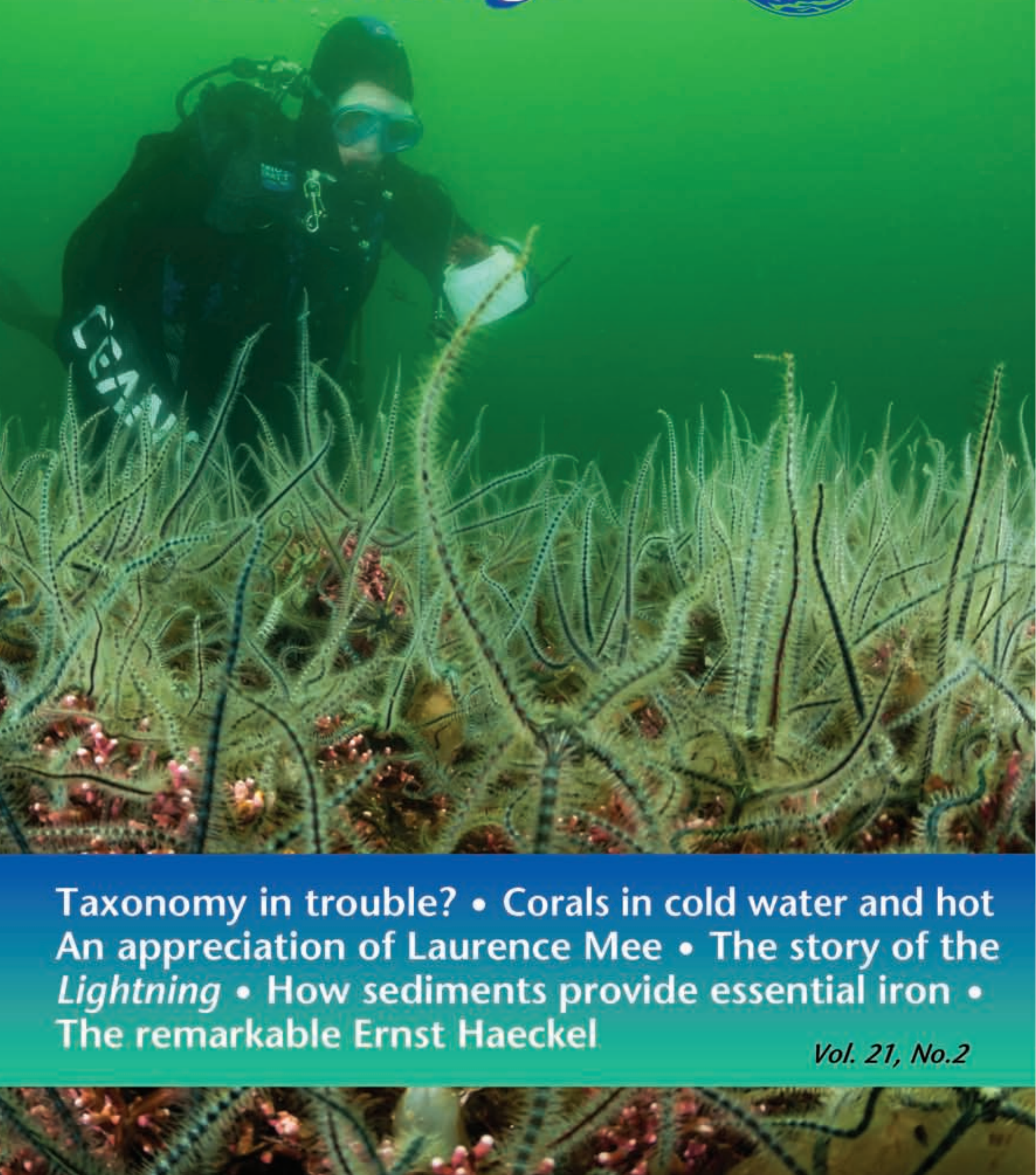
OCEAN Challenge

The Challenger Society for Marine Science



Taxonomy in trouble? • Corals in cold water and hot
An appreciation of Laurence Mee • The story of the *Lightning* • How sediments provide essential iron • The remarkable Ernst Haeckel

Vol. 21, No.2

OCEAN Challenge

The Challenger Society for Marine Science

Volume 21, No.2, 2015
(published 2016)

The views expressed in *Ocean Challenge* are those of the authors and do not necessarily reflect those of the Challenger Society or the Editor.

SCOPE AND AIMS

Ocean Challenge aims to keep its readers up to date with what is happening in oceanography in the UK and the rest of Europe. By covering the whole range of marine-related sciences in an accessible style it should be valuable both to specialist oceanographers who wish to broaden their knowledge of marine sciences, and to informed lay persons who are concerned about the oceanic environment.

Ocean Challenge can be downloaded from the Challenger Society website free of charge, but members can opt to receive printed copies. For more information about the Society, or for queries concerning individual or library subscriptions to *Ocean Challenge*, please see the Challenger Society website (**www.challenger-society.org.uk**)

INDUSTRIAL CORPORATE MEMBERSHIP

For information about corporate membership, please contact Terry Sloane Terry@planet-ocean.co.uk

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AVAILABILITY OF BACK ISSUES OF OCEAN CHALLENGE

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ISSN 0959-0161 Printed by Halstan Printing Group

OCEAN Challenge

The Magazine of the Challenger Society for Marine Science

SOME INFORMATION ABOUT THE CHALLENGER SOCIETY

The Society's objectives are:

To advance the study of marine science through research and education

To encourage two-way collaboration between the marine science research base and industry/ commerce

To disseminate knowledge of marine science with a view to encouraging a wider interest in the study of the seas and an awareness of the need for their proper management

To contribute to public debate and government policy on the development of marine science

The Society aims to achieve these objectives through a range of activities:

Holding regular scientific meetings covering all aspects of marine science

Setting up specialist groups in different disciplines to provide a forum for discussion

Publishing news of the activities of the Society and of the world of marine science

Membership provides the following benefits:

An opportunity to attend, at reduced rates, the biennial UK Marine Science Conference and a range of other scientific meetings supported by the Society. Funding support may be available

Receipt of our electronic newsletter *Challenger Wave* which carries topical marine science news, and information about jobs, conferences, meetings, courses and seminars

The Challenger Society website is
www.challenger-society.org.uk

MEMBERSHIP SUBSCRIPTIONS

The annual subscription is £40 (£20.00 for students in the UK only). If you would like to join the Society or obtain further information, see the website (given above).

COUNCIL FOR THE CHALLENGER SOCIETY

ADVICE TO AUTHORS

Articles for *Ocean Challenge* can be on any aspect of oceanography. They should be written in an accessible style with a minimum of jargon and avoiding the use of references. If at all possible, they should be well illustrated.

For further information (including our 'Information for Authors') please contact the Editor:
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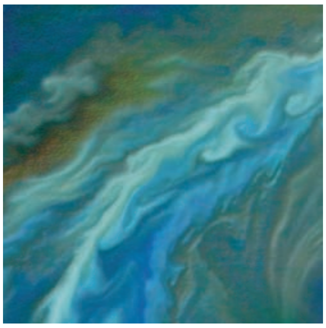
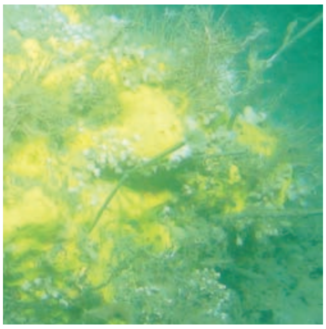




Most of the maps and diagrams were drawn by The ArtWorks.

Cover and heading graphics designed by Ann Aldred.

CONTENTS

Message from the Editor

The two feature articles in this issue couldn't be more different. The first, by Will Homoky, describes how our knowledge of the mechanisms by which iron – an element essential to photosynthetic life in the ocean – is developing. The second, by Dylan Evans, Edith Gruber and Peter Williams, is about the scientist and artist Ernst Haeckel, whose work is probably best known to oceanographers through the wonderful drawings he made for the *Reports* of the *Challenger* Expedition, but whose scientific preoccupations included evolution and embyology. The themes of the development of ideas, particularly about the living world, and of how organisms are related to one another and evolve, seem to crop up throughout the issue, including in the book reviews.

We have a lively interview with Nick Owens, Director of SAMS, and a tribute his predecessor, Laurence Mee, who died in 2014. We also have two articles about coral communities, some in the hottest seas in the world in the Persian Gulf, and others in rather colder waters off the Hebrides.

Challenger Society News

Losses for the Challenger Society and the oceanographic community

Challenger Society members will be saddened to learn of the death in April of Harry Elderfield. Harry, who was President of the Society from 1998 to 2000, was awarded the Challenger Medal in 2012 for his sustained contributions to the Society, and the excellence of his research in ocean chemistry and palaeoceanography.

Also, since the last issue of *Ocean Challenge*, the death has occurred (in November 2015) of John Scott, who was a valued member of the *Ocean Challenge* Editorial Board for many years. His expertise, lively mind and sense of fun were a great asset to our deliberations. In 2004, John was awarded the Challenger Medal, along with Tony Heatherhaw, for achievements in military oceanography.

Challenger Society Conference in September

President's Photographic Prize

At every Challenger Conference attendees are invited to submit entries to the President's Photographic Prize. For the Liverpool conference we are looking for beautiful and entertaining pictures under the theme of 'What the oceans mean to me'. This title is deliberately designed to be broad-ranging and allow you all to bring your creativity to bear to impress your friends and colleagues. There will be fabulous prizes for the best pictures (judged by the President and President Elect) and we anticipate using them in future publications of the Society, with the artist's permission, of course. The cover of this Volume of *Ocean Challenge* shows the photo that won the competition in 2014, taken by Rob Cook.

So please start planning to bring your best photographs to Liverpool!

Other prizes to be won in Liverpool

- As in previous Challenger Society Conferences, the Cath Allen prize will be awarded for the best poster and the Norman Heaps prize will be awarded for the best presentation by an early-career scientist. For more about these prizes, see p.4.

- As usual, 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 – 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.

The winner of last issue's Maritime Crossword Challenge was Jan Kaiser at UEA.


The 17th Biennial Conference of the
Challenger Society
for Marine Science
The Challenger Society for Marine Science
Oceans and Climate Conference
Liverpool, UK
5–8 September 2016
Full details at
https://www.liverpool.ac.uk/
challenger-conference-2016/
or csms_enquiry@noc.ac.uk

Some dos and don'ts for posters and presentations

There are two prizes to be won at the Challenger Society Conference, in addition to those for the best entries 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.
- D**iagrams 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 yourself 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.**

Citizen science – marine style

Capturing Our Coast (CoCoast) is a £1.7m project funded by the Heritage Lottery Fund. Led by by Newcastle University, it aims to develop a network of more than 3000 citizen scientists who can help build an accurate picture of marine life all around the UK – a baseline against which we can better understand the impacts of climate change and other environmental and human factors.

Anyone wishing to register their interest in attending a free CoCoast training course at one of the Hubs around the country (*see map*), where they will learn what to look out for and how to record data, can go online at www.capturingourcoast.co.uk. For those who are unable to get to a training hub, CoCoast will endeavour to provide training at other venues, and there are also other CoCoast projects that will welcome help from budding citizen scientists.

Volunteers (18 years of age or older), even with little or no scientific background, are being trained to work alongside academics to collect extremely important data, and ultimately play a part in how their local coastline is managed and protected. The data collected will fill key knowledge gaps relating to geographic species distributions, movements of warm-water species, and occurrences of invasive non-native species. In addition, the information collected could identify effects of rising ocean temperatures and more acidic seas, which could impact upon economically important species like mussels and oysters, as well as coastal birds that feed on them. The team are particularly keen to know the effects of climate change (including wetter and more stormy winters) on coastal species that are not often recorded, particularly in remote parts of the country. As of the end of June, CoCoast had trained over 1200 people, 3000 people had signed up to the website, and @CapturingRCoast had over 2050 Twitter followers. Data have been submitted from over 250 surveys from all over the UK, from the Isle of Lewis to St Ives, and from Whitby to Holy Island. Data collected by CoCoast will regularly be uploaded to the National Biodiversity Network (NBN) Gateway and thus be available to anyone.

The CoCoast Hubs
The project also involves the Earthwatch Institute, the Natural History Museum, the North-West Coastal Forum, the Northumberland Wildlife Trust, Cefas, the Coastal Partnerships Network, the Thanet Coast Project, the Scottish Seabird Centre at North Berwick, Whale and Dolphin Conservation and the Clipperton Project

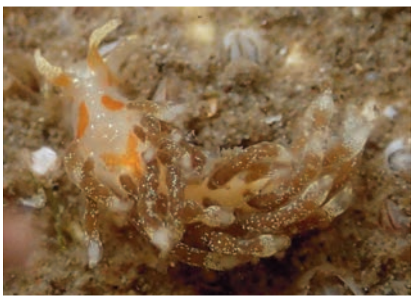
In addition to their main survey programme, to engage a wider audience, hubs are also running side-events such as Bioblitzes, whale and dolphin ID workshops, porpoise-watching and crab hunts. All the hubs have been holding Wine and Science evening events, with topics ranging from Antarctic intertidal research, seaweeds and seagrass, to saline lagoons and sustainable food.

To take just one region as an example, the Yorkshire CoCoast team have been running of a series of Rocky Shore 'Bioblitz' events in conjunction with the Yorkshire Naturalists' Union and the Yorkshire Wildlife Trust. At one of these events, a rare nudibranch was found (*see photo below*).

Ed.

CoCoast volunteers and experts investigate a rocky shoreline in Yorkshire *(Photo: CoCoast)*

The nudibranch (sea slug)* Cuthona foliata *found at a CoCoast event in June at Boggle Hole, near Robin Hood's Bay, Yorkshire – the first ever observed at that site and one of only 42 UK records on the NBN gateway. *(Photo: Paula Lightfoot, Yorkshire Naturalists' Union)*



An interview with the Director of SAMS

Nick Owens describes a varied career in marine biogeochemistry

Anyone who attended the 2014 Challenger Conference at Plymouth will have seen Nick energetically fulfilling his role as Conference Chair. At the time, Nick was Professor of Marine Science at the University of Plymouth and Director of the Sir Alister Hardy Foundation for Ocean Science (SAHFOS), but he has since moved to Oban to take on the Directorship of the Scottish Association for Marine Science. *Ed.*

How did your interest in marine biology begin?

While at boarding school I got very ill with jaundice, and although I recovered very quickly, I wasn't allowed to return to school for three months. We were living in West Cumberland at the time, in a house virtually on the beach, so I spent most of those three months exploring the beach. I discovered all sorts of interesting things, particularly about rocky and sandy shore ecology – I'd noticed that there was zonation, for example. Later I was intrigued when I was taught about these things formally, and I had no doubt that marine biology was what I wanted to do.

You have said that you felt very fortunate to spend time at the Port Erin Lab, on the Isle of Man. Why was it such a valuable experience, and how did it feed into your later career?

During the first two years as an undergrad at Liverpool, Easters were spent on field courses at Port Erin, and then in the final year, the whole year was spent on the island, so it was complete immersion – in many cases literally, as many people took up diving! We walked to the lab across the beach every day, the pub we drank in overlooked the beach and the offices and labs were on the beach. It was such a beautiful place and it's a real shame for today's generation that it's not there any more. However, there is a very current alternative, and that is to study marine science at SAMS, with the labs and lecture theatres overlooking the beach – some students come in by canoe! In fact it's an incredibly similar immersion in marine science!

Port Erin is where I developed my interest in marine biogeochemistry, studying nutrients in Manx rivers, estuaries and coastal waters. I then went and did a Ph.D at Dundee University, again following my interest in nutrients. My study area was the Eden Estuary right by St Andrew's golf course, so when the Open Golf Championship came along I would spend four days at my sampling site by the 9th hole – the only time that a whole lot of colleagues came out to help me!

Then I was very fortunate – especially compared with today's young marine scientists – I got a permanent job at Plymouth Marine Laboratory even before I finished my Ph.D. It was called the Institute for Marine Environmental Research – IMER – in those days. A few years into that job as a full-time researcher I got the opportunity to go to Rhode Island on a John Murray travelling studentship, run by the Royal Society.

I had realised that by focussing in on the chemistry, I was missing out on all the organisms which were driving everything. I wasn't looking at organisms because I had a kind of phobia about microscopes. But I really thought I needed a better awareness of the bugs that were driving all the biogeochemical cycles. At that time, one of the real masters working in this area was John Sieburth at the University of Rhode Island, who had tremendous skill in microscopy and some great people around him. So I went there, learnt some microscopy, leant how to cross-country ski, and learnt how to go fishing through holes in the ice on frozen lakes!

I then spent 14 years in Plymouth – these were luxury times, as certainly for the first 10 years funding was not a problem. I remember when I was still quite junior, the Director coming into my office and saying 'I've got five cruises on the Frederick Russell*, 10 days each. What are you going to do with them?' Unbelievable opportunities – I really do feel for today's generation, it's a much much tougher world now.*

Do you enjoy teaching?

