued while still meeting the management objectives. The difficulties of enforcing licensing and bag limits, and of setting an appropriate price that is high enough to cover costs for strap-cashed public organisations but low enough to ensure uptake, not to mention that bait collection for personal use is a public right, currently all make these methods impractical in the UK.

Some golden rules for local management for conservation

Over the last few years, research on bait collection, including our own studies, has provided baseline data from which a number of general 'rules' can be applied to its management throughout the UK. However, it is also clear that many of these 'lessons' can be applied to local conservation strategies for a wide range of habitats and species that are under exploitation pressure. Here are some of the golden rules:

First, scientifically assess the problem

Plans to manage a resource must first scientifically assess the level of impact at the site. For example, Pagham Harbour has low levels of bait collection, so bag limits and a permit system, combined with temporal and spatial zonation, would be overkill. In other words, implementation of the correct level and extent of management must match the actual (not perceived) pressure at a site.

Build in evaluation

The *ad hoc* way local bait-collection management schemes have been established, and the fact that some were not evaluated until several years after they were set up, highlights a common problem of local conservation management. Any strategy must be established with scientific evaluation and assessment integrated from the start. A BACI (Before, After Control and Impact) or similar approach must be utilised. Although more costly in time and money, ultimately it will provide the data for evidence-based management.

Don't forget local geography!

The differences between the three geographically close sites used as our case studies confirm that any management must be site-specific and tailored to local needs – one size will not fit all. However, it is also important to have regional (or national) level management strategies to minimise displacement of diggers from one site to another, provide parity between regions and simplify the management process.

Consider legal aspects

As mentioned above, the public right to collect bait only extends to collection for personal use; there is no legal right to take worms commercially without the permission of the landowner. It is impossible to separate commercial from personal use in any meaningful way so any management methods must control both types, as the impacts are the same. Ideally, the legal status of the exploited resource (e.g. whether it comes under fisheries or habitat legislation) must be clearly understood before initiating the management process. If this is not the case, any management may be legally challenged, getting bogged down in the legal and public enquiry systems until resolved by case law. (Bait collection is a good example of where case law has not provided workable guidance for management.)

Enforce, or there's just a line on a map

Enforcement is critical to any conservation management (voluntary or backed by statute). Comparisons with Dell Quay and Fareham Creek, and the evaluation of the effectiveness of the Bait Collectors' Code, show that enforcement must mean deployment of people on the ground because signage, leaflets and other passive mechanisms are ineffective in reaching and educating all stakeholders and ensuring that the rules are adhered to.

The difficulty in policing a large number of inshore activities is exemplified by the Inshore Fisheries Conservation Agencies (IFCAs). As an example, the Southern IFCA's jurisdiction covers the Dorset, Hampshire and Isle of Wight coastline (~ 680 km), extending out to 6 nautical miles. However, financial constraints mean that management falls to just a few officers. Targeted approaches to 'hot spots' or areas of concern are used frequently, but it would still require substantial investment in direct observation, and considerable human resources, to monitor and gather appropriate levels of data.

A complementary approach would be to use CCTV (Figure 7) or even UAVs (Unmanned Aerial Vehicles). CCTV is now an everyday part of our lives and is integral to crime prevention and detection. The step-change in technology seen in recent years – analytic software with motion tracking, facial recognition for CCTV, and cheap, build-your-own smartphone-driven UAVs – would make possible cost-effective systems for monitoring and gathering evidence on many inshore activities, including bait collection. They could even be used for enforcement in areas which are difficult to access or remote; also covering activities such as bait collection which we know can often occur at any time of day or night. CCTV and UAVs that can do these sorts of jobs are technologically possible now, but there are a number of issues that would need to be resolved around the *Data Protection Act* (2008) and the *Regulatory Investigative Powers Act* (2000), not to mention authorisation by the Civil Aviation Authority for UAVs. The general public would need to accept this 'surveillance conservation' but might be reassured by the fact that the presence of CCTV and AUVs might reduce crime rates generally.

The future

There is an urgent need to stem the increasing threats to marine resources, notably overfishing, pollution and coastal development. There is also no shortage of regulatory requirements for on-going monitoring of key ecological indicators or of assessments of the condition of coastal resources (e.g. the *Marine Strategy Framework* and *Water Framework Directives*; the new EMS guidance on commercial fishing, and the up and coming MCZs). However, legal statutes have no effect without scientific monitoring on the ground. As our research on bait collection has shown, as long as the golden rules are followed, locally driven conservation methods, which are also relatively cheap, have the power to deliver effective management to help reduce the impacts of these threats now and for the future. Unfortunately, we need to remember that financial constraints on conservation science have never been greater, and the ability to do more with less can only be taken so far!

Further Reading

Leslie, H.M. (2005) A synthesis of marine conservation planning approaches. *Conser. Biol.* **19** 1701–13.

Lester, S., B. Halpern, K. Grorud-Colvert, J. Lubchenco, B. Ruttenberg, S. Gaines, S. Airamé, and R. Warner (2009) Biological effects within no-take marine reserves: a global synthesis. *Mar. Ecol. Prog. Ser*. **384**, 33–46.

Sypitkowski E., W. G. Ambrose Jr., C. Bohlen and J. Warren (2009) Catch statistics in the bloodworm fishery in Maine. *Fish. Res.* **96**, 303–7.

Watson, G.J., J.M. Murray, M. Schaefer, A. Bonner, M. Gillingham (2013) Does local marine conservation work? Evaluating management strategies for bait collection in the Solent. *Report to the Crown Estate and Natural England.*

Watson, G. J., P. Farrell, S. Stanton, and L.C. Skidmore (2007) The effects of bait collection on *Nereis virens* populations and macrofaunal communities in the Solent, UK. *J. Mar. Biol. Assoc. UK* **87**, 703–16.

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ICEBERG RISK IN THE *TITANIC* YEAR OF 1912
was it exceptional?

Grant R. Bigg and David J. Wilton

At 2340 h local time (0310 GMT) on the cold moonless night of 14 April 1912, near 41°47' N, 49°55' W, the crow's nest lookouts on board RMS *Titanic* sighted a large iceberg only 500 m ahead. Despite quick action on the bridge to slow the ship and turn to port, as well as the closing of the watertight doors, the slow response of a large vessel meant that the iceberg still struck the ship aft of the bows. Some 100 m of her hull below the waterline buckled, allowing water to flood into the ship across several compartments. In little more than two-and-a-half hours she had sunk, with the loss of 1514 lives. The *Titanic* was believed to be unsinkable, which she obviously was not – but was she very unlucky to encounter a sizeable iceberg in that year and month?

The weather, ice conditions and time of year did indeed combine to increase the iceberg hazard on that fateful day. High pressure had dominated the mid-latitude, central Atlantic for several days and by the time of the collision a ridge linking two high-pressure centres over Nova Scotia and the south of Ireland extended across the entire Atlantic (Figure 1). This resulted in north-north-westerly

In April 1912 cold winds blowing off NE Canada contributed to icebergs being carried further south than is currently normal

Figure 1 *Sea-level pressure (black, in mbar) and air temperature (red, in °C) for 0000 GMT, 15 April 1912, taken from the ensemble mean of the 20th century reanalysis. X = location of the* Titanic.