I do enjoy teaching! I got into teaching when I was at Newcastle. As I was the Professor of Marine Science, I made it my job to give the marine science students their very first lecture. I used to shock them by ending by saying 'If you can see it, it's not important!' – being a biogeochemist, my final slide was an image down an electron microscope. The poor first-year students were crestfallen, having been fed a diet of whale-watching and swimming over coral reefs. One of the great pleasures for me has been that a number of those then crestfallen students later went on to have excellent careers as biogeochemists.

With your current administrative role at SAMS do you get to develop your own research?

I do sometimes manage to do some, but it's very very little these days, but I get as much enjoyment and satisfaction out of trying to create an environment in which others can be succeessful. That's what motivates me, as a Director of a Lab. I get as much pleasure when someone publishes a really nice paper as I did when publishing one myself.

I often say to people when I'm describ-ing my job, I'm incredibly fortunate – and many marine scientists say the same thing – it's more of a vocation than a job. It's because of that, that you put up with other stuff that you don't get paid for.

When you were at BAS did you miss the sea?

I missed living by the sea, and it's nice to be back by it again. But when I was at BAS I actually saw a lot of the sea: I had to go the Antarctic at least once a year, and whenever possible I used to spend time on the ship.

Do you think it's important for research institutions to have a commercial arm?

I absolutely believe that very strongly. We are still learning how to do it properly, but there is increasing importance in the academic world working much more closely with the commercial world. That can be of real benefit to the science. It's not just one-way though. I have a real belief that there is a positive two-way interaction. And it can help the science move on – as with any scientific work, you can set out with one objective and find something else interesting on the way. And I also believe that now there is almost a moral imperative for scientists, especially if taking public money, to be seen to be doing something genuinely useful with it – though once 'useful' was almost a dirty word when applied to science. That doesn't mean that you don't do blue skies research – of course you do.

You've worked in lots of different places. Do you think this was a good thing for your scientific career?

I think it was a good thing, because I was able to add to my experience. There is nothing like going somewhere else to learn things. You cannot but learn by just moving jobs – new places, new practices, exposing oneself to more people, new ways of doing things, a different ethos. It's very enriching.

But all the moving about must have been quite disruptive for family life?

I was very, very fortunate in having an extremely supportive wife. I couldn't have done it without her. There was a sacrifice made by her and our four sons, but in the end, we managed the problem by keeping the family in one place. I moved but the family home didn't, so although I wasn't there all the time, family life was not disrupted.

Career-wise it was a good thing for me, but if you have two professional people who want to pursue a career it can be a real challenge. In my case, my now late wife – who was a scientist – wanted to remain at home to be a mother to the boys, so it worked for us.

What were you most proud of in your times at BAS and Plymouth?

I was very very satisfied in the creation of Plymouth Marine Laboratory – leading the move from NERC and creating an independent company – that was a tremendously exciting time. It was a white-knuckle ride and it challenged my leadership skills to the absolute limit as I was taking 100 people into the complete unknown, and it worked. I didn't do it alone – I had a tremendous team around me – but it was exceptionally satisfying.

I got almost as much pleasure, in a seemingly much more trivial way, by giving my approval to a picture of a polar bear appearing in the BAS calender, which is put together through a photographic competition for BAS staff. The polar bear overturned 60 years of history and inertia because of course, polar bears are only found in the Arctic. But I wasn't being perverse, it was a very clear statement about polar science being global. We had ceated an entirely new project called Polar Science for Planet Earth. Although I left before we could really see the fruits of this initiative, it was a very positive development.

Did you have time to enjoy the Challenger Society conference in Plymouth in 2014?

I did! Again I was just the figurehead – I had a very good team. They know that I'm not a 'finisher'! In business jargon I'm a 'plant' – a person who has lots of crazy ideas and needs other people to make sure they get done.

What do Challenger Society conferences mean to you?

I might have been to every Challenger Conference since the first – it's the one conference that always gets put in my diary, two years in advance. The conferences are very much for younger scientists, and the early-career people and students bring refreshing new insights to the science, which stops us getting fuddy duddy. So the Challenger Conference is always good fun – and an excellent opportunity for some really serious 'dad dancing'!

It always gives me great pleasure to see the enthusiasm and energy of the next generation coming up. One of the real pleasures here at SAMS is that we are actually part of the University of the Highlands and Islands, so not only do we have post-graduates, we have loads of undergrads.

If you had one piece of advice for a marine scientist at the start of their career, what would it be?

Keep your options open. Work hard but don't forget to smell the flowers!

What would you would like to see for SAMS In the future?

I would like to see SAMS better recognised for the value – both economic and cultural – that its excellent marine science can bring to the local region of Oban and Argyll, and Scotland as a whole. Also, we are trying to develop closer links between town and gown, and there is a project at the moment spearheaded by the Argylle and Bute Council, with support from the Scottish government, for making Oban a university town, so improving the prosperity of the region.

Nick at a field camp near Rothera research station, in the Antarctic

Laurence Mee: an appreciation

Paul Tett

Laurence – by training a chemical oceanographer – was Director of the Scottish Association for Marine Science (SAMS) from 2008 to 2014. Not an easy job, leading a small independent institution that although federated to the University of the Highlands and Islands, runs largely on 'soft' money. The Director's office, on the top floor of the newly rebuilt laboratory at Dunstaffnage near Oban, looks across the bay to the mountains of north Argyll. Laurence wasn't often in this office: there was business to be done around the laboratory, or with the University in Inverness, the Scottish Government in Edinburgh, Research Councils down south, or international organisations beyond. Most of these journeys started and finished along winding highland roads, adding hours to days that had already been long. Decades ago we would have sent a car and driver to meet him, but those days are over, and Laurence had to drive himself.

His energy was what first impressed those who met him. As my colleague Jasper Kenter wrote:

> *Laurence was a bit like a whirling dervish, apparently spinning all over the place, but in the heart relaxed and at ease. It struck me how much Laurence trusted life and others, having a vision and intervening where necessary, but not more than that, and living and working with an openness, trusting that life could run itself and not having to precisely predict or control the outcomes, and instead being curious about what might be revealed and excited about the possibilities that might bring.*

This description perfectly captures Laurence's method for leading projects and organisations. It was also his recipe for human involvement with the natural world. After several decades working for international programmes, he'd concluded that there was no panacea for curing the ills that the 45% of humans who live in the coastal zone were inflicting on the sea. Instead, the need was for 'adaptive management', not only of the marine and maritime ecosystems, but also of the social systems that link to them. The ecosystems provide [the] resources – 'ecosystems services' as we now label them – for society, but it is society itself that must decide on the aims of management and it is human activities that must be managed.

Why adaptive management? Because social–ecological systems are dynamic, and in any case we don't always get management right the first time. So, while there is a need for natural scientists to understand and monitor what is happening in the sea, there is also a need for social scientists to understand what is happening in the social-economic system, and a need for people like Laurence, and those he attracted to work with him, to interface between the institutions and people who, and the institutions which, make up 'Science', 'Policy', and Civil Society, to help 'the ship of humanity' steer its course towards sustainability.

Laurence sailing in the Firth of Lorne

As Laurence shows in his writings – and he was a good writer with the ability to draw a big picture whilst illustrating it with a few key details – he was optimistic that we humans would rise to this challenge despite its difficulties. For his part, he found sources of funding and recruited staff and students who shared his purpose and approach. Two weeks before he died, he joined the first meeting of the SAMS social science team that he'd assembled. Jasper had set up the agenda so that each of us had to say how we found our way here. In most cases this was by a roundabout route, the decision to enter academia being taken after a few years 'before the mast'.

Laurence himself explained that he had been an academic reject before a teacher in his secondary modern school sent him to a 6th-form college. This put his feet on the ladder that led to Liverpool University, Mexico and the United Nations *(see box opposite*). During the UN Black Sea programme in the 1990s, when his task was to bring together scientists and officials from both sides of the former Iron Curtain, he had, he said, learned how to choreograph meetings to get the report he wanted. But those reports, he found, went into filing cabinets and stayed there, achieving nothing. So he had looked around for other places to ground his lever and move the world into a better state. SAMS was such a place, he said, which was why he valued being with us.

In addition to running SAMS as an organisation – no mean task – he never failed to encourage and enthuse the people he worked with, giving us the courage to attempt things we might otherwise have thought beyond us. And he channelled other energies into his families and sailing. The classical Greek word *eudaimonia* means, strictly, having a good demon, and by implication having a life that allows the full expression of one's potential. Laurence's

Professor Laurence Mee *FRSC*

14 February 1951: born Ipswich
13 August 2014: died Inverness

1974 BSc. Chemical Oceanography, University of Liverpool

1977 Ph.D Chemistry and hydrography of Mexican tropical lagoons, University of Liverpool

1977–87 Researcher and then Senior Lecturer in the Instituto de Ciencias del Mar y Limnologia of the Universidad Nacional Autónoma in Mexico, where he was involved in designing Mexico's first purpose-built research vessel *El Puma*

1987–93 Director of the Marine Environmental Studies Laboratory in Monaco

1993–98 Coordinator of the (UN) Global Environmental Facility Black Sea Environmental Programme, based in Istanbul

1998–2000 Pew Fellowship in Marine Conservation

2000–2008 Professor of Marine and Coastal Policy and Director of the Marine Institute, University of Plymouth

2008–2014 Director, Scottish Association for Marine Science (SAMS)

good demon drove him hard; he flourished, and helped others to flourish, but for too short a time. He was 63 when he died, of a stroke, away from home in Inverness. If anyone deserved a driver, to conserve some of his vigour at the end of the day, it was him; but we don't do that any more. With the long exhausting days, he burnt himself up, heroically, but not wastefully, in pursuit of a better world.

See also:

In Memory of Professor Laurence Mee http://laurence-mee.tumblr.com

Musings from the Crow's Nest http://scot-marineinst.blogspot.co.uk

Miller, A. (2014) Obituary, Professor Laurence David Mee, *SAMS Annual Report 2013–14*.

Mee, L.D., R.L. Jefferson, D. d'A. Laffoley and M. Elliott (2008) How good is good? Human values and Europe's proposed Marine Strategy Directive. *Marine Pollution Bulletin* **56**, 187–204.

Mee, L. (2012). Between the devil and the deep blue Sea: The coastal zone in an era of globalisation. *Estuarine, Coastal and Shelf Science* **96**, 1–8.

Paul Tett is the Leader of the Laurence Mee Centre for Society and the Sea.

The Laurence Mee Centre for Society & the Sea, SAMS

The Laurence Mee Centre for Society and the Sea (LMC) was founded at SAMS by Laurence Mee shortly before his death in 2014. This research and innovation centre links social studies to SAMS's research in marine natural sciences and so is continuing Laurence's work.

Researchers at the LMC draw on a broad range of social and ecological fields. By working across a broad range of disciplines, the LMC engages in a unique way with the complex issues of environmental management, planning and governance of the marine and coastal environment. This interdisciplinary and cross-sectoral approach directly influences both how the LMC develops innovative theories and frameworks for understanding the relationships between society and the sea, and how it delivers the evidence that decision-makers need to improve sustainable environmental management.

The three interlinked strands of the Centre's ongoing research are outlined below.

Resilient communities

This research area investigates the social and cultural capital and the resilience of maritime communities, with an emphasis on those that are remote and/or peripheral. Research topics include the implications of top-down versus bottom-up approaches to nature conservation, marine cultural values at the arts/science interface, and the role of local agents for change in renewable energy development in small island communities. Projects include:

Producing seascapes: communities and marine spatial planning in Sweden and Scotland This one-year pilot project explored the tensions between the different visions of 'space' held by locals and the visions reflected in new ecosystem-based marine spatial planning. The goal was to to make the planning process more effective and inclusive.

Community Voice for Managing Marine Protected Areas This involved a series of workshops with stakeholders to establish preferred management options for two designated Marine Conservation Zones on the Sussex coast (Beachy Head West and Kingmere).

Ecosystem services

This work focusses on bridging the natural and social sciences to understand the links between ecosystems and biodiversity, the services they provide, and the benefits to human wellbeing that these services generate in economic and broader non-monetary terms. Taking a whole-system approach, it investigates the impacts of environmental change on the social system, and how responses by society subsequently affect marine ecosystems. Topics studied include the valuation of flood defence services, the value of marine protected areas, and the importance of careful assessment of ecosystem services. Projects include:

IMMERSE: Integrating Marcroecology and Modelling to Elucidate Regulation of Services from Ecosystems The purpose of this project was to make best use of existing data spread among different data holders across the UK and beyond. The integrated data will be used for analyses based on the latest ecological theories to inform and improve a range of models.

CORPORATES: Corporate Participatory Assessment of Ecosystem Services for the marine renewable energy industry This NERC-funded research involved a series of workshops around a case study in the Firth of Forth developing a spatial multi-criteria evaluation approach with a group of stakeholders around siting/configuration of an offshore wind array.

Policy and governance

This research considers interactions between different marine sectors, including renewable energy, aquaculture, fisheries and conservation. It looks at synergies and trade-offs between these different uses, and the policy and institutional context of marine planning. It investigates how marine policy and planning can balance short- and long-term objectives, and govern the cumulative social and environmental impacts of change across various sectors to achieve sustainable development. New mixed method approaches for project and policy evaluation are also being developed. Projects include:

Seychelles Blue Economy Researchers at SAMS providing advice to the Commonwealth secrecretariat on development of blue economy industries in the Seychelles.

AquaFellow Work undertaken by Karen Alexander in this three-year Knowledge Exchange Fellowship included mapping UK academic expertise in aquaculture science and identifying industry research challenges in the aquatic food supply chain.

MERIKA: Marine Energy Research Innovation and Knowledge Accelerator

MERIKA is an EU FP7-funded project which links all three areas, and seeks to establish a marine energy research and innovation hub in the Highlands and Islands of Scotland.

Information by courtesy of Jasper Kenter. For more details see www.sams.ac.uk/lmc

Taxonomy in trouble?

An ocean science perspective

Nick Higgs

A debate that has been simmering within the biological sciences has erupted onto the pages of leading scientific journals in the last few years, and it shows no signs of abating. If you want a taste of the discourse here is Prof Quentin Wheeler: *'I find this claim preposterous, dangerous and complacent*.' What is it that provokes such scathing and strident remarks? The short answer is 'taxonomy', but more specifically, the perceived state of taxonomy and systematic biology in today's scientific landscape. Taxonomy is the science of identifying and describing new species, and falls within the biological discipline of systematics, which is concerned with classifying organisms according to their evolutionary history.

I know what you're thinking. This might seem like an irrelevant and esoteric topic, but I hope to persuade you that one way or another this is something that the whole ocean science community should be paying attention to, not just marine biologists. I also want to make it clear that I am not a taxonomist – simply an interested party, a user of the products of taxonomy, as we all are in some way.

Who needs taxonomy?

Governments, and the funding for ocean science that comes from them, are supremely concerned with the productivity of the oceans. In other words, what we humans get from the seas. Not only biological resources like fisheries species, but hydrocarbons and minerals too. All of this is dependent, directly or indirectly, on taxonomic science. If you were in Jennifer Skinner's talk at the last Challenger Society meeting, you may recall that knowledge of tiny rows of teeth on copepods is essential for understanding large-scale ecosystem shifts in the North Atlantic Ocean and subsequent effects on important fish stocks. Likewise, taxonomic research on fossil plankton is an integral part of oil and gas exploration.

The latest marine resource to pique the interest of government is the prospect of obtaining mineral resources from the deep sea bed. Yes, even mining needs taxonomy – perhaps especially mining. When Prime Minister David Cameron launched the UK's bid to mine metallic nodules from the Pacific sea bed in 2013, the Online Biogeographic Information System (OBIS) had zero records of the most abundant deep-sea animals within the entire UK claim area. Before mining could even be contemplated it was essential to know what was living in this environment and how it might be affected. To do this, UK Seabed Resources hired an international team of taxonomists and ecologists to gather the necessary baseline ecological information. Taxonomic expertise is critical to this whole endeavour.

Determining baseline ecological information is not simply a case of providing run-of-the-mill identifications of specimens. Taxonomy is more than just diagnostics. Besides, you can't assign an ID to something that has never been described before. Previous surveys of this region of the deep sea bed have found that a staggering ~90% of species brought up are new to science! With this level of novelty you need systematic experts to make sense of the picture. At the last Challenger Society conference, Adrian Glover from the Natural History Museum gave an insight into the new approach that the team has been using to document life 4000 m below the surface of the Pacific Ocean. This so called 'end-to-end' taxonomy combines traditional morphological descriptions with DNA barcoding and state-of-the-art bio-informatics to ensure that all data are freely shared online.

In this context, taxonomic expertise becomes an issue of national capability, which is why concerns about the state of taxonomy have been rumbling on since the early 1990s. Over the last 25 years there have been three inquiries by the House of Lords Science and Technology Committee into the issue (1992, 2002, 2008), the last of which deemed UK capacity to be unsatisfactory 'to the point of crisis' in some areas. In response, in 2010 the Natural Environment Research Council (NERC) commissioned a UK Taxonomy and Systematics Review on behalf of all funders in this area to dig deeper and come up with some hard data.

Fragile funding

Although the NERC study found 1100 active taxonomists at work in the UK, most of these were only engaged in diagnostics work (identifying things); only 400 were carrying out descriptive and revisionary systematics. A key finding was that taxonomy in universities had declined markedly, both in terms of teaching and in terms of academic staff numbers. A worrying finding for national capability was that the implementation of government environmental policy is heavily reliant on volunteer taxonomists. A number of recommendations were put forth to address the issues raised and a follow-up paper in 2011 outlined a National Strategy in Taxonomy and Systematics to be monitored by a UK Taxonomy Coordination Committee.

So, what has happened since the 2011 paper on *Developing a National Strategy in Taxonomy and Systematics*? A meeting held at the Linnean Society in 2014, 'Who Needs Taxonomists?', shed some light on the situation, but the short answer seems to be 'not much' (at least to an outsider like me). The meeting report highlights the fact that 'there is no ring-fenced funding for taxonomy nor is there any one body taking a strategic overview of funding in taxonomy'. Funders have little appetite for taxonomy-only initiatives or strategic programmes. Instead, taxonomy must be embedded as part of wider collaborative projects if it is to receive funding. For example, the Natural History Museum combines core capabilities in taxonomy and collections (actually funded through the Department for Culture, Media and Sport) with external research grants to integrate taxonomy into broader scientific collaborations on disease, natural resources, biodiversity discovery and planetary change.

A search of Research Council UK-funded projects since 2011 shows that a total of £1.75 million has been spent on projects that have systematics research as a major element, equivalent to £347 000 per year. And that is just for projects that merely mention taxonomy. The actual amount of money that went to taxonomic work is difficult to calculate but unlikely to be more than half that amount. Only one project actually had 'taxonomy' in the title. Of course, there are other sources of funding but research councils are one of the largest and most directly controlled by government, the other being the Darwin Initiative.

To be fair, NERC's Advanced Training Short Courses do fund the provision of taxonomic training for early career researchers that ensures skills are passed onto the next generation (£314 000 since 2014). They also provide a source of income and status to taxonomic researchers and their institutions. In addition to funding taxonomic training, the research councils run an Individual Merit Promotion scheme that allows senior researchers at NERC institutions and some museums to gain promotions, which has supported a number of excellent taxonomic researchers. NERC have set up the Strategic Programme Advisory Group, allowing the science community to provide input on where it thinks science funding should be targeted. So, the door is at least open to direct funding towards taxonomic research.

It is easy to complain about funding allocations, but it is clear that at least part of the blame for the state of taxonomic science in the UK falls at the feet of the research community itself. There is a perceived lack of regard or esteem for this type of science that some have linked to changes in the way that research output has been assessed, especially in the UK. The problem is that prestige is increasingly bestowed (even by scientists) according to the level of income generated and so taxonomy is hit by the lack of direct funding available. Even more worrying is the lack of consideration for taxonomy in larger grant proposals that just assume taxonomic work will be done for free.

The 'death of taxonomy' mantra is not universal in academia though, and there are some who would argue that the picture is not as bleak as it seems. This is the gist of a 2013 paper published by Mark Costello and colleagues in *Science* enitled 'Can we name Earth's species before they go extinct?' In a series of papers Costello and colleagues have argued that there has in fact been an increase in the number of authors describing new species over time. Secondly, they are having to put more and more effort into finding new species, suggesting that most species have already been discovered. It is these claims that have generated so much controversy, and what seems to be a statistical arms race in the literature about the most appropriate way to analyse the data that we have.

An emerging theme from all sides of the debate is the need to think wider than national interest when assessing taxonomic capability. We work in a global scientific community and it is surely unnecessary for each country to have taxonomic expertise on every possible group of organisms. Should we not be assessing taxonomic capacity at the level of state cooperation; the EU for example, rather than the UK? Nevertheless, at a global level there are still gaps and shortages in knowledge, especially for taxa that are prevalent in the deep sea. Craig McClain cites the example of a whole class of aplacophoran molluscs for which you can count on your fingers all the experts in the whole world, many of which are close to retirement. Such shortages in expertise and knowledge can lead to real problems in science.

As an undergraduate, I worked on a project dealing with the seasonality of reproduction of deep-sea molluscs that were collected in the early 1990s using manned deep-sea submersibles. Over a decade later that experiment had not been written up because no-one could tell whether the animals collected were a single species or multiple species. This was not simply a case of needing the animals identified, but was a taxonomic problem that needed a specialist. Unfortunately, the world expert on the group had died before the samples could be analysed, leaving the data unintelligible. A lot of time and financial resources down the drain. Fortunately, a posthumous monograph was published some time later, which allowed confirmation of a single species and the eventual publication of the data. Many such stories do not end so fortuitously, but rather with samples sitting on a shelf, or worse, in the bin.

Answering big questions

Until recently, it was thought that for some common elements of marine flora and fauna, such as diatoms and copepods, most species have already been described and the taxonomic groups well established. However, both diatoms and copepods are actually among the least well known taxonomic groups in the marine realm, and are thought to contain more than 50 000 and 3000–50 000 undiscovered species, respectively. This is because, due to their small size and apparent lack of distinct morphotaxonomical characteristics, speciating plankton taxa requires highly skilled taxonomists. Additionally, fewer taxonomists focus on less charismatic and small-sized marine invertebrates, such as plankton, than on megafauna such as fish and mammals.

When it comes to the unexplored deep-ocean habitats, the number of undescribed species must be even higher. How many and what types of animals are left to be discovered in the deep ocean is one of the biggest unknowns in marine science. Rates of discovery of new species during deep-sea expeditions vary between 30 and 90% of species collected. The extent to which they really are 'new' needs taxonomic expertise though. Are we simply encountering the same undescribed species over and over again?

Until we can answer such questions, we are limited in our ability to answer the big ones, such as 'How many species are there in the ocean?' Some have tried to come up with estimates but they are widely divergent (ranging from 0.75 to 5 million species). In a recent paper I showed that our records of marine biodiversity are a non-random collection of species and we have picked the low-hanging fruit in terms of species discovery. Because of this we can't even say whether the total biodiversity of the deep oceans is greater or less than that of the shallow seas, and so we can't yet predict how much biodiversity remains undiscovered. As humanity pushes ahead with ever greater exploitation of the deep ocean, it is critical that we can understand what is down there. To do that we must preserve the knowledge and expertise of taxonomists and ensure that it is passed on. Perhaps crucially, there must be career pathways for systematic scientists and that will involve increasing the perceived value and credit bestowed upon taxonomists by the wider scientific community.

I am an unashamed advocate for the work of taxonomists because my own work relies on it heavily. But the aim of this piece has not been to elevate taxonomy above other areas of basic science. What I hope to have shown is that taxonomy is a vital element of an increasingly multidisciplinary scientific landscape. Working with taxonomists will be a part of the new era of big projects aimed at solving the grand challenges in ocean science. So the next time that you start a grant application, ask yourself 'How many taxonomists do I know?'

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Algal partners protect Persian Gulf corals from heat stress

But how and where did this heat-tolerance arise?

As global temperatures rise, the decline of coral reefs is being hastened by episodes of bleaching caused by heat stress. Bleaching occurs when the coral's symbiotic algae (dinoflagellates of the genus *Symbiodinium*; see Box) are damaged and either expelled by the coral or lose their pigmentation (which contributes significantly to the colour of the coral). However, corals in the southern Persian Gulf – the warmest part of a very warm body of water – regularly endure summer temperatures of up to ~ 35 °C. It seems likely that in the case of some corals this heat resistance is due to the heat-tolerance of their symbiotic alga *S. thermophilum* (Figure 1). Understanding how heat tolerance in coral–symbiont associations arose is crucial in assessing the potential of coral reefs in general to adapt to global warming.

So how did this 'hot spot' of heat-tolerant symbionts the Persian Gulf come about? As described in a recent *PNAS* article by Hume *et al.* (see Further reading), researchers from the UK and the Middle East investigated the origin of *S. thermophilum* to assess whether this thermotolerant symbiont emerged as the result of rapid evolution driven by an extreme change in environmental conditions in the Persian Gulf, or whether it originated elsewhere.

The modern Persian Gulf started to form 12 500 years ago when water from the Indian Ocean began to flow into the previously dry basin as sea-level rose at the end of the last glacial period. The present-day shorelines were reached only ~ 6000 years ago, by whch time the climate in the Middle East was becoming progressively warmer and more arid; today's conditions were attained some 4000 years ago. The coral communities of the Persian Gulf are therefore composed mostly of a subset of Indian Ocean species, and have had to adjust rapidly to high temperatures.

S.thermophilum populations can be identified by a specific mutation of its DNA, of a type known as an 'indel', a mutation class that includes both insertions and deletions of genetic information. The researchers collected samples from 46 genera of coral along 5000 km of shoreline, from the north-western Persian Gulf to the Gulf of

Coral–algae partnerships

Stony or scleratinian corals, which build reefs, have a symbiotic relationship with a dinoflagellate of the genus *Symbiodinium*, of which there are many species around the world. These dinoflagellates (also known as zooxanthellae) usually live in the soft tissues of coral, but can become planktonic and may be carried long distances in ocean currents.

Coral tissues may contain around 30 000 algal cells per mm³. The coral provides the algae with protection, as well as compounds necessary for photosynthesis: CO_2 from coral respiration, along with inorganic nutrients (ammonium, nitrates and phosphates) in its waste products. In turn, the algae supply the coral with organic products of photosynthesis (e.g. glucose, lipids and amino acids) which the corals use for metabolism and in the manufacture of proteins, fats and carbohydrates. They also help to remove its waste products.

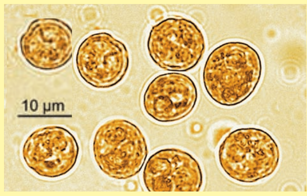
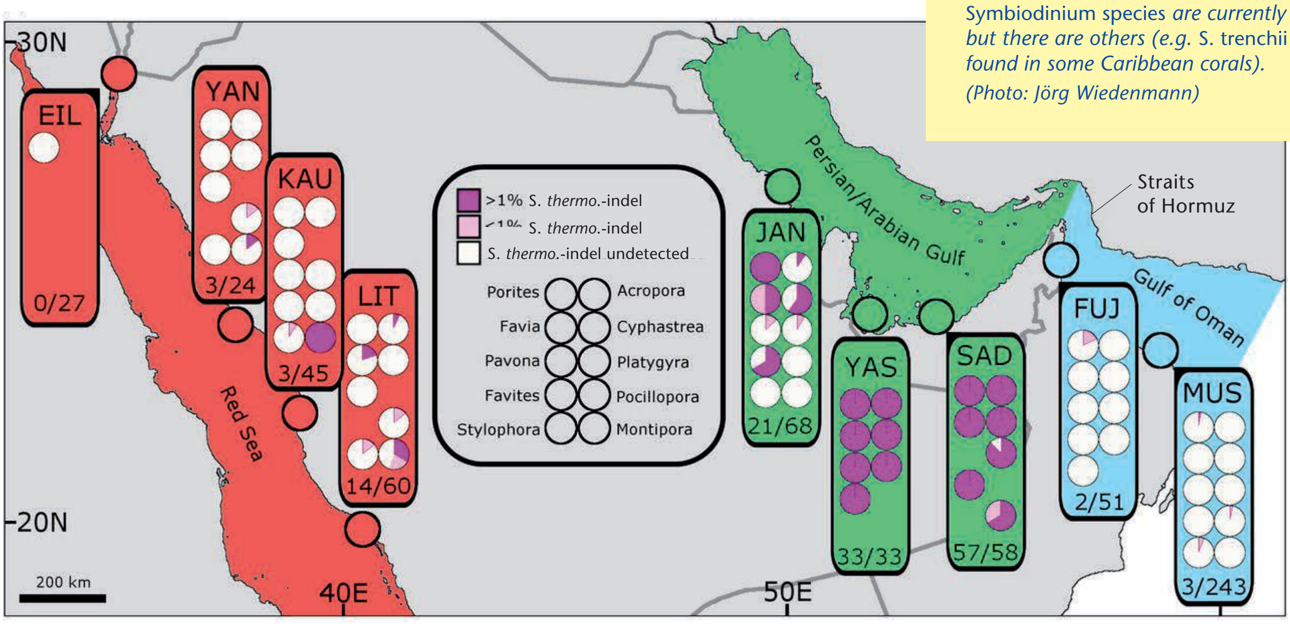
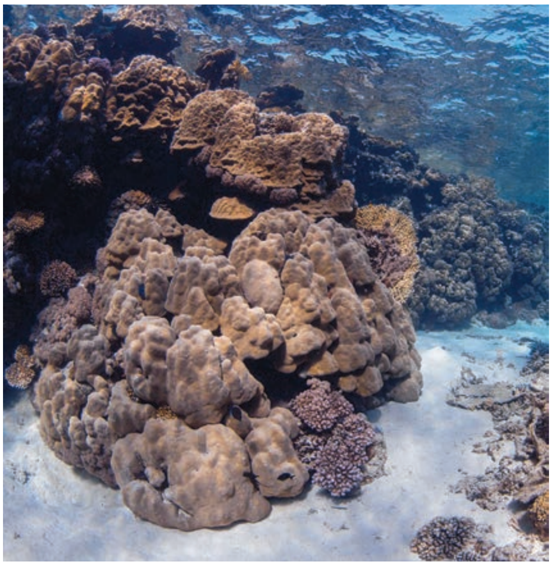


Figure 1 *The heat-tolerant alga* Symbiodinium thermophilum *found in Persian Gulf corals. Heat-tolerant* Symbiodinium species *are currently rare, but there are others (e.g.* S. trenchii *found in some Caribbean corals).* *(Photo: Jörg Wiedenmann)*

Figure 2 *Map summarising the relative abundance of* S. thermophilum *in various areas of the Persian Gulf, the Gulf of Oman and the Red Sea. The coloured boxes contain information about the abundance of the various* S. thermophilum *symbionts within the 10 most sampled genera of corals in the areas concerned. Percentages indicate the relative abundance in coral tissue of* S. thermo.*-indel, which indicates the presence of* S. thermophilum*; >1% (dark purple) represents those corals that host predominantly* S. thermophilum*. At the bottom of each box is the fraction of samples containing* S. thermophilum *over the entire region. Sampling areas: EIL = Eilat, YAN = Yanbu, KAU = King Abdullah University of Science and Technology, LIT = Al Lith, JAN = Jana, YAS = Yassat, SAD = Saadiyat, FUJ = Fujairah, MUS = Muscat.*





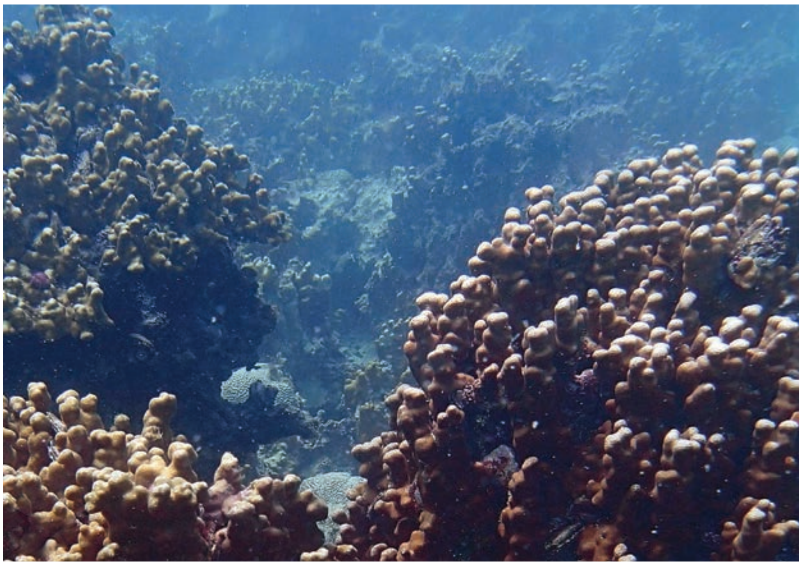


Figure 3 Left *Red Sea* Porites *corals host a diversity of symbiotic algae, but little* S. thermophilum. *(Photo by courtesy of Anna Roik)*
Right Porites *corals on Delma Reef in the Persian Gulf harbour* S. thermophilum *almost exclusively. (Photo by courtesy of Jörg Wiedenmann)*

Eilat/Aquaba in the Red Sea. In all, 900 samples were collected from 23 sites in nine different areas (Figure 2). The ten most frequently sampled coral genera are listed in the grey box in the centre of the map. As shown in the green boxes, members of the *S. thermophilum group (*identified by the *S. thermo.*-indel mutation*)* were found in 8 out of the 10 most sampled genera in the southern (hotttest) part of the Persian Gulf, and were also found, though less frequently, on the western side of the Gulf. In addition, they could be found in mostly low abundances in ~4% of samples in the Gulf of Oman and the Red Sea (blue and red, respectively, in Figure 2).