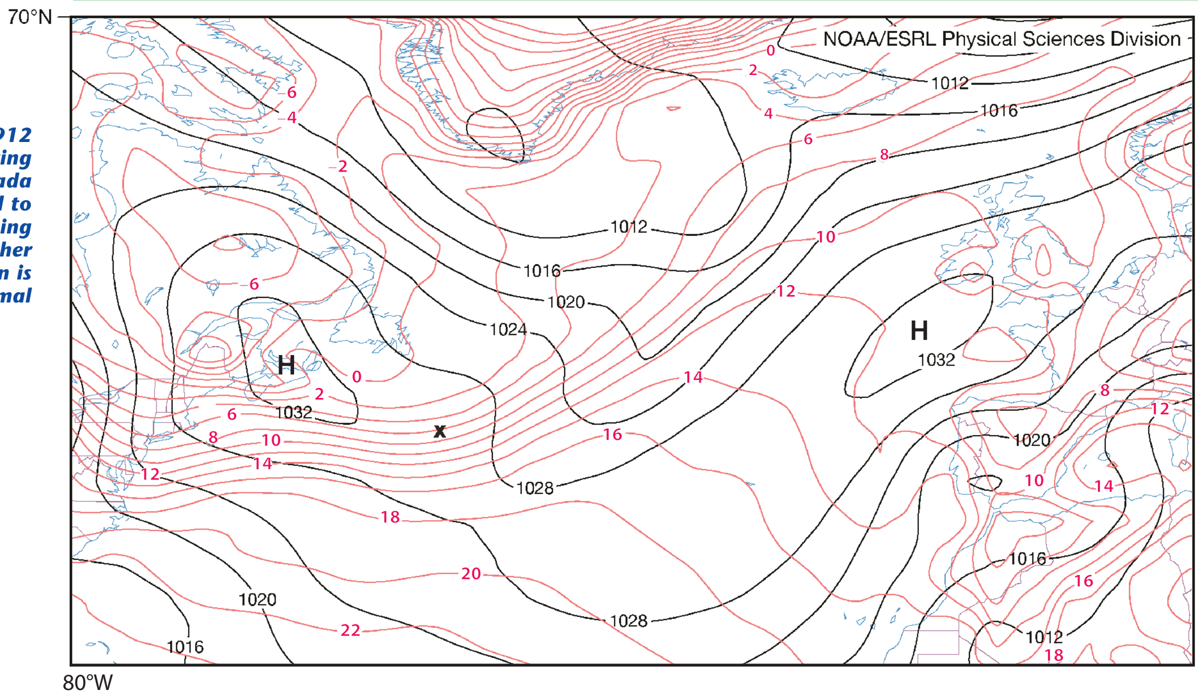
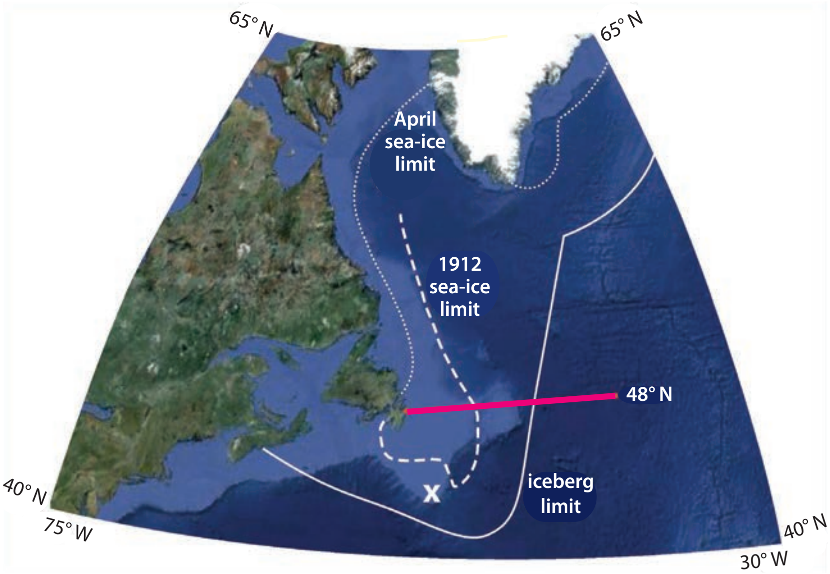


Figure 2 *The maximum iceberg limit for 1900–2000. Also shown are the the 48°N line of latitude, the average sea-ice limit for April 1979–2013 (dotted) and a typical Newfoundland maximum sea-ice limit for the early 20th century (dashed and labelled as for 1912). The location of the* Titanic *is shown by an 'X'. The blue shading shows depth, with the lightest blue denoting the continental shelf (<100 m depth).*



winds transporting near-freezing air from north-east Canada over the western Atlantic south of Newfoundland. These winds and temperatures, assisted by the prevailing southward flow of the Labrador Current on the Grand Banks, led to transport of icebergs and sea ice further south than is currently normal for the time of year, although not beyond the known limits to icebergs during the 20th century (Figure 2). A number of reports of extensive sea-ice fields and icebergs ahead had reached the *Titanic* earlier on the day of the collision.

April and May are the peak of the iceberg hazard season in the western North Atlantic (Figure 3), partly because of the release of icebergs previously held fast within the pack ice. In 1912, the greatest number of icebergs was recorded in April, whereas normally it occurs in May, and there were nearly two-and-a-half times as many icebergs as in an average year. Thus, 1912 had a significantly greater iceberg flux off Newfoundland than normal, and this has been taken to imply that such a flux must have had an unusual cause.

Previous theories have suggested that there were exceptional numbers of icebergs in 1912 due to lunar or solar effects. Here we will examine just how unusual 1912's iceberg record really was in the 20th century, and discuss various possible explanations for the increased flux.

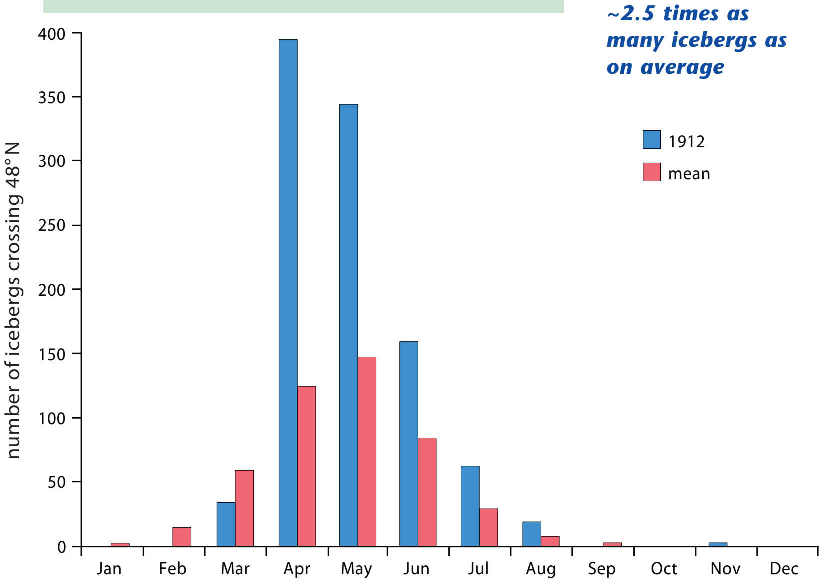
The iceberg record at 48°N

The International Ice Patrol (IIP) of the US Coast Guard has operated since 1913, collecting data on iceberg locations and sea-ice extents in the north-west Atlantic in order to provide ice navigation hazard warnings to shipping, and so prevent a repeat of the *Titanic* disaster. Although there is very occasionally an iceberg incident with shipping in the region (http://www.icedata.ca/Pages/ShipCollisions/ShipCo_Index.php), the IIP claims that, since 1913, no ship that has followed ice warnings has been damaged or sunk. A series of comprehensive annual reports on ice conditions from the IIP is available back to the 1920s. The observational methods have changed significantly over the years, from ship reports and dedicated cruises in the early years, through aircraft patrols in the middle decades of the 20th century, to satellite image analysis and iceberg modelling in recent times. Despite the evolution of observational techniques, there is confidence that the general magnitude and yearly variability is captured. Throughout this period a simple measure of the volume of icebergs encountered in a given year has been given by I48N, the monthly number of icebergs crossing latitude 48°N, from Newfoundland to ~40° W (Figure 2). This includes any iceberg larger than 5 m in above-surface length. The series extends back to 1900, incorporating ice reports pre-dating the establishment of the IIP. The series has great variability from year to year (Figure 4, overleaf), reflecting strong variability in calving fluxes from western Greenland. There is an indication of episodic increase in this flux in recent decades, probably due to increases in both sea-surface temperatures in Greenland fjords and ice-sheet surface meltwater.

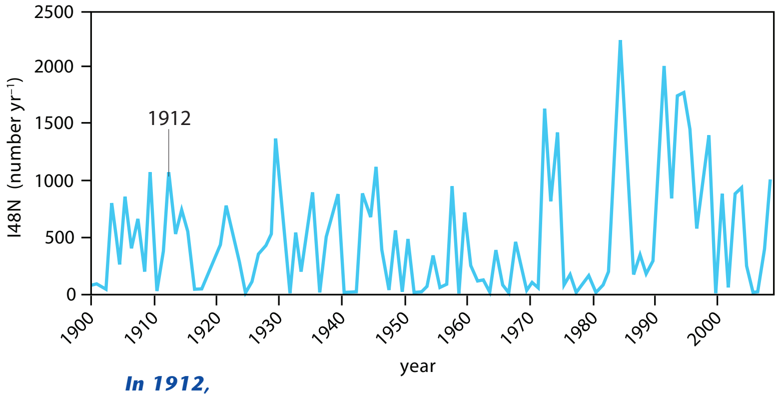
In April 2012 icebergs were further south than is currently normal for the time of year

Figure 3 *Mean seasonal cycle of the number of icebergs crossing 48°N, 1900–2008, and the corresponding values in 1912. The 48° N line extends from Newfoundland to 40° W (cf. Figure 2).*

(The source of the I48N data for this and the following two figures is given in the Acknowledgements)



In 1912, April was the peak iceberg month, rather than May, and there were ~2.5 times as many icebergs as on average



In 1912, 1038 icebergs travelled south of 48°N

Figure 4 *Total number of icebergs crossing latitude 48°N each year since 1900. Note that the years are 'ice-years', beginning in October of the year before the notional record and extending to September of the ordinal year.*

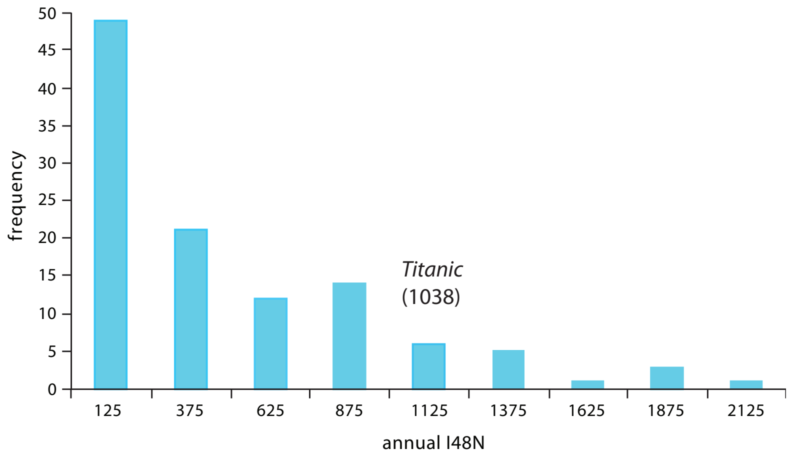
The year 1912 was indeed unusual, with 1038 icebergs observed to cross 48°N (Figure 4). However, this number does not even reach the 90th percentile of the annual number distribution (Figure 5) – in the 112 years shown in Figure 4, 14 recorded an I48N exceeding this number. Indeed, a secondary peak in the distribution occurs just below the 1912 total.