In addition, when screening public databases for genetic sequences containing the *S. thermo*.-indel, the researchers retrieved a close match with a sequence originating from Hawaii, which was recently entered in GenBank (the National Institutes of Health genetic sequence database, an annotated collection of all publicly available DNA sequences). This hit may indicate the presence of a *S. thermophilum* group member in the Indo-Pacific, indicating an even wider, though so far undetected, distribution.

Genetic analysis of a large number independent samples showed the genetic diversity of *S. thermophilum* was low in samples from the Persian Gulf compared with samples from the Strait of Hormuz, the Gulf of Oman and the Red Sea, and was least of all in the hottest southern part of the Persian Gulf. This might indicate a recent bottleneck event (a sharp reduction in the size of the population, which decreased the size of the gene pool) or a founder event (establishment of a new population by a very small number of individuals). However, *Symbiodinium* has the potential to disperse over considerable distances (either alone or as a 'hitchhiker in free-swimming coral larvae) and the Persian Gulf is well connected to the Gulf of Oman via the dominant inflow of surface water through the Strait of Hormuz. Such conditions should produce a rapid homogenisation of the distribution of symbionts, which suggests that founder or bottleneck effects are unlikely to be the cause of the distinct distribution pattern, with the lowest genetic diversity in the southern Persian Gulf. It seems much more likely that the genetic uniformity of this symbiont in the warmest coral reef ecosystem in the world resulted from relatively rapid selection of a few of the most thermally tolerant genotypes from an old lineage with a more widespread distribution.

The fact that coral–algae symbioses may change rapidly in response to warming waters may be good news for corals. However, the extent of climate change in the region of the Persian Gulf occurred over millennia, whereas a similarly large change associated with anthropogenic warming is expected to occur over decades.

Another problem is that whereas scleratinian corals usually build up reefs through continuous calcium carbonate accretion, the thermally tolerant coral communities of the Persian Gulf form only a living veneer over suitable substrates (Figure 3 right). These coral structures may therefore not build upwards sufficiently fast to keep pace with the rising sea level which is accompanying global warming. There is concern that if other coral hosts also begin partnerships with heat-tolerant symbionts, they may also decrease their rate of building upwards and may similarly be at risk of drowning.

Yet another worry is that within the southern Persian Gulf, the diversity of habitat-forming scleratinian corals (34 species) is much lower than that in the adjacent Gulf of Oman (68 species), and the central and northern Red Sea (289 species). This suggests that adaptation of coral ecosystems will be associated with a drastic loss of species diversity, and in a warming world, ecological communities with a broad diversity of species are better placed to adapt and survive.

Finally, the relationship of Persian Gulf corals with *S. thermophilum* might not be the only reason for the heat tolerance of the partnership. For example, the exceptionally high salinities, not commonly found elsewhere, might be important.

For all these reasons, a change in coral–symbiont relationships, so that more corals host heat-tolerant algae, will not necessarily save reefs from their expected demise. under the stress of global warming.

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This article was written with the kind assistance of Jörg Wiedenmann. Ed.

A 'cranky little vessel': The story of HM steam vessel Lightning

Part 1: From launch to sweet F.A.

Tony Rice

When I was putting together *British Oceanographic Vessels* (*BOV*) more than thirty years ago I became convinced that HMS *Lightning* deserved more credit for her contribution to the history of oceanography than she is usually given. In fact, I was so enamoured by her that I used O.W.Brierly's painting of her in the Baltic during the Crimean War as a Frontispiece for the book, and in the caption to the picture I stuck my neck out and suggested that, day for day, the *Lightning* cruise was even more important than that of the greatly revered *Challenger* – sacrilege or what! So what was my love affair with *Lightning* based on?

Well partly, of course, on the little vessel's six-week cruise to the Faeroe–Shetland Channel in the summer of 1868, though it was, at first sight, hardly the stuff of legends. The weather was dreadful, the ship was ancient and falling apart, and the gear and instruments her scientists were using were pretty basic and not very efficient. Moreover, the maximum water depth in which they were able to dredge and obtain bottom temperatures was only 650 fathoms (about 1200 m), compared with the 1000 fathoms they had hoped to reach.

Nevertheless, by the time they came home, the *Lightning*'s scientists, William Carpenter and Charles Wyville Thomson, had metaphorically driven a coach and horses through two of the key tenets of mid 19th century marine science: Edward Forbes' azoic theory, according to which no life in the sea extended beyond a depth of about 300 fathoms, and the erroneous idea that the bottom of the sea was filled with water at a temperature of 4 °C (39 °F), at which, like fresh water, it reached its maximum density. It was no great surprise to Carpenter and Wyville Thomson to find a wide range of life in their deepest dredge hauls because the azoic theory had already received a few near-fatal knocks, so to speak. But the deep temperature results came as a complete shock; at depths of around 1000 m they had recorded temperatures as low as an unprecedented −1.2 °C, while just a few miles away, at a similar depth, the near-bottom water was more than 6 °C warmer. As Wyville Thomson wrote in *The Depths of the Sea* (1873), his classic account of the *Lightning* and *Porcupine* cruises published as the *Challenger* sailed, these results showed '... that great masses of water at different temperatures are moving about, each in its particular course; maintaining a remarkable system of oceanic circulation, and yet keeping so distinct from one another that an hour's sail may be sufficient to pass from the extreme of heat to the extreme of cold.'

Though Thomson didn't realise it at the time, the two water masses were separated by the submarine ridge eventually named after him and first surveyed from the *Knight Errant* in 1880 and HMS *Triton* in 1882. But ridge or no ridge, the *Lightning*'s temperature results, confirmed and extended during the much longer and more successful cruises of HMS *Porcupine* in 1869 and the subject of furious arguments about their explanation, were paradigm-changing and were crucial elements in the case successfully made for what became the *Challenger* Expedition. And the rest, as they say, is history (oceanographic, that is).

So my argument, in a nutshell, is that without the *Lightning* cruise there would have been no *Challenger* Expedition. A touch far-fetched, I grant you, since the build-up in interest in the deep oceans in a number of countries in the middle years of the 19th century made a *Challenger*-style expedition more or less inevitable. But without the *Lightning* results it would probably not have taken place in the 1870s and might well not have been British. Now there's a thought!

However, my interest in *Lightning* didn't end with the 1868 cruise because, as I wrote up her entry in *BOV*, I realised that by this time she had already had a long and fascinating, if not particularly glittering, career. Wyville Thomson himself provided the first clues when he described the *Lightning* on p.57 of *The Depths of the Sea* as '... a cranky little vessel enough, one which had the somewhat doubtful title to respect of being perhaps the very oldest paddle-steamer in her Majesty's navy'. With this snippet as a lead, I discovered that the *Lightning* was, indeed, one of the very first steam vessels to enter the *Navy List* (in 1828) and that, over the succeeding

A model of HMS* Lightning *made by John Roe about 1979.
Courtesy of the National Maritime Museum, Greenwich

four decades, between several spells as a surveying vessel in peacetime, she had also played a crucial role in the Baltic theatre during the ill-named Crimean War. I briefly summarised what I then knew in *BOV*, but I have subsequently discovered that the *Lightning* story is even more interesting than I originally thought, and it has led me into corners of maritime history that I never knew existed and about as far away from oceanography as you can get. If I live long enough, and find a suitably gullible publisher, the full text may appear as a must-have book for a small number of naval/military/oceanographic history anoraks. But some parts transcend their historical context and are interesting or amusing enough on their own account, with little or no background detail. It is a few of these stories that I hope to bring to *Ocean Challenge* readers in the next few issues, beginning with this one dealing, not with the *Lightning* herself, but with her birthplace, Deptford dockyard, where she was launched on 19 September 1823, and ending with, well, not very much at all! So please bear with me.

Deptford and the Royal Navy

Deptford stands on the south bank of the River Thames, about ten kilometres downstream from Waterloo Bridge and the Houses of Parliament and more or less at the apex of the great loop of the river sweeping around the Isle of Dogs, currently home of the rather surprising bedfellows Canary Wharf and Millwall football club! Deptford's name apparently derives from the 'deep ford' that crossed the River Ravensbourne just before it enters the Thames a few hundreds of metres to the west of the *Cutty Sark* and long since replaced by a bridge. The dockyard lay even further to the west, i.e. nearer to Westminster, and in the 1820s, when the *Lightning* was being built, it was already old! In fact, along with that at Woolwich a few kilometres downriver, Deptford was one of the original Royal Naval dockyards, having been established in 1512–13 by Henry VIII both to repair and to build naval vessels.

By the end of the 17th century both Thames yards had been somewhat eclipsed by the establishment of Royal dockyards on the Channel at Portsmouth and Plymouth in the 1690s. But even before this, despite being closer to the centre of London and therefore regal power, Deptford was always at a bit of a disadvantage compared with Woolwich because of its distance from the open sea and the problems that sailing vessels have in navigating in confined waters. As the size of ships required by the navy increased, and the Thames silted up more and more during the 18th century, this disadvantage became even greater. Then, with the ending of the Napoleonic wars and the resulting drastic reduction in naval personnel and ships, the days of Woolwich and Deptford as major naval yards were numbered and both were eventually closed in 1869. But in the early post-war years the yards played important, if short-lived, roles in the introduction of steam into the navy, with most of the early steam vessels actually built by the navy being constructed in one or other of them.

The story of Deptford dockyard was particularly fraught. Having launched the navy's first five steam vessels between 1821 and 1824, the Deptford yard lost its role as the navy's main engineering yard when this function was passed to Woolwich in 1826 because of a perceived lack of space at Deptford. In fact, the Deptford yard was actually closed in 1830, but the following year, when the refurbished Woolwich yard was finally finished, it was already clear that it would not be able to cope with the increasing steam workload; by then the Admiralty had a dozen steamers compared with the five it had possessed when the yard was being planned in 1825 and a further 20 were to enter service over the next ten years. The ultimate solution was to establish the navy's main engineering yard much closer to the mouth of the Thames at Chatham on the River Medway. But as part of the interim arrangement the Deptford yard was reopened in 1844 and saw the building of a number of steam vessels ranging from the 141 feet long 490 ton paddle steamer *Porcupine*, launched in June 1844, to the 220 feet long 1800 ton wooden screw corvette *Druid* launched in 1869 just as the yard was finally closing. But quite apart from its role in building and maintaining naval vessels, Deptford was also important at that time as a centre for the distribution of stores to individual ships and whole fleets, both at home and abroad. In this role, it became curiously linked in its final days with my adoptive home town of Alton in Hampshire, based, would you believe, on sweet F.A.

Sweet Fanny Adams

The expression 'sweet F.A.' is pretty well known globally, at least in the English -speaking world, as a euphemism meaning something like 'very little' or 'not very much'. It is often modified to 'Sweet Fanny Adams', but most people using it assume that this, in turn, is a 'code' for a socially less acceptable original form using the four-letter 'F' word. They

The launch at Deptford Dockyard of the 4th rate 60 gun St Albans in 1747. The building on the left is the Master Shipwright's house, built about 1710. The larger building on the right is the Great Storehouse, probably built just a few years before the launch of the St Albans as part of Deptford's important role in supplying stores, and particularly victuals, to naval vessels from 1742 to the time of the Lightning.

Painted by John Cleverly the Elder. Courtesy the National Maritime Museum, Greenwich.

are wrong. The original form was, in fact, 'sweet Fanny Adams', named for a tragically unfortunate eight-year-old Alton girl who was brutally murdered on the outskirts of the town on Saturday, 24 August 1867. The perpetrator, Frederick Baker, a 29-year-old clerk to a local solicitor, was convicted at Winchester Assizes in December 1867 and hanged in front of the County Prison on Christmas Eve. The case inevitably received very widespread publicity, not least because the crime was so horrific, Fanny's body having been mutilated appallingly and the body parts spread over a wide area.

The previous year the Admiralty had decided to issue tinned boiled beef to the fleet through the victualling yard at Deptford. The navy had been issuing tinned food, both meat and vegetables, since 1811, much of it through Deptford, but supplied by external contractors. These contractors included the infamous Stephan Goldner, who had supplied tinned food to a number of famous naval expeditions, including the ill-fated Franklin Arctic expedition of 1845. From 1866 the canning process was undertaken actually in the Royal victualling yard at Deptford under the supervision of a Mr Hogarth, a member of a then well known firm in Aberdeen.

Hogarth apparently bought in the necessary equipment and the resulting tinned boiled beef (not mutton, as is often stated) was first issued to the fleet in 1867. It did not go down well with the sailors and it was not issued after 1871. In the meantime, however, the British matelot, with fairly typical seagoing black humour, had taken to referring to it as 'Fanny Adams', presumably at least partly with reference to its unattractive appearance. It was but a short step for the expression to be used more generally for anything that was not very satisfactory or not very substantial. Such colourful 'Jack speak' would have spread through the fleet very quickly, so that by the time *Lightning* sailed from Oban, almost exactly a year after Fanny's tragic death, her sailors would undoubtedly have been aware of the expression, though I have no evidence that they were being supplied with the offending Deptford-prepared boiled beef!

From ships to cattle

The closure of Deptford Dockyard in 1869 freed up a valuable riverside site. That same year saw the passing of the *Contagious Diseases (Animals) Act* which attempted both to control the spread of diseases among farm livestock within the country and, particularly, to prevent the import of diseased animals from abroad.

The gravestone of Fanny Adams in Alton cemetery. The epitaph begins 'Sacred to the memory of Fanny Adams aged 8 years and 4 months who was cruelly murdered on Saturday August 24th 1867'.

The Act had been prompted especially by a disastrous outbreak of cattle plague or *rindepest* in England in 1865, which caused the death or culling of well over 100 000 animals within a few months.

Historically, cattle plague has been one of the most serious diseases affecting domesticated animals and its global eradication was not officially announced by the World Organisation for Animal Health until 2011. It is caused by a virus quite similar to human measles virus, though this was not, of course, known in the mid 19th century. However, its seriousness and high mortality rate were well appreciated and it had already caused devastation in continental Europe over the previous decade. The 1865 British outbreak was eventually traced to Asiatic cattle imported through Hull via the Baltic port of Revel (Talin) and was first detected in London when infected animals reached the Metropolitan Cattle Market (later the Caledonian Market) in Islington, then the capital's main entry point for cattle, sheep and pigs and operated by the Corporation of the City of London. When it finally came into force, the *Contagious Diseases Act* insisted that the Corporation should open a separate dockside market for the reception of all imported foreign livestock by 1 January 1871, otherwise it would lose its monopoly. Deptford Dockyard was acquired by the City and became the Foreign Cattle Market, Deptford, until taken over by the War Office in 1914.

Deptford's historic site today

Sadly, in the last one hundred years virtually all obvious traces of Deptford's long and distinguished association with the Royal Navy have disappeared, though recent archaeological investigations suggest that by far the greater part of the dockyard survives as buried structures filled in intact between 1869 and 1950.

The site of the dockyard, known as Convoys Wharf and including most of the site of the diarist John Evelyn's Sayes Court manor house and gardens, was purchased in the 1980s by News International who, in 2002, applied to the London Borough of Lewisham for planning permission to erect 3500 residential units on it. London's Mayor, Boris Johnson, controversially threw his weight behind the proposal in 2011, but the resulting furore continues to this day, with a number of suggestions and counter suggestions as to what should happen to the historic site. So the chance of an amicable outcome seems to be pretty well sweet F.A!

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For more information on the tragic story of Fanny Adams visit the hampshireculturaltrust.org.uk/curtis-museum and follow 'local history'.

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Postscript The Royal Navy was not the only maritime organisation to have its own derogatory term for tinned meat supplied to its staff in the 19th century (see *Mariner's Mirror*, **8** (1) 1922 and **23** (4) 1937). The Merchant Navy also used the term 'Fanny Adams', but more often used 'Jane Shaw' and either 'Sarah' or 'Harriet Lane'. Like Fanny Adams, these other names may have similarly ghoulish origins and the 1922 *Mariner's Mirror* item confidently identifies Harriet Lane as a lady murdered in 1874 by a Henry Wainwright who was hanged at Newgate the following year. But you can't trust everything you read in this prestigious journal, because the next item dates Fanny Adams' murder to 'somewhere between 1805 and 1815 ...'. So my advice is to believe me, of course, but otherwise put your trust in sweet F.A.!

Coral cities of the deep

Species–habitat associations on the Mingulay Reef Complex

Lea-Anne Henry, Covadonga Orejas, Georgios Kazanidis, Laura Durán Suja, Ursula Witte and J. Murray Roberts

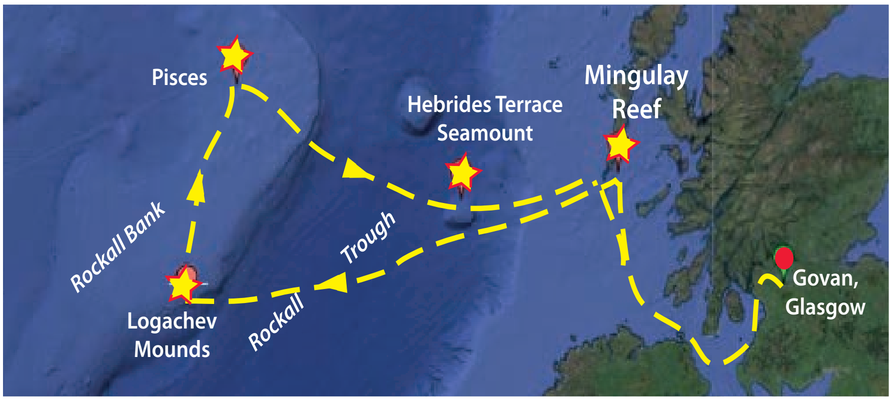
Mission to the Mingulay Reef

Global climate change is buffered in large part by Earth's oceans, which can capture and transport huge quantities of heat, salt, oxygen and carbon dioxide. The biome for which ecological impacts of this ocean buffering are least understood is the deep sea, and a race is underway to address this knowledge gap before impacts on deep ecosystems cannot be mitigated or managed.

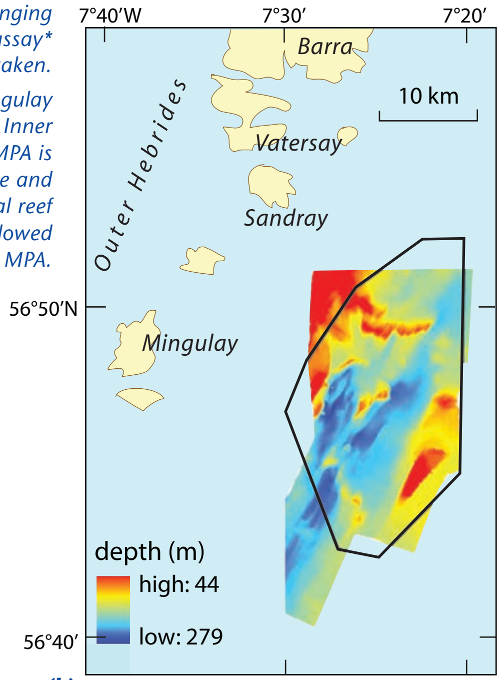
With this challenge as its main focus, in May 2012 the Changing Oceans Expedition set sail from Govan, Scotland, on the RRV *James Cook* (cruise JC 073; Figure 1(a)) for a 5-week expedition to the outermost limits of the UK's 200 nautical mile exclusive economic zone, and into the high seas beyond national jurisdiction, to study some of Earth's most remote deep-sea ecosystems. The cross-disciplinary international team of researchers used the Irish Marine Institute's *Holland 1* Remotely Operated Vehicle (ROV) and a full suite of the latest oceanographic and acoustic *in situ* instrumentation to measure fine-scale hydrography and map deep-sea habitats. This approach delivered a full programme of research, allowing detailed investigations of the often complex relationships that deep-sea species have with their changing environments.

Part of the cruise mission was to re-visit the Mingulay Reef Complex (Figure 1(b)), a rare inshore shallow setting for cold-water coral reef ecosystems, which are typically found in the deep sea. Several researchers in the Changing Oceans science party, including Chief Scientist J. Murray Roberts, have been studying the complex since its discovery in 2003, and contributed the body of evidence needed for the Scottish government to designate it a Natura 2000 Marine Protected Area (MPA) under the EU *Habitats Directive*. The vulnerability of corals to disturbance by mobile fishing gear such as trawls and dredges, and the biological diversity associated with reef habitats (notably that supported by *Lophelia pertusa*; Figure 2), were core issues at the 2014 stakeholder consultations on fisheries management for the MPA. These discussions favoured a management option that would ban mobile gear throughout the complex, but allow creel pot fishing[†] between the reefs, thereby limiting disturbances to the reefs and reef fauna.

As work continues on the cruise data, new information about species' relationships with the reef habitats is emerging that strengthen the evidence



(a)



(b)

Figure 1 (a) *Track of the Changing Oceans cruise. Stars = sites where bioassay* experiments were undertaken.*

(b) *The location of the East Mingulay Marine Protected Area, between the Inner and Outer Hebrides. The extent of the MPA is indicated by the black box. The extensive and ecologically important cold-water coral reef ecosystem is the feature that allowed the area to be designated an MPA.*

Figure 2 *Large colonies, ~ 2 m across, of the hard coral* Lophelia pertusa. Lophelia pertusa *reefs support thousands of other animal species.*

*A bioassay is an experiment to measure the effect of a substance on an organism (in this case, various concentrations of CO_2).

†Creel fishing – using baskets on the seabed – is an environmentally sustainable form of fishing with very little by-catch.

base for MPA designation. Species are often densely packed in these reefs, which makes observing their movements, and how they use the reefs, seem a little like visiting 'underwater cities'. In this article, we are focussing on three of these relationships that demonstrate not only how the different reef settings support an abundance of marine life including predators, but also how reef organisms contribute to the stability of the ecosystem and to biodiversity.

Figure 3 *Sponge habitats at the Mingulay Reef Complex are home to hundreds of other species, including these ophiuroids (brittlestars).*

Sponge parks in the city

The reef complex is inhabited by a rich sponge fauna, with over a hundred species present including a previously undescribed species which has been named *Cliona caledoniae.* This lives by eroding into hard substrata.

The Changing Oceans Expedition conducted the first ever ROV video survey of sponge megafauna at the Mingulay Reef Complex, and there is much new knowledge to be gained from the video footage collected, particularly as it relates to how sponges promote biodiversity in deep-water ecosystems. Covadonga Orejas at the Spanish Institute of Oceanography, with Johanne Vad and Lea-Anne Henry at Heriot-Watt University, analysed the ROV dives and found many species-specific habitat preferences related to geology and hydrography. For example, the large habitat-forming sponge *Geodia barretti* occurred on flatter, south-facing habitats exposed to prevailing currents (blue areas in Figure 1(b)). In contrast, the sponge *Mycale lingua* occurred on hilly topographic highs (red areas in Figure 1(b)), whereas another sponge species, *Phakellia* sp., occurred on rocky habitats with little to no live coral cover. Therefore, where the various species of sponges occur is determined mostly by differences in environmental settings.

Associated with each kind of sponge are communities of other organisms, which exploit the characteristics of the sponge in question (e.g. using micro-currents created by the sponge drawing food into its body, or hiding from predators in small cavities in the sponge). JC 073 scientists have conducted a detailed investigation of the smaller macro-inhabitants such as hydrozoans and polychaetes, and those animals living on top of the massive habitat-forming yellow sponge *Spongosorites coralliophaga* (Figure 4). This aspect of research was carried out by Giorgios Kazanidis, Lea-Anne Henry, Ursula Witte and J. Murray Roberts at the University of Aberdeen and Heriot-Watt University. Analysis of these large yellow 'sponge parks' in the busy reef city revealed species-rich communities of animals (see Figure 4), which appeared to be using the surfaces of the sponges as platforms to feed from, and internal sponge cavities as places of refuge from predators – mainly polychates and crustaceans but also small fish.

Figure 4 *One of the 'sponge parks' of bright yellow* Spongosorites coralliophaga *at the Mingulay Reef Complex. This large cluster of yellow sponges is nearly 2 m across.*

Tunicate builders

Research on cold-water coral reef biodiversity flowing from the JC 073 cruise continues to demonstrate how species other than the reef framework-forming corals can also enhance biodiversity. This is becoming evident in the case of the sponge fauna, but another new discovery at the Mingulay Reef Complex involves a rather inconspicuous sessile animal, the solitary tunicate *Polycarpa pomaria*. Laura Durán Suja at Heriot-Watt University discovered that besides providing habitat for a variety of epifaunal organisms such as bryozoans, hydroids and bivalves, *P. pomaria* densely colonises loose pieces of coral and binds these together into a very strong matrix, essentially stabilising coral patches over large areas (Figure 5). Like sponges, tunicates pump of water into themselves, creating micro-currents that attract other animals which can benefit from the incoming food. They also provide yet another surface for other animals to attach to and grow on. Our findings show how species living on the reef undertake

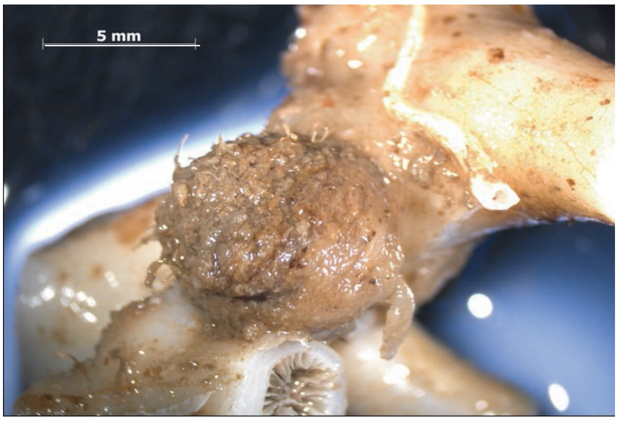


Figure 5 *The tunicate* Polycarpa pomaria *joins two pieces of dead coral reef framework (either side of the tunicate) together. This activity strengthens the reef, a previously undescribed role for tunicates in cold-water coral ecosystems.*

activities that make it more physically stable, which then attracts more species so increasing biodiversity, and so on. The ecosystem-engineering capacity of tunicates living on cold-water coral reefs has also been observed in the predatory polychaete worm *Eunice norvegica* and further demonstrates ecosystem feedback between reef biodiversity and long-term habitat stability.

New insights into predatory reef fish

Hundreds of invertebrate species have been found living in association with the Mingulay Reef Complex since the first programme of cold-water coral research began there in 2003, but until the Changing Oceans ROV video little attention was paid to the fish community, so little information was available on it. However the JC 073 scientific party undertook a novel investigation based on the ROV video. Among fish predators captured by the ROV video system were a few well known species including saithe *Pollachius virens* and the lesser spotted catshark *Scyliorhinus canicula*.

Unexpectedly, many egg cases of the deep-water blackmouth catshark *Galeus melastomus* were also collected. A more detailed investigation led by Lea-Anne Henry at Heriot-Watt University revealed that the egg cases had also been collected during previous missions to the complex. Habitat-mapping showed that spawning was occurring only in very specific environmental settings on the reef, and eggs were found in these sites year after year. Specifically, eggs were only deposited on live corals, in sea-floor valleys about 160 m deep, with moderate currents. This evidence suggests that *G. melastomus* may have environmental preferences for spawning in the complex and possibly exhibits high site-fidelity over several years.

Future research into the Mingulay Reef Complex

The JC 073 Changing Oceans Expedition will continue to provide a wealth of data with which to explore reef biodiversity, its effects on ecosystem stability, and the intricate and complex relationships between species and their habitats and global climate change. Beyond the three case studies outlined here, future research on biodiversity at the reef complex will include addressing major gaps in our knowledge of the fish fauna and the pelagic realm. To launch this new programme, a team of investigators including Lea-Anne Henry and J. Murray Roberts are collaborating with the Ocean Tracking Network (headquartered in Canada) to plan the first array of acoustic listening stations specifically designed to investigate movements and long-term habitat use by predators associated with a deep-water coral reef.

Figure 6 *Holland 1's sampling arm reaches for shark egg cases among the reef framework of the Mingulay Reef Complex*

Figure 7 *A developing embryo of the deep-sea blackmouth catshark* Galeus melastomus *found in an egg case deposited on corals in the reef complex. Still attached to its yolk sac, the shark is about 30 mm in length.*

Acknowledgements

The Changing Oceans Expedition was funded by the UK Ocean Acidification Research Programme (Natural Environment Research Council grant NE/H017305/1 to JMR).

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Covadonga Orejas is a Scientific Investigator with the Instituto Español de Oceanografia in Spain. Her research covers the reproductive ecology, physiology and distribution of cold-water scleractinian and gorgonians in deep-sea habitats.

Georgios Kazanidis is a post-doctoral researcher at the University of Aberdeen working on the biology and ecology of sponges from cold-water coral reefs. His Ph.D studies were funded through a scholarship by the Marine Alliance for Science and Technology for Scotland (MASTS).

Laura Durán Suja is a Ph.D student at Heriot-Watt University. Her expertise is in the taxonomy and ecology of the meiofauna and macrofauna associated with cold-water coral ecosystems.

Ursula Witte is Professor of Biological Oceanography at the University of Aberdeen. She investigates the impact of climate change and anthropogenic perturbance on the diversity and function of benthic ecosystems.

Murray Roberts is Professor of Marine Biology and Director of the Centre for Marine Biodiversity and Biotechnology at Heriot-Watt University. His research focusses on the biology and ecology of cold-water coral ecosystems and the means by which vulnerable deep-sea ecosystems can be conserved.

Elements for life: efforts to quantify iron release from ocean sediments

William B. Homoky

The ocean is surrounded by Earth's rocks and minerals, which provide seawater with the chemical ingredients that sustain marine life. Understanding the fluxes of chemical elements passing between these reservoirs is essential if we want to learn about conditions for life in the oceans today, in the past, or in the future. Quantifying these fluxes is not at all straightforward, however. For starters, what do we measure, and why, and where and how do we to measure it? In this article, I will discuss the early rationale for wanting to measure the supply of iron to the ocean, and will then explain how our knowledge of the mechanisms by which iron is supplied from ocean sediments is evolving and why innovative approaches are needed to measure them. I will illustrate some of the scale and complexity of the challenge and argue why we ought to be expanding these efforts to encompass other chemical constituents needed to sustain marine life.

The seawater salts

Our earliest thinking about ocean chemistry concerned the saltiness of the ocean, and quantifying the amount and rate at which common elements like sodium (Na) and potassium (K) enter the ocean from the land, via rivers, and leave the ocean buried in subducting oceanic crust, or precipitated as salt minerals in shallow coastal regions of net evaporation.

We now know why the sea is salty and why it isn't getting saltier over time, but for every element there's a different story, and in recent years the biologically active trace element micronutrients like iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), cobalt (Co) and nickel (Ni) have attracted a concerted effort to understand and quantify their sources, sinks and cycling in the ocean. These elements present new challenges since unlike sodium (which makes up about 1% of seawater by weight) they do not behave conservatively* in the ocean; they have shorter residence times, and are very scarce (each one is about 10 billion times less abundant in seawater than sodium), with patchy distributions near points of input, biological assimilation, reaction or recycling. Knowledge and understanding of their distribution is vital, however, if we wish to understand the conditions sustaining ocean life.

*Away from the sea surface (which is subject to rainfall and evaporation), conservative element concentrations can only be changed by mixing together of seawater with different concentrations of the element in question.

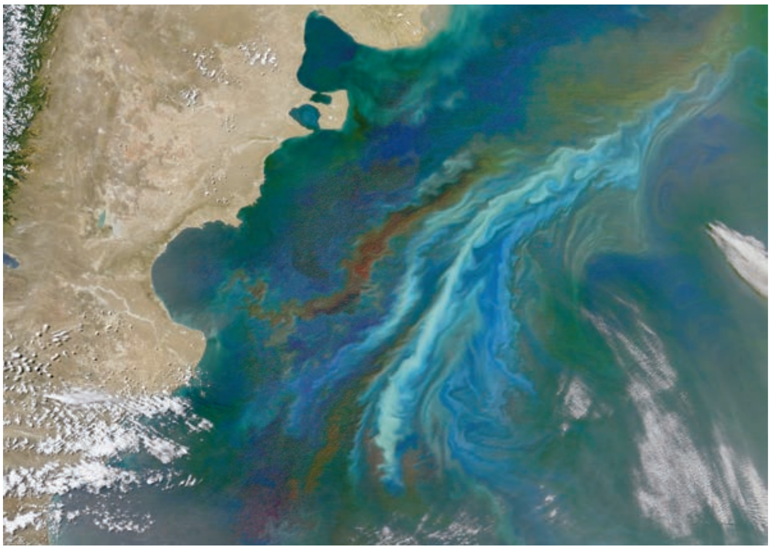
Iron: a key player in life and climate

Quantifying the amount of iron entering the oceans is an enduring problem for many of us, but solving it is of paramount importance for understanding the ocean's role in mediating Earth's climate. This is because iron is often the most deficient of the ingredients in seawater that phytoplankton need to grow in the surface ocean (Figure 1). Once photosynthetic life has used up the iron available, whole ecosystems are forced to adapt to more efficient use of their iron inventory. Importantly, changes to the availability of iron are known to affect the overall effectiveness of the 'biological carbon pump', the processes by which primary producers draw down carbon dioxide from the atmosphere, and fuel the ocean's food web, resulting in the export of carbon from the surface to the deep ocean and underlying sediments.

The earliest postulations on the importance of iron in the oceans were in the 1930s, long before we had the analytical capabilities to measure the scale of its impact in the open oceans. Investigators like Haakon Gran and Hildebrand (H.W.) Harvey observed the nutrient-limiting effects of iron for phytoplankton in experiments and the vanishingly small quantities of iron in the surface ocean, and naturally concluded there must be a regulatory role for iron in governing ocean plant life. Some 50 years later John H. Martin finally demonstrated this role for iron in the ocean and so solved a long-standing mystery: Why do vast ocean

Figure 1 *A satellite view of phytoplankton blooming in the South Atlantic Ocean near Patagonia. Their growth is stimulated here by the plentiful supply of nutrients and sunlight in the swirling confluence of the Brazil and Falkland/Malvinas Currents. The UK GEOTRACES Programme undertook a transect through this region in 2011 to investigate the processes driving productivity across the South Atantic.*

Image captured by the NASA satellite Aqua *in Dec. 2010.*



regions that contain high levels of macronutrients (phosphate and nitrate, PO_4^{3-} and NO_3^-) have relatively low levels of chlorophyll?