The origin of the Titanic iceberg

The iceberg that sank the *Titanic* was relatively large at the time of impact at 42° N. Reports from survivors claimed the iceberg responsible was some 50–100 feet high (15–31 m) and 400 feet (122 m) long. The *Carpathia* reported sailing through ice up to 200 feet (61 m) high on the way to the rescue and on the following day. Although the density of ice relative to water suggests that only 13% of an iceberg should be above water, the eroded shape of most icebergs means that the value is more like 16.7% (5 : 1), so the *Titanic* iceberg is likely to have been at least 90–185 m deep, while being ~125 m long. The Weeks–Mellor stability/overturning criterion enables us to tie down the iceberg's size more tightly.

More than 10% of years have more icebergs than there were in 1912

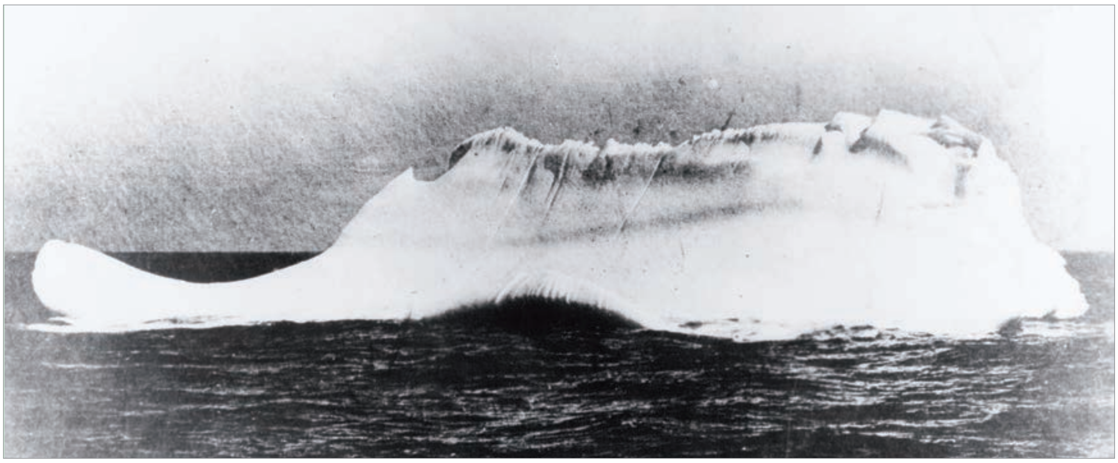
Figure 5 *Distribution of annual number of icebergs crossing 48° N, 1900–2011. The labels indicate the iceberg number at the centre of each range shown; the number corresponding to the* Titanic *year falls within the column labelled 1125 (= 1000 to 1250).*



As an iceberg is eroded or melted preferentially from the sides, its centre of gravity eventually becomes too high for the iceberg to remain upright and it rolls over. If the reported length of 125 m is assumed to be roughly correct, then this stability constraint suggests that the vertical thickness of the iceberg could not have been greater than ~100 m, putting the likely above-water height around 15–17 m (50–60 ft), with a mass of ~2 Mt. This is consistent with the dimensions of an iceberg with a red paint streak photographed by Captain de Carteret of the *Minia* (Figure 6) when at the site of the disaster searching for bodies and wreckage (http://www.titanic-nautical.com/RMSTitanic-Iceberg-FAQ.html).

For an iceberg to still be > 100 m in size at 42° N suggests that it began life as a large iceberg when calved into a Greenland fjord. We have studied the distribution of icebergs in the Atlantic during the 20th century by using a coupled ocean–iceberg model that is basically an ocean circulation model with an in-built dynamic and thermodynamic iceberg-trajectory model, in which the icebergs are regarded as points advected within the ocean model, using the ocean circulation as forcing and supplying the ocean model with freshwater from the melting icebergs. The iceberg model has previously been well tested in both the Arctic and Antarctic. This combined model is forced by the daily wind, heat and freshwater fluxes of the 20th century atmospheric reanalysis, with icebergs seeded into the ocean from 70 sites around the Northern Hemisphere and 29 off Antarctica. The ocean-model resolution is dependent on position, but is ~20 km near Greenland and 100 km in the region of the sinking of the *Titanic*. The annually varying calving rate from the 27 sites off Greenland was set proportional to the magnitude of the I48N series, as this produces an excellent correlation of the model iceberg flux at 48°N with this series. We are thus able to model the likely iceberg trajectories of 1912, within the limitations of the forcing and the model (Figure 7).

Although few icebergs have been tracked from source to Newfoundland waters, it is believed that the vast majority of icebergs in the main western Atlantic stream in the Labrador Sea originate from southern, western or north-western Greenland. This is consistent with the limited distributional data, ocean circulation and modelled iceberg trajectories. However, according to modelling (see Further Reading) the origin of the majority of icebergs crossing 48° N decisively switched from southern Greenland in the early decades of the 20th century to the more



The Titanic *iceberg probably weighed about 2 Mt and was around 125 m long*

Figure 6 *Iceberg believed to have been responsible for the sinking of the* Titanic*; a dark streak of what was identified as red paint is clearly visible. (Reproduced with permission of The US Coast Guard Historian's Office)*

northerly Baffin Bay coastline of west Greenland after ~1930. It is therefore likely that the *Titanic* iceberg originated from south-west Greenland.

Our model produced a range of possible trajectories for icebergs reaching the general area of the *Titanic*'s sinking within a window of ± 3 months of the collision, shown in Figure 7. Only one of these is for a pathway originating from Baffin Bay (the green track leaving Davis Strait). The modelled iceberg passing closest to the sinking site around the correct date is highlighted in red. This calved from south-west Greenland in early autumn 1911, beginning life as a model iceberg roughly 500 m in length by 300 m in depth and 75 Mt in weight, but reducing to 2.1 Mt by mid-April 1912, remarkably close to the size estimated from observations at the time.

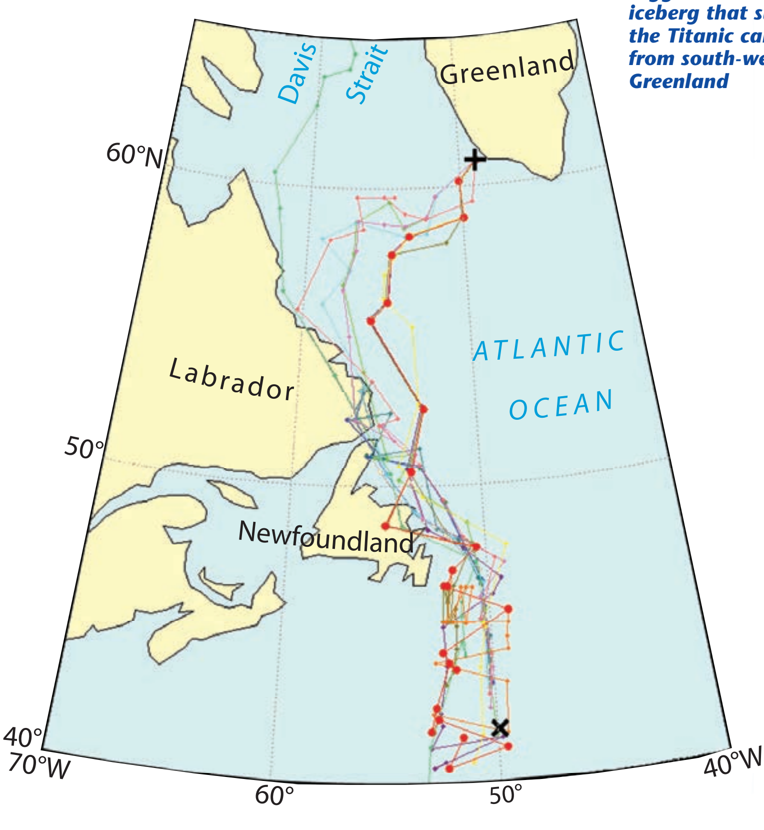
The iceberg hazard in 1912

We have seen that 1912 was a year of raised iceberg hazard, but not exceptionally so in the long term. In the surrounding decades (1901–1920) there were five years with at least 700 icebergs crossing 48° N, and 1909 recorded a slightly higher flux than 1912 (Figure 4). More recently, the risk has been much greater – between 1991 and 2000, eight of the ten years recorded more than 700 icebergs and five exceeded the 1912 total. Several other periods during the 20th century experienced iceberg risk at a level similar to or greater than that in 1912 (Figure 4). Although the uncertainty in the early numbers will be higher, the continuous need to forecast this hazard for shipping suggests that the I48N series is generally reliable – ships would have been sunk regularly if it were not. For example, from reports of the time it is very likely that the *Titanic* iceberg had been previously observed.

But why was the risk greater that year, even if not exceptional? Olson and colleagues believe that enhanced tidal stress, due to a very rare amplification of a high spring tide in January 1912 when the Moon was at its closest approach to Earth, led to greater calving and so iceberg risk. The tidal range, and hence tidal current, is indeed always enhanced along the south-west Greenland coast. Modelled icebergs from

Figure 7 *Trajectories of representative modelled icebergs reaching the general area (south of 44° N and west of 50°W) of the sinking of the* Titanic *between mid-January and mid-July 1912. The track of the iceberg most closely matched to the time and place of the* Titanic*'s sinking (marked by an 'X') is shown in red, with positions every 10 days marked. The '+' indicates the major iceberg release site off south-west Greenland. The real land boundary is shown, rather than the model's representation of this; icebergs appear to cross the Labrador and Newfoundland coasts where there are differences in these boundaries.*

Modelling studies suggest that the iceberg that sunk the Titanic calved from south-west Greenland



south-west Greenland take 3–7 months to travel from the open ocean outside the fjord to 48°N, which is consistent with a specific and exceptionally early January tidal signal contributing to an increased iceberg risk in the north-west Atlantic shipping routes in April 1912. An impact on the 1912 iceberg risk due to this astronomical event is therefore possible. However, an enhanced calving period concentrated over a few days in winter, when many fjords would be blocked with sea-ice, is unlikely to have been the prime cause of an increased iceberg risk, and our modelled iceberg most similar to the *Titanic* iceberg had left Greenland three months earlier. Note that this astronomical situation did not occur in any of the other years of significant risk, and the early iceberg peak is not unusual – a March or April peak in I48N occurs in 41% of the years from 1900 to 2011. One must conclude that the enhanced tidal forcing along the south-west Greenland coast around 4 January 1912 is unlikely to be a significant cause for the increased iceberg risk encountered by the *Titanic*.

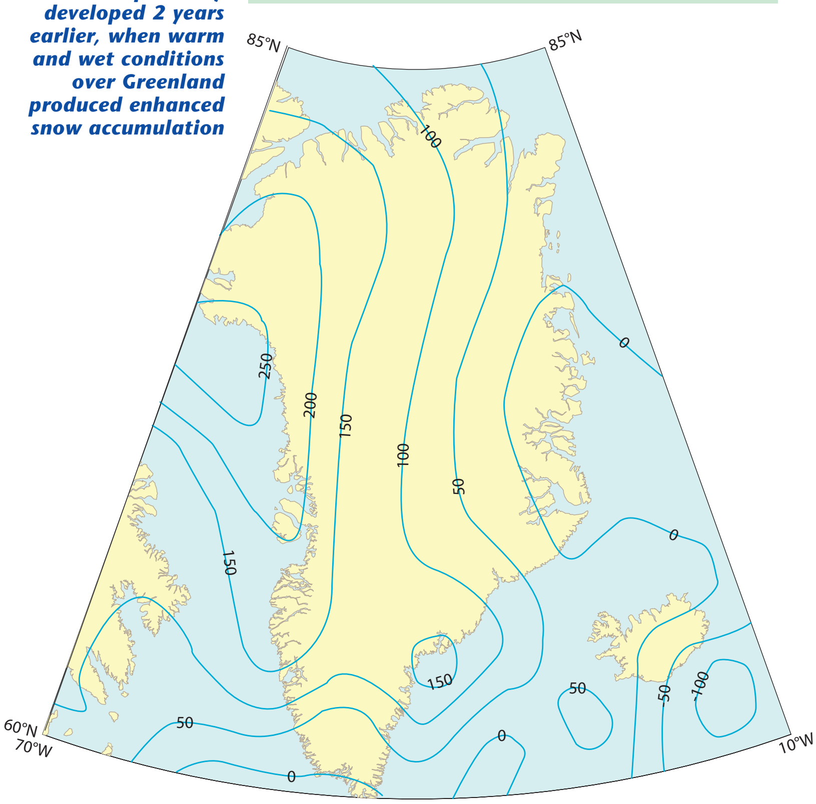
Another possibility, suggested by Lawrence (see Further Reading) is that the 11-year cycle in sunspot numbers may have been responsible; sunspots are relatively cool areas of the sun's surface, so the more sunspots, the lower the radiative flux from the sun. Low sunspot years are indeed associated with high iceberg risk, but the correlation coefficient between annual sunspot number and I48N over 1900–2011 is only −0.043, thereby not supporting such a link.

We therefore turn to consider more complex reasons for the enhanced risk of 1912. Our team have examined the question through nonlinear systems identification, assuming that iceberg calving is a non-linear function of the surface mass balance of the Greenland ice sheet, the large-scale atmospheric state, as given by the North Atlantic Oscillation Index, and the sea-surface temperature of the Labrador Sea, which is related to water temperatures in fjords where icebergs are calving. The surface mass balance is the balance between precipitation (as snowfall) and melting at the ice-sheet surface, rather than the total mass balance, which includes iceberg discharge but is poorly known.

For the early part of the 20th century the overwhelmingly dominant term relating I48N (and hence west Greenland calving) to this combined glaciological, atmospheric and oceanic forcing is a linear expression of the Greenland ice-sheet surface mass balance, with a lag of 4 years and a correlation of ~0.6 from 1900 to 1930. Other, non-linear terms, including the Labrador Sea surface temperature, with similar lags, help to explain the variance during this period more completely, but most of the explained variance is due to a significantly lagged surface mass balance. The physics underlying these links is not yet well understood. However, the iceberg risk to the *Titanic* is likely to have predominantly developed around 1908, when a moderately warm and wet year over Greenland produced enhanced snow accumulation (Figure 8). We believe that this gradually penetrated through cracks in the ice sheet and accumulated around its margins, which probably led to enhanced short-term outlet glacier sliding, with resulting enhanced calving.

The iceberg risk to the Titanic probably developed 2 years earlier, when warm and wet conditions over Greenland produced enhanced snow accumulation

Figure 8 *Anomalous precipitation rate over Greenland in 1908, relative to 1981–2010, taken from the ensemble mean of the 20th century reanalysis. Units are mm year^{-1}.*



Conclusions

The *Titanic* set sail in a year when sea-ice transport and iceberg calving rates were high, but not exceptionally so. The most likely origin for the iceberg that sank the vessel is south-west Greenland, with a calving time in the autumn of 1911 but related to an enhanced precipitation–melting balance over Greenland in 1908.

Icebergs still remain a navigation hazard. The IIP has largely removed the risk of an unexpected iceberg encounter in the north-west Atlantic, but the cruise ship MV *Explorer* was holed by an iceberg in the Weddell Sea off Antarctica in 2007 and the MS *Fram* collided with a glacier in 2008, although it was not sunk. A Russian fishing boat was sunk off Antarctica in 2011. As use of the Arctic, in particular, increases in the future with declining sea ice, the ice hazard will increase in waters not previously used for shipping. As polar ice sheets are increasingly losing mass as well, the iceberg risk is likely to increase in the future, rather than decline.

Further Reading

Bigg, G.R., M.R. Wadley, D.P. Stevens *et al.* (1997) Modelling the dynamics and thermodynamics of icebergs. *Cold Reg. Sci. Technol.* **26**, 113–35.

Bigg, G.R., H. Wei, D.J. Wilton *et al*. (2014) A century of variation in the dependence of Greenland iceberg calving on ice sheet surface mass balance and regional climate change. *Proc. Roy. Soc. Ser. A* 470, 20130662; doi: 10.1098/rspa.2013.0662

Christensen E. and J. Luzader (2012) From sea to air to space: a century of iceberg tracking technology. Coast Guard *Proceedings of the Marine Safety and Security Council* Vol. 69, Issue 2, pp.17–22.

Gardiner, R., and D. Van der Vat (1995) *The Riddle of the* Titanic. The Orion Publishing Group Limited, Weidenfeld and Nicholson:London.

Havern, C.B. (2012) The short life and tragic end of RMS *Titanic*. *Coast Guard Proceedings of the Marine Safety and Security Council*, Vol. 69, Issue 2, pp. 6–12.

Hill, B.T and S. Jones (1990) The Newfoundland ice extent and the solar cycle from 1860 to 1988. *J. Geophys. Res.* **95**, 5385–94.

Howells, D.K. (1992) The maiden voyage of the *Titanic* – a meteorological perspective. *Weather* **47**, 417–23.

Lawrence, E.N. (2000) The *Titanic* disaster – a meteorologist's perspective. *Weather* **55**, 66–78.