Upon discovering the stimulating effects of iron on phytoplankton growth rates in the high-nutrient/low chlorophyll (HNLC) regions, Martin went further. He proposed that the addition of iron to seawater was so important for stimulating the biological carbon pump, and affecting the atmospheric concentration of the greenhouse gas carbon dioxide, that it could have driven past glaciations on Earth. Martin's 'iron hypothesis' has since been supported by the results of larger-scale iron-seeding experiments in HNCL regions, and by sedimentary records that indicate that variations in the supply of iron to the Southern Ocean (the largest HNCL region) were closely correlated with atmospheric carbon dioxide during the most recent glacial–interglacial periods. The sources of iron that fuel Southern Ocean primary production remain keenly debated, as does the strength of their influence in driving glacial–interglacial variations in atmospheric carbon dioxide. However, the important role for iron in affecting ocean life and the carbon cycle is now widely accepted.

Growing concern over anthropogenic carbon dioxide emissions in the time since Martin's discovery brought iron further into the spotlight. Artificially seeding the ocean with iron has been seen (and by some, continues to be seen) as a possible geo-engineering route to mitigate the effects of anthropogenic carbon emissions. A popular consensus among many scientists is that a quantitative understanding of iron's influence on primary production and the coupled ocean and atmosphere is essential to inform this debate, but we are limited by our knowledge of the natural state of the ocean's iron cycle. Efforts to measure the rates of processes adding and removing iron to and from the ocean have accelerated, and it was in the mid-2000s (when I started my Ph.D) that marine sediments were proposed as the major 'missing' source of dissolved iron to the ocean, knowledge of which would help us balance the ocean's iron budget. The pioneering measurements of benthic Fe fluxes were made by special chambers designed to incubate and monitor the chemistry of seawater in contact with the sea floor (Figure 2). These produced the first major demonstration that the sea floor is not just a a repository for iron that entered the sea from elsewhere – marine sediments are capable of supplying a large amount of dissolved iron to the ocean too.

Variations in the supply of iron have a significant effect on phytoplankon populations in the South Atlantic

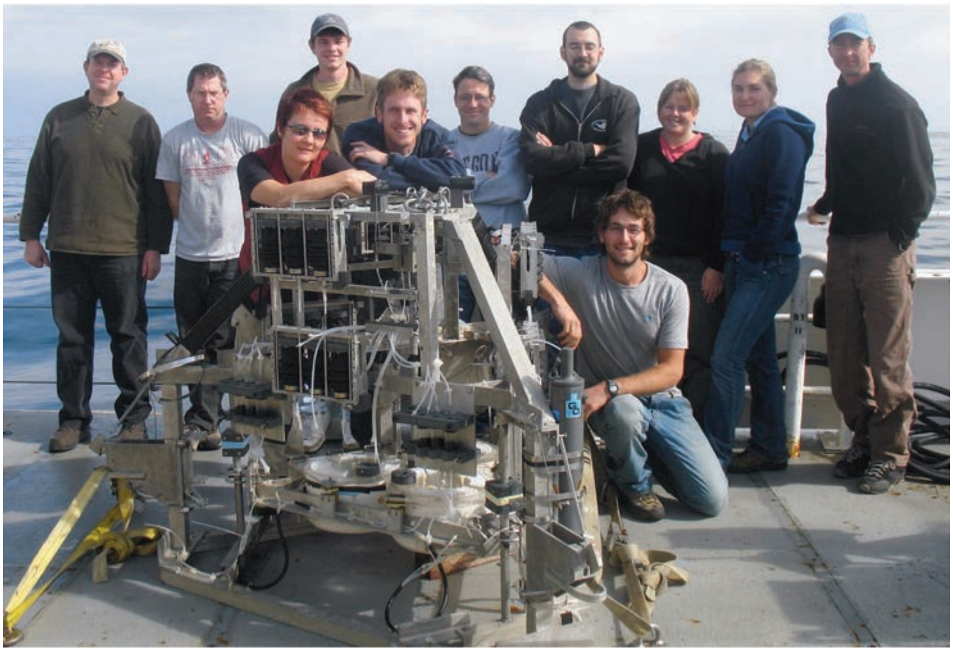


Figure 2 *Some of the pioneer investigators of benthic iron fluxes, with one of their landers, and the science party of the NSF-funded Benthic Iron Flux (BIF) campaign, on RV* Wecoma *in 2007. The landers were developed by Will Berelson (2nd from left, University of Southern California) and James McManus (6th from left, University of Akron), and it was this equipment that measured the relationships between organic carbon decomposition, dissolved oxygen and the amount of iron released from the sea floor. Working with those mentioned above, Silke Severmann (3rd from left, Rutgers) identified the isotopic composition of reduced Fe released from the sea bed. The author, (kneeling) joined this expedition as a graduate student sponsored by a Challenger Society Travel Award.*

Sediments provide the 'missing source' of iron for phytoplankton

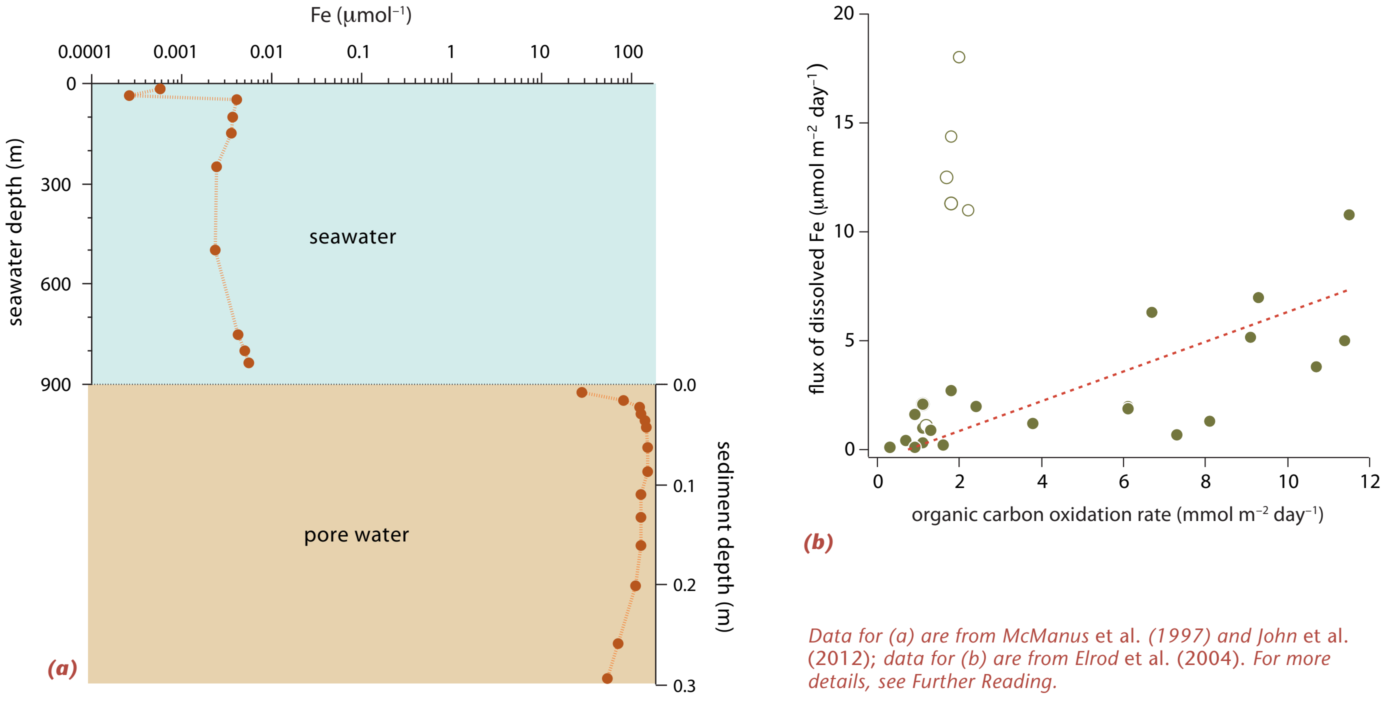
The first investigators of iron supply to the ocean understood that the conditions which make dissolved iron so scarce in seawater change dramatically just a few millimetres beneath the ocean floor. Oxygen reacts quickly with the soluble (ferrous or Fe^{2+}) form of iron, forming insoluble (ferric or Fe^{3+}) oxide minerals that precipitate from seawater. With oxygen nearly ubiquitous in the ocean today, there is a chronic absence of iron compared with the oxygen-devoid oceans of our early Earth. The iron that we do measure is often stabilised by organic complexes, or is present as nano-sized iron particles, which we term 'dissolved' (*see later*). However, drop down into the sea-floor mud just a short distance and the chemical environment changes, as if stepping back in time, to one without oxygen, where soluble ferrous iron can accumulate to very high concentrations.

Oxygen is consumed in sediments by micro-organisms as they decompose organic matter, and in the presence of a large amount of organic matter, oxygen can be consumed faster than it can diffuse in from the ocean above, with the result that subsurface sediments become largely devoid of oxygen. In this instance, metal-reducing microbes take over the decomposition of organic matter by donating electrons to metal oxides such as ferric iron. These bacteria gain energy by chemically reducing ferric iron back into its ferrous and soluble state, so enriching sediment pore waters with dissolved iron. The more organic matter that is supplied to the sea floor, the more rapidly oxygen is depleted and the more reductive dissolution of iron occurs, potentially leading to rich reservoirs of dissolved iron just beneath the ocean floor.

The link between large supplies of organic material and dissolved iron in pore waters was well established by the end of the 1970s. Some 20 years later, the benthic release of iron came to light in studies of sediments off California, a region of coastal upwelling which sustains high productivity and has correspondingly depleted oxygen in bottom waters. Here it was found that dissolved iron is so plentiful in the near-surface pore water that it diffuses back into the ocean before it can be completely oxidised and trapped in the sediment. Data collected off California (Figure 3(a)) shows not only high concentrations of dissolved iron in pore water just below the sea-bed, but also relatively high concentrations in seawater approaching the sea floor. The low oxygen content of these waters slows down the natural rates of Fe removal by oxidation to mineral phases, a phenomenon also seen in other low oxygen zones on continental margins, from where high concentrations of dissolved Fe may be transported substantial distances in the water-column. Much of the Fe released from the sea floor may never actually

In many locations, the concentration gradient of dissolved iron across the sea-bed drives an upward flux of Fe, some of which may eventually support phytoplankton growth

Figure 3 (a) *Dissolved Fe concentrations in the water column and sediment pore waters of the San Pedro Basin, California. Note the concentrations of dissolved iron increase by 3–4 orders of magnitude between bottom waters and the upper few centimetres of sediment pore water. The concentration gradient across this critical zone drives an important flux of Fe, a fraction of which ultimately supports phytoplankton growth, as indicated by the sharp drop in Fe concentration at ~ 40 m in the water column, overlying a sub-surface maximum (~70–150 m) where Fe is released back to the water column during the breakdown of sinking organic debris.* ***(b)*** *Dissolved Fe flux measurements made by* in situ *chambers in the Borderland Basins off California, plotted as a function of the rate of organic decomposition (carbon oxidation) in the sediment. Open circles = sites where bottom water O_2 was especially low (<20 μmol l^{-1}). The dashed line is the linear regression used to estimate the benthic flux of dissolved Fe to the global oceans based on knowledge of the organic carbon oxidation rates elsewhere.*



Data for (a) are from McManus et al. *(1997) and John* et al. *(2012); data for (b) are from Elrod* et al. *(2004). For more details, see Further Reading.*

reach the sunlit surface ocean; the fraction that does depends almost entirely on the movement and mixing of ocean waters, and the reaction pathways for Fe in the ocean interior – processes so complex that we rely on gobal 3D models to evaluate the impacts of benthic Fe supply on surface primary production.

Accurately measuring the release of this dissolved iron is not easy; so far our best estimates of Fe flux come from *in situ* incubation chambers designed to trap and record the amount of iron being released from the sea floor over time. Such studies have measured the relationship between the rate of organic matter decomposition in the sediments and the amount of iron released from the sediment (dashed line in Figure 3(b)). To date, this empirical relationship has endured with only modest refinements, and provides our best means of estimating the amount of iron entering the ocean from marine sediments globally – by taking what we know about iron fluxes in particular areas and scaling up using what we know about the distribution of organic matter and oxygen throughout the oceans. A potential flaw in this approach, however, is that it cannot account for any mechanisms of iron release from sediments that do not share this relationship with organic carbon decomposition.

Fe dissolves from sediment in different ways

We are now learning that there is more than one way iron can be released to the ocean from rocks and minerals, and the influence of one particular suite of mechanisms is being seen on a large scale. What has become the classical view of iron release from marine sediments coupled to organic matter decomposition (outlined above) is only part of the story. Measurements of the relative abundances of the different isotopes of iron are shedding light on another, distinctly non-reductive, process, that is releasing dissolved iron into pore waters, overlying waters and the open ocean.

Iron (Fe) has four naturally occurring stable isotopes: atoms with small variations in their atomic mass but otherwise identical chemical properties. Around 92% of naturally occurring Fe is ^{56}Fe; the three other isotopes are ^{57}Fe (~2%), ^{54}Fe (~6%) and ^{58}Fe (0.3%). We describe Fe with a low ^{56}Fe/^{54}Fe ratio relative to a standard reference material (which is isotopically similar to average crustal rock) as isotopically 'light', and iron with a relatively high ^{56}Fe/^{54}Fe ratio as isotopically 'heavy'. These tiny variations in isotopic ratio are measured

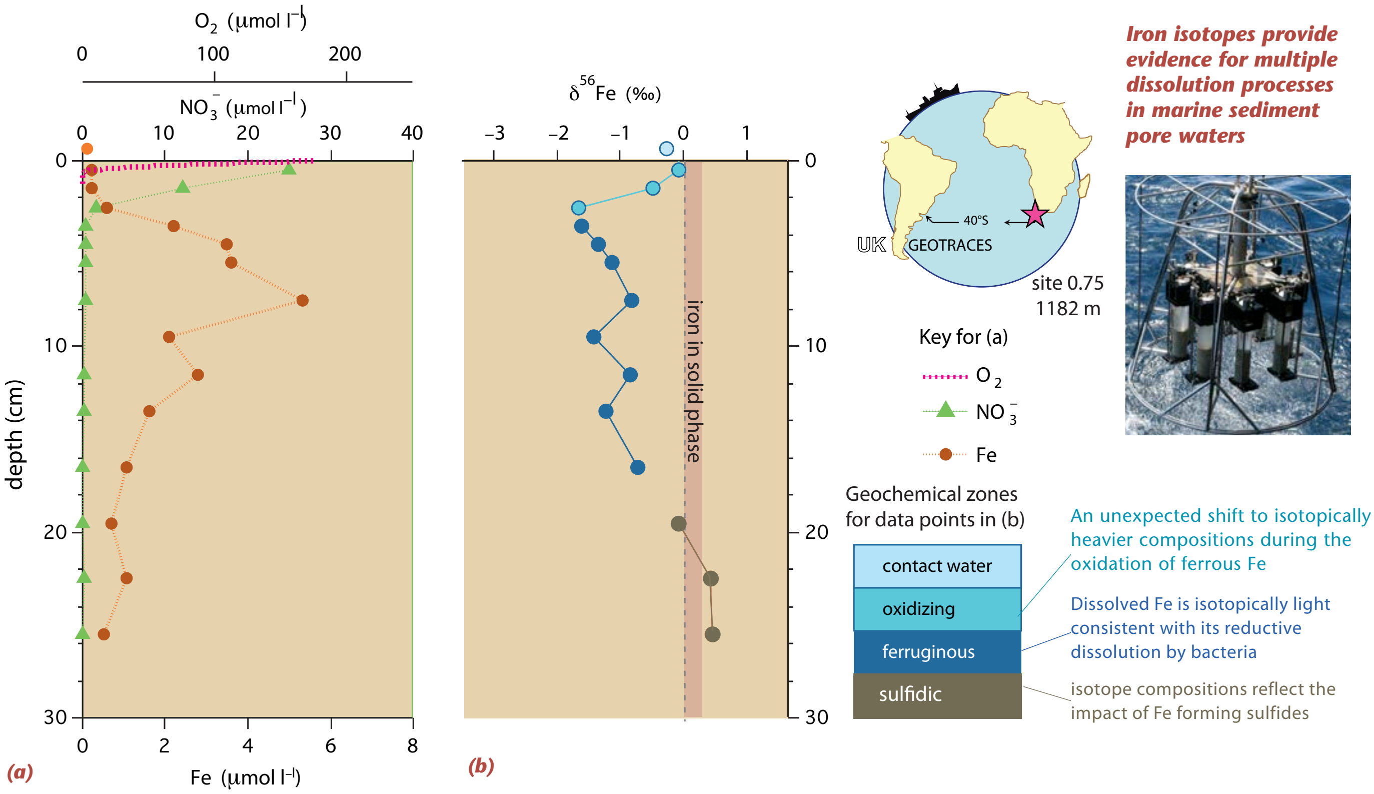


Figure 4 ***(a)*** *Concentrations of dissolved oxygen (O_2), dissolved nitrate (NO_3^-) and dissolved iron (Fe) in sediment pore water and immediately overlying seawater. Dissolved O_2 drops to zero within 1 cm of the surface and dissolved NO_3^- within 3–4 cm, as they are used up by bacteria during the decomposition of organic matter. Dissolved Fe concentration peaks in a zone where it is enriched in the pore water by its microbial reduction and dissolution from ferric minerals. The concentration of Fe decreases from its subsurface maxima as it diffuses towards the surface, where oxidation reactions with O_2 and NO_3^- re-form and precipitate solid ferric Fe. Iron also diffuses downward from its maxima and meets 'sulfidic' conditions that precipitate Fe-sufide minerals (e.g. pyrite).* ***(b)*** *The isotopic composition of dissolved Fe (δ^{56}Fe) in pore water corresponding to the data in (a). Data points are colour-coded according to the geochemical conditions in the pore waters: a ferruginous zone where microbial reduction of ferric minerals occurs to form dissolved ferrous Fe; a sulfidic zone where dissolved ferrous iron is trapped as solid Fe-sulfide minerals; and an oxidizing zone, where dissolved ferrous Fe is trapped as solid ferric Fe minerals. A shift to isotopically heavier Fe during oxidation of ferrous Fe is unexpected, and is strong evidence for a secondary process, not involving reduction, supplying dissolved Fe that is isotopically heavy and similar to the bulk sedimentary material.* ***Inset photo*** *The Bowers–Connelly 'megacorer' used to collect intact sediment samples from the seawater/sediment interface at 1182 m, during a 2010 GEOTRACES cruise. (From Homoky* et al. *(2013); see Further Reading)*