Marine Accident Investigation Branch. (1992) RMS *Titanic: Reappraisal of the Evidence Relating to SS Californian*. Department of Transport, HMSO: London.

Marko, J.R., D.B. Fissel, P. Wadhams *et al.* (1994) Iceberg severity off eastern North America: its relationship to sea ice variability and climatic change. *J. Clim.* **7**, 1335–51.

Weeks, W.F. and M. Mellor (1978) Some elements of iceberg technology, in *Proceedings of the First Conference on Iceberg Utilization for Freshwater Production*. Husseiny AA (ed.). Iowa State University. Ames, IA, pp. 45–98.

Newell, J.P. (1993) Exceptionally large icebergs and ice islands in eastern Canadian waters: a review of sightings from 1900 to present. *Arctic* **46,** 205–11.

Olson, D.W., R.L. Doescher and R.W. Sinnott (2012) Did the Moon sink the *Titanic*? *Sky Telescope* **123**, 34–39.

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The I48N iceberg series (used in Figures 3–5) comes from http://www.navcen.uscg.gov/pdf/iip/International_Ice_Patrols_Iceberg_Counts_1900_to_2011.pdf

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Jakobshavn Isbræ glacier speeds towards the sea

Jakobshavn Isbræ glacier in south-west Greenland is thought by many to be the most likely source of the iceberg that sank the *Titanic*. Whether it was or not, this glacier has real significance in the context of global climate change. It drains 6.5% of the Greenland ice sheet and produces around 10% of all Greenland icebergs. Some 35 billion tonnes of icebergs – many extremely large – calve from it and pass out of the fjord every year, contributing to sea-level rise through displacement of seawater and melting. Between 2000 and 2010, this one glacier contributed to global sea-level rise by ~1 mm – probably more than any other glacier in the Northern Hemisphere.

Jakobshavn Isbræ is one of the fastest flowing glaciers in Greenland, which is why it is contributing so much to sea-level rise. Furthermore, its speed has been increasing, with its average speed in 2012 and 2013 approaching three times that in the 1990s. Its flow rate during the summer was even faster. In summer 2012, Jakobshavn Isbræ reached speeds of ~46 m per day – believed to be the fastest ever recorded for any glacier in Greenland or Antarctica.

As the Arctic region warms, Greenland glaciers such as Jakobshavn Isbræ have been thinning, and their calving fronts have been retreating. In the case of Jakobshavn Isbræ, the thinning and retreat coincides with an increase in speed. The glacier's calving front is now in a deep part of the fjord, a trough going down to ~1300 m. As it has been retreating into deeper water, it has been losing the ice in front that has been holding back the flow, and so it has been speeding up. The calving front will probably reach the deepest part of the trough in a few decades, after which the speed of the glacier, and the rate of calving, will begin to decrease.

Iceberg calved from Jakobshavn Isbræ, photographed in Disko Bay
(Photo by courtesy of Ian Joughin, PSC/APL/UW)

The glacier's speed was measured using synthetic aperture radar (SAR) satellite data. See: Joughin, I. *et al*. Brief Communication: Further summer speedup of Jakobshavn Isbræ, *The Cryosphere*, **8**, 209–14. doi:10.5194/tc-8-209-2014, 2014

Coral reef research at Southampton

For researchers at Southampton, coral samples may simply be collected from the aquarium facilities of the Coral Reef Laboratory (CRL), headed by Prof. Jörg Wiedenmann. The most visible part of the facility is a 600-litre coral reef tank in the foyer of the National Oceanography Centre.

In the CRL, more than 40 species of reef organisms are studied using a multi-compartment aquarium system (*below left*), through which circulate more than 15 000 litres of artificial seawater. The laboratory hosts sea anemones, tube-dwelling anemones, soft corals, gorgonians and numerous species of reef-building corals, including heat-tolerant corals from the Persian Gulf (see the following article).

The laboratory's activities include: using genetics and the structure/function of proteins to understand the response of reef corals to environmental stress, including that caused by climate warming; investigating how nutrient pollution can render corals vulnerable to bleaching; studying how the purple and pink 'sunscreens' of reef corals work; and exploring the function of fluorescent proteins in deep-water invertebrates. It is also developing fluorescent reef coral pigments into advanced imaging tools for biomedical research. The work, funded by the Natural Environmental Research Council and the ERC Starting Grant Scheme, greatly benefits from the combination of controlled laboratory experiments with coral reef field studies.

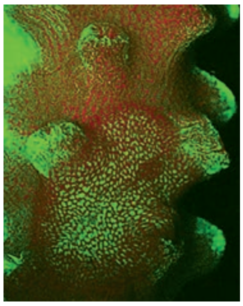
CRL's coral reef tank, which is situated in the foyer of the National Oceanography Centre, Southampton. The corals on display are propagated at the CRL and provide a sustainable source of coral tissue for research purposes. They also contribute to the conservation of endangered species, and provide students with a living display of organisms relevant to their courses.

A dangerous parasitic worm

Work at the CRL has indicated that a parasitic flatworm, found in aquaria across the globe, including regions bordering coral reef habitat, could cause significant damage to those reefs if was released into the wild.

Amakusaplana acroporae usually lives upon the staghorn coral A*cropora*, and is extremely hard to spot. By using molecular biological techniques, CRL researchers discovered how it achieves its excellent camouflage: when eating the coral tissue it also takes in the coral's symbiotic algae. Instead of digesting them all, it keeps some alive and distributes them in its gut so that its colour mimics the appearance of the coral. To perfect its camouflage, it also incorporates the green fluorescent protein pigments that lend a greenish glow to the coral host.

The flatworm A. acroporae *(~ 3 mm across) on* Acropora pulchra*; both are fluorescing*



Only quarantine can control the spread of this parasite between aquaria. It's not known whether it occurs naturally and, if so, whether it has any natural predators. Its release into an environment which is not adapted to its presence might have unforeseeable consequences for the regional *Acropora* populations.

Careless handling of aquarium organisms has already contributed to the spread of alien species with serious results for local ecosystems. The Indo-Pacific lionfish *Pterois* has spread through the Caribbean, and the alga *Caulerpa taxifolia* (from the Coral Sea off north-eastern Australia) has displaced the local algae from extensive areas of the Mediterranean Sea. Ed.

For more about *A. acroporae*, see: Hume *et al.* (2014) The corallivorous flatworm *Amakusaplana acroporae*: an invasive species threat to coral reefs? *Coral Reefs* **33**, 267–72, which can be freely downloaded from http://link.springer.com/article/10.1007%2Fs00338-013-1101-6

Left *The molecular facility of the CRL, where Ed Smith is analysing coral pigments*
Right *Adam Reed monitoring the water chemistry in the multicompartment aquarium system.*

John Burt, Hanneke Van Lavieren and David A. Feary

The eight countries surrounding the Persian Gulf – Bahrain, Kuwait, Iran, Iraq, Oman, Qatar, Saudi Arabia and the United Arab Emirates – share a valuable ecosystem that, like many other places in the world, is being seriously degraded by a human impacts. Since the oil boom of the 1970s there has been massive economic and population growth throughout the Gulf, and resultant rapid expansion of urbanised seascapes. This has had severe impacts on coastal and marine ecosystems, particularly the unique coral reefs of the Gulf which contain corals that have adapted to the highest sea temperatures experienced by corals anywhere in the world. The Gulf corals provide a significant opportunity for science and can serve as a model for the rest of the world's reefs, where Gulf-like temperatures are not expected to occur until the end of the century. If coral reef fauna are capable of acclimating* or even adapting to such naturally extreme temperatures, there may be hope for the continued persistence of reefs globally under future climate change. The conservation and protection of Gulf reefs is essential to safeguard these unique ecosystems into the future.

*Acclimation is an organism's short-term response to environmental change, whereas adaptation is an evolutionary response.

Coral reefs in a warming world

Coral reefs are one of the most diverse and productive ecosystems on Earth (Figure 2, overleaf). They are particularly important in tropical developing countries where they can provide economically important services and products for populations in coastal areas. However, these ecosystems are under the growing threat of climate change associated with substantial global increases in greenhouse gas emissions over recent decades. Scientists have promoted the importance of limiting atmospheric concentrations of CO_2 to no more than 350 p.p.m. – a level considered sustainable for the long-term maintenance of coral reefs – but they reached

Figure 1 *Map showing the geographical setting of the Persian Gulf (also known as the Arabian Gulf), along with a selection of places mentioned in the text. The red patches indicate the historic extent of reef habitat, of which only about 30% now remain.*

Coral-reef communities already living in very warm waters present an opportunity for science

Figure 2 *Diverse coral and fish communities associated with nearshore reefs at Al Harf, Oman, in the Strait of Hormuz at the entrance* to the *Persian Gulf (cf. map in Figure 1).*

400 p.p.m. in April 2014 – and continue on an upward trajectory.

In association with increases in CO_2, there has been a general trend towards rising sea-surface temperatures and a concomitant global increase in the number of mass coral bleaching events. As a result of such mass bleaching events, as well as impacts from various other natural and anthropogenic stressors, coral reefs throughout most of the tropics have undergone significant decline in the past several decades. It is projected that coral reefs will continue to degrade as seas continue to warm under increasing atmospheric CO_2 loads; many global climate scenarios predict the collapse of modern coral reefs by the middle of this century.

The degree of impact that future climate change will have on coral reefs will be contingent on whether or not society acts to reduce atmospheric CO_2, how the atmosphere–ocean system (which is still not well understood) will respond on a physico-chemical basis to such warming, and how the organisms which compose and live in association with coral reefs react to a rapidly changing climate. If coral reef fauna are capable of quickly acclimating or even adapting to climate change over the long term, there may be hope for their continued persistence; if not, they are likely to degrade and disappear in our lifetime.

The hottest reefs on Earth

Corals in the Persian Gulf survive the highest temperatures known to be experienced by coral reefs globally, with maximum daily sea-surface temperatures in summer often exceeding 36 °C. Corals in the southern Gulf – where conditions are most extreme – can experience several months a year at temperatures exceeding 34 °C. By contrast, the majority of corals making up the Great Barrier Reef (Australia) and the Meso-American Reef (Caribbean Basin) would suffer mass bleaching and significant mortality if exposed to water temperatures of 32 °C for a single day. However, even within these systems, corals found in very shallow areas (e.g. lagoons, rock pools), can withstand short spikes in temperature of up to and exceeding 36 °C. These observations indicate that at least some coral reef fauna are capable of acclimating or adapting to extreme sea temperatures. As Gulf-like temperatures (i.e. 34–36 °C) are not expected to occur globally until the end of the century, there may yet be some hope for the world's coral reefs.

As a result of the extreme thermal conditions in which they live, coral reefs in the Gulf present a significant opportunity for science. By using the naturally extreme conditions of the Gulf as a proxy for future climate change in other areas, patterns of community structure, population dynamics, life history, and other aspects of coral ecology can be assessed. This work could then be used to predict the role of climate change in the condition of coral reefs globally, as they approach Gulf-like temperatures over the coming century of climate change. In addition to providing an opportunity for understanding the ecological patterns that result from extreme temperatures, the Gulf also provides a substantial opportunity to investigate the molecular and physiological mechanisms being used by corals and reef-associated fauna (invertebrates, fishes, etc.) to allow them to persist in this extreme environment, as well as an opportunity to explore whether these traits might be brought to other regions through assisted migration, cross-fertilisation, or transgenic means.

These opportunities to use the Gulf as a model ecosystem to explore the implications and potential amelioration of future climate change impacts in other regions have generated considerable regional and international scientific attention in the last several years. A recent meta-analysis of publications on Gulf coral reefs found that of the 270 papers published in the past half-century, over half were published in the last 10 years (the first came out in 1964). In addition, the meta-analysis also found that the interest in Gulf coral reefs is rapidly accelerating, with more papers published in 2012 than at any other time in the history of Gulf reef research: in fact, 10% of the total number of papers focussing on Gulf reefs published up until 2012 came out in that year.

Gulf reefs as models for a warmer future

The rapidly growing interest in examining the factors which allow Gulf reefs to live in one of the most thermally extreme environments in the world has produced unique insights into how extreme temperatures impact coral and reef fish communities.

Coral communities in the Gulf are a unique byproduct of their environment. They are low in diversity and tend to be dominated by more 'tolerant' coral taxa (faviids and poritids* in particular), while more environmentally sensitive groups, such as the acroporid staghorn corals, are relatively under-represented compared with elsewhere in the Indo-Pacific. In most areas in the Gulf, corals do not form true reefs, but are better described as 'coral carpets', where individual colonies grow on exposed rocky substrates rather than building on older dead coral skeletons. These types of communities are particularly common in the southern Gulf where conditions are most extreme, and recurrent sea-surface temperature anomalies cause reef die-offs on a regular basis, preventing the formation of a true reef-building framework (Figure 3).

Gulf coral colonies are on average smaller in size relative to their counterparts living in more benign conditions outside the area. The absence of larger sized colonies within the Gulf indicates that most individual colonies may not survive for the lengths of time they do in areas outside the Gulf, as a result of the extreme nature of the Gulf environment and the recurrent mass mortality events. Despite the generally smaller size of colonies, coral cover in the Gulf can be quite high in some areas, and is often particularly dense in areas where just one or two stress-tolerant species dominate coral communities.

A number of studies have shown that, like the coral communities, reef fish communities in the Gulf are species-poor, and the abundance of fish is low, in comparison with reefs in the Gulf of Oman and the Arabian Sea – bodies of water which undergo much less extreme seasonal changes in temperature. On average, reef fish in the Gulf are smaller than their conspecifics (fish of the same species) outside the Gulf. As a result of the lower abundance and smaller size, the biomass of fish inhabiting reefs in the Gulf is significantly lower than the biomass observed on reefs outside the Gulf, even in the absence of fishing activity. All this suggests that as sea-surface temperatures rise, other regions are likely to experience reductions in reef fish size, abundance, biomass and diversity. Given that reproductive output in fish is linked to maternal size and condition, it is likely that these shifts in fish demographic structure will result in reductions in the supply of larvae to replenish reef fish populations.

As well as causing structural changes to reef fish communities, extreme temperatures also appear to affect how fish communities function on reefs in the Gulf. In general, fish observed on reefs in the Gulf tend to have a lower affinity for particular live coral than those on reefs outside of the Gulf, with Gulf communities instead dominated by fish that are using reefs opportunistically rather than by species that have obligate associations with live coral. This is likely to be a reflection of the unique structural nature of the Gulf's coral communities, where most reefs are relatively flat and are dominated by mound and brain corals rather than structurally complex staghorn corals.

*Most faviids are known as brain corals, while poritids are generally mound-like.

Coral carpets are found where repeated coral die-offs caused by extreme temperatures prevent a reef framework from building up

Figure 3 *Ras Ghanada Reef, north-eastern Abu Dhabi, UAE, with a 'coral carpet' of poritid corals covering a rocky substrate.*

The diet of reef fish in the Gulf also often differs from that of conspecifics elsewhere, reflecting differences in availability of food items growing on and living amongst reefs within the Gulf as well as different ecological pressures (e.g. competition among a distinct suite of species). In general, fish communities in the Gulf tend to be more heavily dominated by grazing herbivorous fish and piscivorous predators than are communities outside the Gulf, while planktivores, macroinvertivores, and general omnivores tend to be less well represented. Overall, these observations on the unique structural and functional attributes of reef fish communities in the Gulf tell us much about how extreme environmental conditions affect reef fish assemblages, and inform us of potential changes to expect in other regions as they warm under climate change.

The distinctive nature of Gulf corals and their associated fish populations provides insight into how coral reef communities in other regions might change as temperatures rise in the coming decades.

Expanding areas of coral reef science

One area of reef science that has shown particularly strong growth in the Gulf in recent years is molecular biology/physiology, as science shifts from describing ecological patterns to trying to identify the mechanisms that allow reef fauna to survive in these incredibly extreme conditions. Recent work on a number of different species of coral reef fishes has demonstrated that Gulf fish can survive at substantially higher temperatures than individuals from the same species from just outside the Gulf, with much of this tolerance due to differences in the aerobic physiology of fish adapted to the Gulf's extreme temperatures.

With the exception of those around offshore islands, table corals have been virtually lost from the Gulf

There has also been groundbreaking research on the symbiotic relationships between corals and the algae known as zooxanthellae, that live within the cell walls and provide essential energy for the growth and survival of corals. Recent research in the Gulf has demonstrated that several coral species there have associations with types of algae that are unique to this region. Some of the coral species found within the Gulf have extremely high fidelity to one specific type (or 'species') of zooxanthellae wherever they occur in the world. However, an exception has been found within colonies in the southern Gulf, where a unique symbiotic relationship between a coral and particular species of zooxanthellae has been found. Overall, most coral species, surprisingly, are not associating with types of zooxanthallae that have traditionally been described as 'heat tolerant', but rather are associated with a strain of zooxanthellae not recognised as thermally tolerant. Why these unique patterns should occur in the Gulf is under intense study at the moment; there are also a number of studies which are exploring the role that the coral host (as opposed to the zooxanthellae) play in thermal tolerance, as well as cross-breeding experiments which explore whether these thermal traits are heritable and could perhaps be bred into corals in other regions. Obviously there is much that the unique fauna of the Gulf can still teach science.

The collapse of Gulf reefs

Since the 1970s there has been rapid and dramatic economic and population growth throughout the Gulf as a result of oil and gas wealth, with the expansion of cities occurring mainly along the coastline. Given the small, interconnected nature of marine systems in the Gulf, the already fragile reefs in this area have been under increasing threat from pressures associated with human activities and climate change.