in units of per mil (‰); more negative values are isotopically 'lighter' and more positive values are isotopically 'heavier'. Early measurements of iron isotopes revealed the reduction of ferric iron by microbes produces isotopically lighter ferrous iron; a phenomenon that also occurs in marine sediment pore waters, where dissolved (and in this case ferrous) iron produced by reductive dissolution is isotopically lighter than the ferric minerals it originates from. *In situ* flux chamber observations have verified these results too, and recorded light iron diffusing out of the sea floor along the low-oxygen coastlines of California and Oregon. However, we have now expanded observations of iron isotopes in sediment pore water to deeper sites with lower carbon content, and to sediments comprised of younger and more easily weathered basalt minerals, where we are beginning to see very different results from more oxidising zones.

Contrary to our expectations, the isotopic composition of residual dissolved iron in the thin oxidising layer of surface sediments more closely reflects the isotopic composition of the sediments it came from (Figure 4(b)), rather than the very light isotope values that are understood to form by the oxidation and precipitation of dissolved ferrous iron. What is more, we've found that dissolved iron with similar isotopic compositions often contains iron colloids* – suspended solids, just a few nanometres in size.

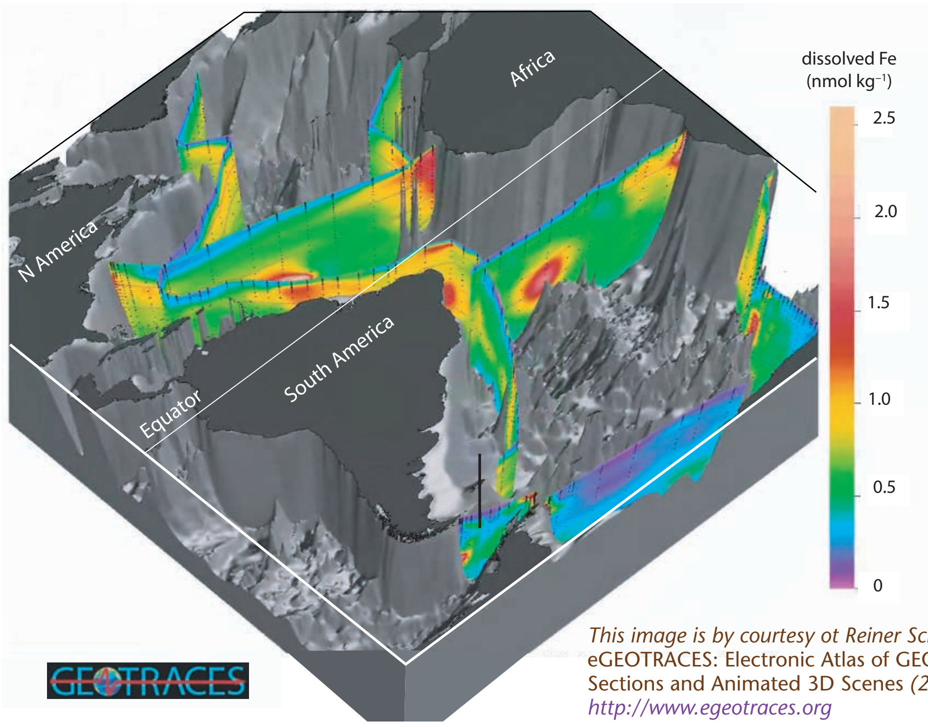
*Colloidal particles are neither truly dissolved (as they have a surface boundary) nor large enough to be influenced by gravitational settling. They are considered to occupy a size range from simple molecule to small particle (~0.003 to 1 µm). Colloids account for about half of the dissolved Fe measured in the ocean, but their precise composition and origin are largely unknown.

The processes that form these Fe colloids in pore water are not clearly understood, but we do know that sea-floor weathering can alter rocks and minerals to form colloidal sizes of iron-containing clays and iron oxyhroxides (types of rust) without the need for the chemical reduction, and corresponding isotope fractionation, of iron. Complexation of iron with organic compounds may also prove to be significant in aiding the release and stabilisation of dissolved iron from sediments. What *is* clear, is that non-reductive dissolution mechanisms for iron are likely to be decoupled from the reductive dissolution relationship to organic carbon that is used to derive global budgets of iron supply to the ocean.

We do not yet have sufficient understanding of the mechanisms involved, nor the empirical relationships needed, to interpret the global contribution of iron released to the ocean through non-reductive sediment dissolution. However, dissolved iron isotopes in seawater are providing a measure of the potential impact of this newly discovered source. With the advent of GEOTRACES, an internationally coordinated effort to map the distributions of trace elements in the global ocean, novel opportunities are emerging to evaluate the amount of iron entering the ocean from different sources, and non-reductive dissolution is seemingly responsible for much of the iron observed.

Figure 5 *A vertically exaggerated 3-dimensional view of dissolved iron concentrations in the Atlantic Ocean and the Atlantic sector of the Southern Ocean. Inputs from various sources can clearly be seen, notably from Saharan dust off north-west Africa, from the Amazon river plume off north-east South America, from hydrothermal vents on the Mid-Atlantic Ridge, and from margin sediment dissolution off south-west Africa and the north-east United States (the latter reflecting non-reductive dissolution processes). Low dissolved iron concentrations can be seen in open ocean waters, reflecting the uptake of iron by phytoplankton, and the broad contrast in dissolved iron concentrations between Atlantic and Southern Ocean regions is symptomatic of the widespread Fe-limitation to phytoplankton growth in the Southern Ocean.*

GEOTRACES data provide a completely unprecedented map of iron in the ocean but the processes controlling the availability of iron in different regions are still unclear



Data contributed by: Andrew Bowie, Ken Bruland, Tim Conway, Hein de Baar, Fanny Chever, Seth John, Maarten Klunder, Patrick Laan, Francois Lacan, Rob Middag, Abigail Noble, Mich Rijkenberg, Mak Saito, Deraldine Sarthou, Peter Sedwick and Jingfeng Wu

This image is by courtesy ot Reiner Schlitzer, eGEOTRACES: Electronic Atlas of GEOTRACES Sections and Animated 3D Scenes (2015) http://www.egeotraces.org

New perspectives on sediment dissolution in the ocean

Through the combined effort of thirty-five nations, GEOTRACES is changing the face of ocean science and mapping the distributions of trace elements including, where relevant, the distributions of their isotopes, in the global ocean (Figure 5). Thanks to analytical developments, refinements in sampling protocol and intercalibrations between laboratories, precise and detailed maps of ocean trace element composition of seawater are emerging for the very first time. The Atlantic Ocean has been the focus of two UK-led expeditions that intersect with efforts led by American, Dutch, French and German researchers. In a transect spanning the width of the North Atlantic Ocean (cf. Figure 5), distinct mechanisms of sediment dissolution are now evident in the isotopic composition of iron in seawater.

The proportion of dissolved iron released from sea-floor sediments to the North Atlantic Ocean via reductive and non-reductive dissolution mechanisms has been quantified by calculating the fractions required from different sources to explain the observed isotopic compositions of dissolve iron in the water column. While Saharan dust dominates the input of iron overall in the subtropical North Atlantic, iron isotopes reveal that non-reductive dissolution from the sea floor can account for up to 100% of the dissolved Fe that extends from the western margin of the United States (cf. Figure 5). These findings support an earlier proposition of non-reductive dissolution from the equatorial Pacific, where isotopes of both iron and neodymium along a section between Papua New Guinea and the central Pacific indicate that non-reductive dissolution from margin sediments supplies iron to seawater thousands of miles from land in the upper 1000 m of the central Pacific Ocean.

Even far from their source, iron isotopes provide clues to the origin of iron in seawater, which help us evaluate the relative impact of different supply processes in the ocean. However, we still do not know the rates of iron supply to the ocean that these processes sustain, or how accurately existing rate measurements at the sediment–water interface capture the true extent to which dissolved Fe escapes bottom waters or is returned to the sediments (e.g. by scavenging* processes). A measure of iron release that can reduce these uncertainties is needed to more accurately incorporate the iron cycle into coupled ocean–atmosphere models of Earth's climate. These issues were foci for a discussion meeting of the Royal Society held in December 2015; they are targets for NERC's Shelf Seas Biogeochemistry Programme, and they motivate many aspects of my current research.

*Scavenging refers to the removal from the water column of dissolved and colloidal matter by particulate matter: dissolved metal ions and complexes may be attracted by electrochemical charges onto the surface of suspended biological or mineral particles. Some dissolved trace elements are susceptible to scavenging (e.g. Th), while others (e.g. Ra) are not. Dissolved iron is sensitive to scavenging, while particulate iron oxyhydroxide minerals are also effective at scavenging other dissolved trace elements. Because particles are prone to gravitational settling, scavenging ultimately results in dissolved trace elements being incorporated into sea-bed sediments.

Towards a new measure of element fluxes from the sea floor

A grand challenge for the determination of benthic trace-element fluxes is to capture, accurately, the influence of multiple processes that may each individually serve to moderate the net fluxes from the sea floor. A good example of equipment designed to achieve this is *in situ* benthic chambers, which should provide a advantage over diffusive pore-water flux calculations because they also record the influence of burrowing animals that 'pump' solutes between pore waters and the ocean. However, by trapping overlying bottom waters, *in situ* chambers also perturb oxygen conditions and risk altering animal activity and ambient oxidation rates, and so introduce new artefacts for consideration. Furthermore, neither pore waters nor *in situ* chambers adequately reflect the influence of particle suspensions in the benthic boundary layer. In this respect, no method could be without inherent challenges. Nonetheless, there are opportunities to develop new approaches which could capture a greater number of important moderating effects on trace metal fluxes over spatial scales arguably better suited to comparison with ocean transect data, such as produced by the GEOTRACES programme. The combined use of radioisotope tracers and micronutrient metal distributions across the benthic boundary layer is one such approach that could break new ground.

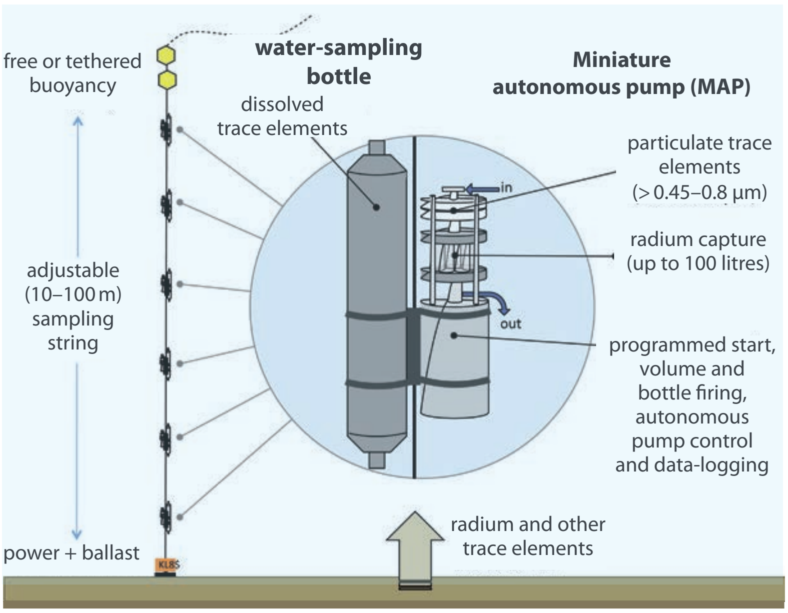
The radioactive element radium (Ra) offers a powerful toolkit to chemical oceanographers, because it is essentially soluble and chemically inert in the ocean, with four of its naturally occurring isotopes having half-lives between 3.6 days and 1600 years. The predictable decay rates of these radium isotopes means that their activities can be used as natural clocks to derive rates of dispersion over different time- and space-scales in the ocean. The elements uranium and thorium are largely insoluble in the ocean, but are plentiful in continental rocks and minerals; the radioactive decay of uranium and thorium produces the shortest lived isotopes of radium (^{223}Ra and ^{224}Ra, with half-lives of 11.2 and 3.6 days, respectively), which by contrast are highly soluble in seawater and so may be particularly well suited to use as radioisotope tracers in the water column to measure the integrated rates of iron release across the benthic boundary layer.

Figure 6 *The author preparing Miniature Autonomous Pumps (MAPs) for their first sea-going trial during NERC's Shelf Seas Biogeochemistry Programme aboard the RRS* Discovery. *MAPs pumped measured volumes of ocean bottom waters through in-line particle filtration and radioisotope sampling apparatus with a view to measuring vertical gradients of chemical properties that could be used to derive fluxes across the benthic boundary layer. The MAPs were designed and built in collaboration with NOCS in Southampton.*

(Photo by courtesy of Torben Stichel)

Figure 7 *A future deployment scenario for MAPs to measure the benthic flux of trace elements across the benthic boundary layer. A mooring string carries MAPs powered in series across the benthic boundary layer. Water-sampling bottles are closed simultaneously prior to pumping via pre-programmed commands stored in MAP hardware. Together, water bottles and MAPs provide a highly depth-resolved gradient of dissolved and particulate trace elements and radioisotopes near the sea bed. Dissolved trace element flux calculations will use constraints on effective vertical diffusivity derived from ^{224}Ra and ^{223}Ra decay curves.*

Data collected by carefully located miniature pumps will help us determine fluxes of trace elements between the sea bed and the ocean



The benthic boundary layer is a physically distinct 10–100 m-thick turbulent layer of ocean water overlying the sea floor, which is largely inaccessible to our routine water-sampling methods. Mixing in the benthic boundary layer is expected to smooth out small-scale variability in chemical fluxes over its region of influence, but also to lead to dynamic interactions between solutes and particles that will mediate chemical fluxes from sediments to the interior ocean. By observing chemical gradients across the benthic boundary layer, a new measure of benthic trace element fluxes may be achieved, which would reflect additions to seawater (reductive and non-reductive dissolution), removals from seawater (e.g. oxidation, scavenging) and their combined influences on the isotopic composition of trace elements like iron.

To this end, engineers at the National Oceanography Centre in Southampton have collaborated in the design and development of Miniature Autonomous Pumps (MAPs, Figure 6), which are capable of stripping the short-lived radio-isotopes of dissolved radium out of large water volumes in the particle-rich benthic boundary layer. The pumps benefit from 'trace-metal clean' materials, are operational down to 5000 m, and collect suspended particles as small as 0.45 μm for various types of analyses. Prototype MAPs were successfully field-tested during NERC's Shelf-Seas Biogeochemistry Programme in 2015. Future efforts will focus on ideal deployment scenarios for collecting simultaneous dissolved trace metal samples needed to calculate their fluxes (Figure 7).

Conclusion

Over the past century we have discovered and measured the importance of iron for phytoplankton and the ocean's atmospherically coupled carbon cycle. Much of the knowledge we have acquired over this time can be attributed to analytical advances and carefully planned field observations and experiments which have avoided contamination. Of all the micronutrient trace elements, iron is the one whose cycle in the ocean has received, and continues to receive, the greatest attention, yet the quantification of its supply still presents a major challenge. To date, pore water and *in situ* studies have provided the most relied-upon evidence to interpret the impact of sediments on surface ocean productivity. In comparison with what we know about iron, our knowledge of the mechanisms and rates governing the cycles of the other bio-essential trace elements at the sea floor is poorer still.