Among the most severe and widespread impacts to reefs regionally occurred in the mid-1990s, when mass coral bleaching and mortality occurred as a result of elevated sea-surface temperatures. During 1996 and again in 1998, summer temperatures were over 2 °C higher than their normal summer maxima, with sea temperatures as high as 37.7 °C observed in the southern Gulf. Although Gulf coral fauna represent a resiliant subset of communities compared with those observed elsewhere, the majority of these species were already living at the margins of their thermal

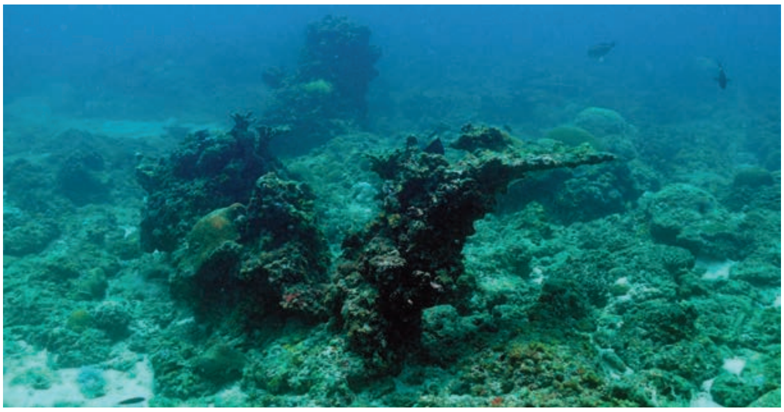


Figure 4 Upper *Large stands of table corals still dominate reefs near offshore islands, such as this reef at Sir Bu Nair island, UAE.* ***Lower*** *Since the 2010 coral bleaching event, eroding skeletons are all that remain of table corals at the Bulthama reef in Bahrain.*

tolerance and these extreme temperature anomalies pushed many corals over the brink.

By far the most severe impacts were felt by the table-like staghorn corals that had been the dominant corals on most reefs in the southern Gulf prior to these events (Figure 4). These sensitive corals were virtually eliminated from most reefs in the southern Gulf, with only small pockets remaining in surrounding offshore islands, where water was deeper and temperature spikes less extreme. Because these species made up the majority of live coral on reefs prior to the high water temperature events, the bleaching and subsequent mortality of these species resulted in a dramatic reduction in the amount of live coral, with more than 90% of total live coral lost from reefs throughout many hundreds of kilometres of coastline in the southern Gulf by the late 1990s. Although all taxa were affected by bleaching and mortality, the more stress-tolerant taxa, such as the faviid brain corals and the poritid mound corals, were impacted to a lesser extent, and this formerly subordinate group of corals became the most common survivors in reef communities (Figure 3). As a result, what remained after the late 1990s were extensive areas of dead coral reef framework throughout the Gulf with remaining coral communities characterised by low live cover, low diversity, and dominance by only a relatively hardy subset of what had once existed.

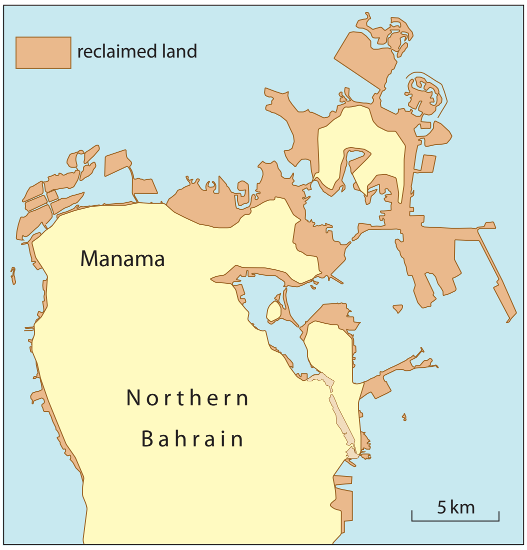
In the years following the devastating 1996 and 1998 bleaching events, recovery began to occur in some coastal reefs, as staghorn coral larvae began seeding the area from offshore populations and juveniles started recolonising dagraded near-shore reefs. However, weaker but still significant coral bleaching events occurred again in 2002, 2007, 2010 and 2011, further reinforcing the dramatic changes that had occurred earlier and often reversing the little recovery that had taken place. As a result, most areas that were formerly described as reefs – and are still labelled as such on many maps – are now large tracts of algae-covered dead coral skeleton slowly being eroded into sand over time. What does remain of 'healthy' coral reefs today should be recognised for what they are: a vestige of their former state.

The widespread and long-lasting decline of reefs in the wake of bleaching events in the late 1990s has been further exacerbated by the expansion of large-scale coastal development throughout the Gulf (Figure 5). Coastal modification, channelisation, and infilling had been occurring to some extent for the past half a century as the oil and gas industry grew, but the scale of coastal development has particularly accelerated in the last decade. Such development is epitomised by the construction of a number of 'iconic' and mega-scale real estate developments such as the Palm Islands in Dubai, United Arab Emirates, the Pearl in Qatar, Durrat al Bahrain in Bahrain, Half Moon Bay in Saudi Arabia, and Sabah Al Ahmed City in Kuwait. In most cases these projects have resulted in the reclamation, dredging, and/or infilling of many square kilometres of coastal habitat, often in areas with fringing coral communities. Such development has been so widespread and at such a grand scale that most coastal cities in the Gulf now have more artificial coastline than there was natural coastline historically. This scale of development has come at a high cost to marine ecosystems, partly because of the loss of habitat, but also because sediment in the water column causes severe stress to corals by reducing the efficiency of their photosynthesis and feeding, and by increasing the energy costs associated with producing their protective mucus coatings.

Expansion of coastal development could not have occurred at a worse time for coral reef communi-

Most coastal cities in the Gulf now have more artificial coastline than natural coastline

Figure 5 Left *Changes to the coastline of northern Bahrain between 1973 and 2012. Large additions of reclaimed land around the city of Manama have added over 10% to the original area of the island nation.* ***Right*** *Aerial view of villas on the artificial Palm Jumeriah Island, Dubai, UAE.*



ties in the Gulf, with near-shore reefs throughout the region already in a precarious state. In Dubai, for example, the reef in the Jebel Ali Marine Reserve (western Dubai) was beginning to show signs of recovery as early as 2000, with numerous juvenile staghorn colonies establishing on the remnants of preceding reefs. However, in 2004 the Palm Jebel Ali (the first of the three proposed islands within the Palm Island development; cf. Figure 5, right) was constructed directly within the marine reserve, burying an estimated 8 km^2 of live coral reef habitat. Despite these impacts, small patches of reef persisted further to the west in Dubai (near the border with Abu Dhabi; Figure 1). In the following years the staghorn corals did show strong growth in those areas, and within a decade of the 1996 bleaching event had returned to dominance on these patch reefs. This recovery was short lived, because in 2007 development of the Dubai Waterfront project began, and the construction of a causeway resulted in direct burial of corals, and sediment-plume induced loss of corals, from the densest and most diverse sections of what reefs remained in Dubai. Today, of the >10 km^2 of reef that once existed here, all that remain are a few degraded patches peppering the coastline.

The decline of near-shore coral reefs is not isolated to Dubai, but has occurred throughout the Gulf. The Kingdom of Bahrain once contained among the most diverse and extensive coral reefs in the southern Gulf. However, since the 1970s there has been dredging of channels through reefs, burial of near-shore reefs through infilling, blasting of reefs during seismic oil exploration, and indirect loss of more distant offshore reefs through sedimentation from coastal development on the mainland. As a result of these stressors, as well as later bleaching events, live coral cover is now almost non-existent on the formerly extensive reefs that once bordered this island nation.

The extensive 'red tide' of 2008–2009 was particularly devastating for corals off the UAE and Iran

Figure 6 *Aerial photo of the harmful algal bloom that occurred in coastal waters of the UAE in 2008/2009. (The 'haze' is dust in the atmosphere.)*

Similar declines have been observed around virtually all major coastal cities in the Gulf, and there is widespread recognition that unless the rapid growth of coastal development is reined in soon, near-shore coral reefs are likely to cease to exist in many areas of the Gulf.

Human activities are also having widespread impacts on the coral reef ecosystems in the region through introduction of invasive species via the exchange of ballast water from ships. The largest ever harmful 'red tide' algal bloom to enter the Gulf occurred in late 2008 and lasted until mid-2009. This bloom, caused by the dinoflagellate algae *Cochlodinium polykrikoides*, probably introduced by ballast water discharge, spanned an area from the southern Gulf of Oman through to the Strait of Hormuz into the central Persian Gulf. In areas where the bloom was most dense, anoxic conditions occurred and resulted in mass die-offs of corals and fishes, with particularly devastating impacts on the extensive and diverse reefs in southern Iran and parts of the UAE (Figure 6). Here, several reefs experienced loss of over half of their coral reefs and declines in fish abundance by as much as 90%. These formerly extensive reefs soon became dominated by filter-feeding tubeworms and algae, and even now, more than five years later, there has been only limited recovery of coral on many of these reefs.

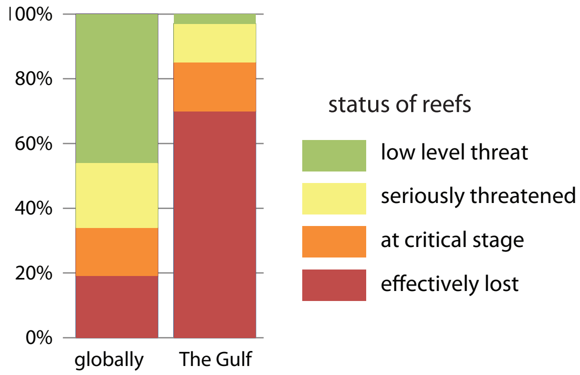
Managing a unique and fragile ecosystem

As a result of the increase in magnitude and frequency of natural and anthropogenic stressors, the global assessment in *Status of Coral Reefs of the World* considers reefs in the Gulf region to be 'among the most damaged in the world', with over 70% of Gulf reefs considered 'effectively lost' (Figure 7). Widespread recognition of the rapid degradation and loss of such a unique and important ecosystem has led to urgent calls for improved regulation and management. In recent years there has been increasing attention given to regional reef conservation and management in the Gulf, with the number of publications on this topic doubling between 2007 and 2012. Conservation and management is also now the second most common theme for reef science literature in the Gulf (after articles reporting results of ecological surveys), and according to a recent survey of practising scientists working in the region, among one of the highest priority areas for future coral reef research.

The Gulf represents one of the most environmentally distinct marine environments in the world and it is of considerable economic importance to the countries which share it. However, historically marine conservation and management in the region has been plagued by a number of inadequacies that have led to the current situation. A persistent undervaluation of the marine environment, coupled with lack of awareness of the potential threat it faces from human activites, have resulted in public policies focussed on intensive coastal development at the cost of environmental sustainability. Environmental legislation has been slow to evolve and is weakly regulated in many cases, with the benefits of economic development often considered more important than environmental conservation and sustainable development. Where management interventions have occurred, they have often been in response to events that have already occurred.

If the overall status of reefs in the Gulf is to improve significantly there needs to be a shift towards more proactive management of marine systems, with decision-making that is data-driven and informed by large-scale and long-term reef monitoring programmes. Currently, there are only a handful of isolated reef-monitoring programmes in the Gulf. It is only with the establishment of a cohesive, collaborative region-wide coral reef monitoring network that these unique ecosystems can be managed and conserved for future generations. Such a monitoring programme will only be successful if it is developed and operated by Gulf nationals. Although there has been incredible growth in reef science in recent years in the Gulf, more than half of all articles published have been authored by visiting scientists and consultants from outside the region. While this has led to a better understanding of how these reefs are structured and function, such studies often provide only a snapshot in time and space that is not particularly useful for driving decision-making. It is only with the establishment of a spatially widespread and temporally sequential monitoring programme that trends can be documented, data-driven management decisions can be made, and the effectiveness of intervention can be assessed. There is also a pressing need for more public awareness of, and engagement in, environmental decision-making. While scientific knowledge of regional reefs has grown in recent years, this has not generally translated into a better informed public who might act as advocates for these ecosystems. Additionally, public participation in decision-making processes is almost non-existent due to the highly centralised role played by governments, the limited freedom of media in highlighting environmental concerns, and the general lack of publicly available environmental data.

The Gulf's geography and the continued cumulative impacts of industrial, infrastructure-based, residential and tourism development activities, combined with climate change impacts, will synergistically amplify the already rapid decline in the health of marine ecosystems. What can Gulf countries do to better prepare themselves for the potential impacts of climate change on their coastal and marine areas? Urgently needed are forward-looking, proactive and adaptive management programmes and strategies that protect



In the Gulf, over 70% of the reefs are effectively lost

Figure 7 *An assessment of the status of reefs globally versus that in the Gulf (adapted from data in* Status of Coral Reefs of the World*).*

vital ecosystem goods and services, are based on reliable data, and can be used to assess current and future risks. At the same time, countries need to address climate-change drivers, e.g. by cutting carbon emissions, curbing water use, reducing energy demand, and promoting renewable low carbon energy sources.

Generally, there are few disincentives in place to slow the pace of coastal development in the Gulf. The construction cost of coastal development in the Gulf's shallow waters is relatively low compared with many other regions, financial rewards for developing shoreline real-estate are high, and the regulatory system for reviewing, controlling, and limiting development is weak. Jurisdictions responsible for managing and regulating coastal areas are often highly fragmented, and this has led to small-scale and short-term planning which is not environmentally sustainable in the long run. Ideally, this situation could be improved by developing legislation and policies that apply a more integrated, long-term and large-scale view of the coastal zones and that provide strong incentives for their sustainable development, particularly near highly sensitive ecosystems such as coral reefs. A key first stage in this process will be the strengthening of the legal and regulatory framework for Environmental Impact Assessments (EIAs) for proposed projects. Historically,

Coastal development in the Gulf is proceeding apace

Figure 8 *Luxury villas on the man-made Palm Jumeirah island, Dubai, UAE.*

the EIA process in the Gulf has been weak as a result of inadequate regulatory requirements. They are often conducted after construction has begun, they have focussed on isolated impacts rather than cumulative impacts of neighbouring projects, they have generally ignored social aspects of environmental assessment, and are not generally supported by robust sampling programmes. Improvement of the EIA process will be a critical first step in enhancing conservation of the remaining reefs in the Gulf.

Previous experience has shown that low levels of trans-boundary cooperation, combined with deficiencies in institutional arrangements for bringing key stakeholders to the table, has made it difficult for this region to develop integrated solutions to the problem of declining coral reefs. However, the only sensible way forward to healthier marine ecosystems lies in the adoption of a common approach to managing the Gulf. Regional cooperation is essential if priority environmental concerns for coral reefs are to be addressed successfully. There are several regional governmental organisations that could take a lead role in achieving this, but none has done so yet.

Do coral reefs in the Gulf have a future?

There have been some developments recently that suggest the situation may improve for coral reefs in the Gulf. Numerous regional and international reef scientists are in the process of initiating dialogue and collaboration through the recently established Mideast Coral Reef Society.* There has also been rapid growth in regionally-focussed reef science conferences and technical training workshops, and discussions are ongoing about the establishment of a region-wide reef science and monitoring network. Although these initiatives are relatively small-scale and embryonic in nature, their rapid recent growth does illustrate that there is a wide regional interest in understanding and conserving these ecosystems. There has also been an increased interest in establishing and strengthening marine protected areas (MPAs). While MPAs will not solve all problems, they do provide a framework through which stronger and more effective management may become established over time.

*The Mideast Coral Reef Society is an association of researchers and members of governmental, non-governmental, academic, industry and private sector organisations with an interest in a broad range of aspects of Middle Eastern reefs, including the Persian Gulf, the Sea of Oman, the Gulf of Aden, and the Red Sea.

There is hope for Gulf reefs. An opportunity exists for institutions and governments within the Gulf to improve their current management practices and limit development pressures, so serving as model environmental stewards for surrounding nations. In fact, some Gulf countries have already taken innovative steps to mitigate environmental impacts of development projects. For example in Kuwait and Qatar, multidisciplinary approaches and design teams including marine civil engineers, oceanographers, architects and biologists have helped limit the negative environmental impacts of certain coastal developments. Such approaches should be given high priority in future deliberations for coastal planning and management, serving as a model on which to continue to improve in the coming years.

It is not yet the end for the Gulf's valuable coral reef systems, but the rate and extent of degradation and losses that have occurred in the past decade should be a dire warning that we need action now if we are to stem further decline and promote recovery of this ecologically unique and scientifically important ecosystem.

The image of Kuwait City in the title graphic is by courtesy of the Arabian Gazette, and appeared in 'Dubai, Kuwait, in Top 100 most livable cities' by Mahsoom Thottathil (29 August, 2013)

Further Reading

Burt, J. (2013) The growth of coral reef science in the Gulf: A historical perspective. *Mar. Pollut. Bull.* **72**, 289–301.

Burt J, K. Al-Khalifa, E. Khalaf, B. and A. Abdulwahab (2013) The continuing decline of coral reefs in Bahrain. *Mar. Pollut. Bull.* **72**, 357–63.

Burt J, S. Al-Harthi and A. Al-Cibahy (2011) Long-term impacts of bleaching events on the world's warmest reefs. *Mar. Environ. Res.* **72**, 225–9.

Feary, D., J.A. Burt, A. Bauman, P. Usseglio, P.F. Sale and G. Cavalcante (2010) Fish communities on the world's warmest reefs: What can they tell us about impacts of a climate change future? *J. Fish Biol*. **77**, 1931–47.

Feary, D.A. and 26 others (2013) Future changes in the Gulf marine ecosystem: identifying critical research needs. *Mar. Pollut. Bull.* **72**, 406–16.

Riegl, B. and S. Purkis (Eds) (2012) *Coral reefs of the Gulf: adaptation to climatic extremes*. Springer Science+Business Media B.V., NL. Pp. 379.

Sale, P.F. and 10 others (2011) The growing need for sustainable ecological management of marine communities of the Persian Gulf. *Ambio* **40**, 4–17.

Sheppard, C. and 23 others (2010) The Gulf: A young sea in decline. *Mar. Pollut. Bull.* **60**, 13–38.

Van Lavieren, H. and 8 others (2011) *Managing the growing impacts of development on fragile coastal and marine systems: Lessons from the Gulf*. A Policy Report, United Nations University, Institute for Water, Environment, and Health. Hamilton, Canada. h.unu.edu/wp-content/uploads/2013/05/PolicyReport_LessonsFromTheGulf.pdf

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