However, new data emerging from the GEOTRACES Programme mark a new era for ocean science; the oceanic distributions of many trace elements and isotopes are being seen for the very first time. A newly informed effort to study the underlying processes controlling these distributions is now needed, so that we can accurately simulate their cycles and impacts in ocean biogeochemical models. The UK Shelf Seas Biogeochemistry Programme is one such initiative aiming to deepen our understanding of benthic exchange process in the wake of GEOTRACES. Now it is opportune to replicate our focus on iron across diverse regions of the sediment–water boundary; to innovate where necessary to make quantifications of chemical exchange processes; and to consider all the chemical ingredients of seawater needed for life in the ocean. This research should discover the empirical bases needed to build the predictive power of trace element cycles in ocean biogeochemical models. Thereby, it will inform our view of the past and future ocean, and help us make wise decisions concerning its stewardship.

Related links

https://www.earth.ox.ac.uk/people/will-homoky/
https://twitter.com/willhomoky www.geotraces.org
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Acknowledgements

I am indebted to my former supervisors, collaborators and mentors who have collectively been a source of ideas, data, training, critique, encouragement and opportunity for this research; notably, Rachel Mills, Peter Statham, and Gary Fones; Silke Severmann, Jim McManus and Will Berelson; Seth John and Tim Conway; Amber Annette, Walter Giebert, Alan Hseih and Gideon Henderson. I'd also like to thank all who have supported in the collection and analysis of samples, particularly Kevin Saw and his team at NOC, Southampton, who have co-designed and engineered the prototype MAPs; and the UK Natural Environment Research Council who have generously supported the development of MAPs and the preparation of this article through the provision of an Independent Research Fellowship (NE/K009532/1).

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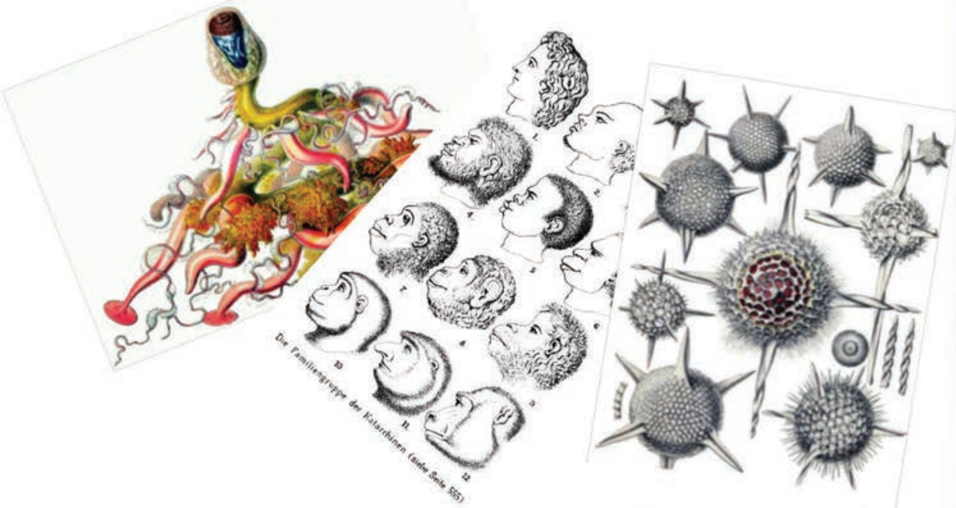
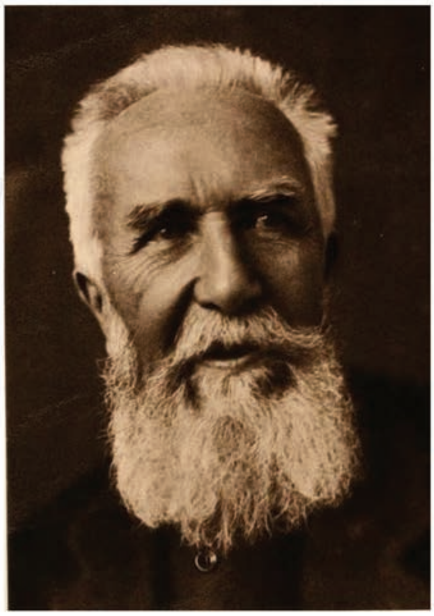
Visionary, heretic, genius or charlatan?

The remarkable Ernst Haeckel





Dylan Evans, Edith Gruber and Peter Williams

Polymath, fraudster, philosopher, eugenicist, revolutionary, proto-Nazi, anti-Semite, genius, visionary … this is only a short list of the many epithets attributed to Ernst Haeckel. He was, without doubt, a driven man whose impact on contemporary and modern scientific thinking, as well as on the way that we now see the world, is at least as significant as that of many great scholars through time including, one may argue, his close friend and collaborator Charles Darwin.

Haeckel was an eminent scientist, a converted and militant Darwinist, and an incredibly active and articulate advocate of the public understanding of science. Haeckel's promotion of Darwin's theory of evolution was conducted with a fierceness that eclipsed even that of his British counterpart Thomas Huxley – 'Darwin's bulldog'. Haeckel is regarded as having a greater impact on evolutionary thought at the time in Europe than Darwin did through his own writings.

Haeckel made major contributions to a number of areas in biology, the arts, and also contemporary philosophy. Many terms that are now in common use, for example Caucasian, ecology, metazoan, phylum and stem cell, were coined by Haeckel. Crucially important concepts, such as the separate functions of the cytoplasm and the nucleus in the cell, the proposal that embryos passed through the evolutionary stages of the species ('ontogeny recapitulates phylogeny') also came from him. He brought forward the concept of the protists and gave the group comparable stature to the Plant and Animal Kingdoms. In many respects, although Haeckel's words and concepts are in current use, he is probably better remembered for his art than his science, even amongst scientists. In science, Haeckel is unfortunately remembered by some, and we suggest unjustly, for the little he got wrong, rather than the significant amount he got right, a privilege we normally reserve for politicians.

Whatever you choose to make of Ernst Haeckel, it is difficult, in our opinion, to quarrel with our description of him as 'remarkable'. His output, delivery, and the concepts he communicated so well, led him into a host of controversies in several independent disciplines. He was without doubt provocative, and not in the least inclined to hesitate; to this day his work and writing attracts fevered debate.

Here we examine his career, his thoughts, and their impact. We present his art, and his belief in moving boundaries and ideas beyond what is supported by direct evidence. We discuss the way in which he helped to mould the scientific and philosophical landscapes of his time through his contributions to research and to the development of ideas that are still considered fundamental.

Haeckel was a man of his time and he lived through a period of arguably unparalleled advances in the fundamental aspects of biology. Jena, where he held his professorship, was at that time the epicentre of philosophical debate in Germany. We, like others who have studied Haeckel's scientific and other achievements, are of the view that they have to be considered in the context of the scientific and philosophical developments and debates of his times. Accordingly we start by discussing these, before picking up his life history.

The mid 1800s was a period of rapid advances in the understanding of the underlying principles in biology and ecology. Arguably these advances in fundamental concepts in biology in this era were probably significantly greater than those of the past half-century or so. There was of course far greater scope at that time. The modernisation of German universities in the early 1800s gave rise to a breed of professional research scientists who were responsible for major changes in our understanding of the natural sciences. A notable exception to the then German dominance in biology was the development of the theory of evolution by natural selection of Darwin and Wallace. They were the archetypal 'amateur' Victorian British scientists; amateur, however, only in that they were not embedded in an academic institution or paid a salary for their work. Further, and relevant to the ensuing discussion, the links between science and philosophy appear to have been much closer in Germany than in English-speaking countries, and so as a consequence, was the discourse and communication between the two fields of study. Germany's great poet Johann Wolfgang von Goethe, for example, straddled the philosophical and scientific camps. He discovered the intermaxillary bone, known also as the Goethe bone in the human embryo; its absence in adults was then thought to distinguish man from the apes. He also put forward the idea that the skull was constructed from modified vertebrae.

Johann Wolfgang von Goethe, aged 30

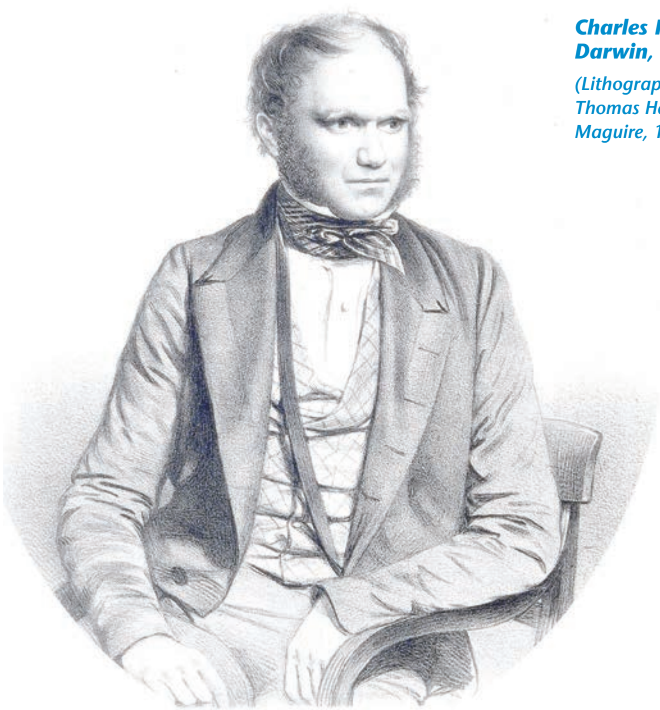
(Etching by W. Unger after G.O. May, 1779)

A major German scientific advance of the time was the development of cell theory in 1838 by Matthias Schleiden and Theodor Schwann. They put forward the idea that the basic building block of organisms and tissues, both in animals and plants, was the cell – now something we would not give a second thought to, but at the time a quite radical notion. The idea brought with it the question of whether a multicellular organism was truly an individual, or rather a collection of individuals – a conundrum particularly acute in the case of colonial animals such as the siphonophores (e.g. Portuguese Man O'War), a group of marine animals that fascinated Haeckel.

Haeckel's 'props' in a Jena theatre that he rented for a public lecture on 'The problem of Humanity and Linné's Master Animals' in 1907

More or less concurrent was the development of the concept of protoplasm. The term was first used in 1846 by Hugo von Mohl, who described a 'tough, slimy, granular, semi-fluid' in living cells. Huxley felt that it was no less than the 'physical basis of life'. In essence, and accepted now, it is the living contents of a cell, itself surrounded by a plasma membrane. Both ideas are absolutely fundamental to our understanding of life.

Haeckel spent the major part of his scientific career in Jena where he was embedded in a lively intellectual environment, in many respects a complete contrast to Darwin who laboured very much in isolation. While Darwin pursued his own work with dogged determination against the will of the Church in Britain, Haeckel did the very same in Germany and throughout Europe, often staging elaborate touring shows (*see photo above*) in which he presented arguments that were then considered to be heretical (and by some still are).



Charles Robert Darwin, aged 40

(Lithograph by Thomas Herbert Maguire, 1849)

Examination of the significant correspondence between Haeckel and Darwin provides evidence that these men became close friends, who clearly and deeply understood both their own cultural landscape and that of each other. It may have been this very understanding and mutual respect that allowed the arguments about evolution to flourish in both Britain and Germany, as both men used the other's position as a lever, or perhaps even as a convenient excuse to introduce ideas that they knew to be controversial and difficult for their own society to accept. Either way, the relationship between the two appears to have accelerated the discussion to the point of wide recognition in both countries and beyond.

In Germany the morphologist movement was active in describing and defining the process of change in biology. The morphologists included notable German scholars such as Goethe and Alexander von Humboldt, and of course, Haeckel. They believed that species form was not fixed, but that it changed towards some predetermined form over time. This concept, in the scientific literature, is referred to as transcendentalism. At that time, this new and radical ideology posed a number of questions, the most significant of which were:

How was the eventual form coded?

What process drove the change?

In what form did the process start?

These questions were hotly debated and drew on occasions sharp dividing lines between German scientists, and also brought along understandable tensions between their scientific promoters and the established Church. The morphologists' view that the eventual end of the development would be some perfect form appeared to be acceptable at some level to the Church, providing the evolution of mankind was kept out of the discussion! The main issue was how or when the design originated. The widely accepted view at the time was that the blueprint was coded into the species at the time of creation. In many respects, if you accept the act of creation by some infinitely wise deity, as did the overwhelming majority of scientists of the era, then this perhaps is a perfectly reasonable explanation. Some, however, were not prepared to accept the idea that life began at the whim of a divine Creator. Huxley and Haeckel were particularly vocal members of this group. They thought, or were at least moving towards thinking, that the initial formation of living material was a purely chemical event. Not only was such a notion sharply at variance with the basic tenets of the western religions, it also ran contrary to the longstanding vitalistic theory. Vitalism took on a number of guises; most relevant here was the then prevailing notion that living organisms were fundamentally different from non-living entities because some mystical vital spark (*élan vital*) was breathed into them in the act of their creation. Importantly, this extended to their organic products, so that the synthesis of organic compounds from inorganic constituents was, as a consequence, impossible. The accidental synthesis of urea in 1828 from wholly inorganic reactants by the German chemist Friedrich Wöhler in principle repudiated this, although it seems to have had very limited impact at the time. However, the point was made and so, if required, provided a basis with which to counter the vitalistic perception that life relied upon the act of divine creation. Removing the need for the divine creation of species brought with it a fundamental problem for the morphologists: how did the different codes for the great variety of proposed perfect forms for extant species arise?

Then, indirectly, into this ferment, in the summer of 1860, a bombshell arrived from quiet rural Kent: Darwin's *Origin of Species*, published the previous year, was translated into German by Heinrich Bronn. It basically and succinctly provided answers to two of the three questions that the morphologists' theory gave rise to, namely:

The process that drove change was the species' response to an ever-changing environment.

There was no code for a final form, the process itself defined what lived and thrived and what was 'fit' (literally and figuratively) for contemporary prevailing circumstance.

However, it did not answer the third and contentious question: In what form did the process start? According to Robert Richards, Bronn in his translation dropped Darwin's sentence 'Light will be thrown on the origin of man and his history'. Bronn, like others in the German scientific community, was not wholly convinced by Darwin's thesis and the debate rumbled on in Germany, as elsewhere, through the remainder of the century. Haeckel however grasped the concept and ran with it with the force of a rugby second-row forward.

A brief history of the man

Haeckel was born in 1834 in Potsdam (then in Prussia) to an upper middle class family, and christened Ernst Heinrich Philipp August Haeckel. His father was a jurist who served as privy councillor to the Prussian Court. His parents had ambitions for him to take up a medical career, and in 1852 he was sent to study in Würzburg, the Medical Faculty at the University being the pre-eminent in Germany at that time. There he was taught by two influential educators, Albert von Kölliker and Rudolf Virchow, who both communicated careful observation as a mode of learning, rather than absorbing by rote, a practice that was all too common in that era. Some decades later, Haeckel fell out with Virchow over the latter's concerns surrounding the dangers of teaching evolution to the 'untutored' mind. Haeckel strongly challenged this view and argued for the teaching of evolution to be introduced into the lower school curriculum – his British counterpart Huxley was involved in much the same discussion. The debate over the teaching of creationism and evolution still rages – *plus ça change, plus c'est la même chose*.

Although Haeckel was inspired by his teachers he had no wish to become a physician, and much of his spare time during his undergraduate years was spent reading the works of Kant and Goethe, leaders in the fevered German philosophical landscape of the time. He was also drawn by the accounts of the travels of Alexander von Humboldt and Darwin, and his great ambition became to follow their example. In 1856, after a gruelling part of his medical course, Ernst took off to the French Riviera where he languished in an idyllic world, only to later be brought back to Berlin, and the reality of medical studies, by a concerned father. Haeckel duly completed his medical studies in March 1857. He planned to begin a study of science in Berlin under Johannes Müller, but Müller's death meant a change of plan, and he instead moved to Jena, where Karl Gegenbaur was the Professor of Anatomy. Gegenbaur became a great inspiration to Haeckel, and also a life-long and stalwart friend. Late in 1858, he invited Haeckel to join him on fieldwork in Naples. This, after a false start, was a turning point in his career. Gegenbaur had to withdraw from the field trip, so Haeckel set off alone and in the spring of 1859 set himself up in Naples where he received benthic samples from local fishermen. However, he felt that he was making no progress and after a couple of months abandoned the work and departed to the nearby island of Ischia. There he met Herman Allmers, a poet and painter, and through the summer the two became soul mates, enjoying a Bohemian lifestyle, eventually moving to Messina, via Capri (*see above right*).

Allmers had to depart in mid-October and so Haeckel turned back to his original purpose, that of collecting, categorising and cataloguing marine specimens. Here came the breakthrough which Haeckel seized with both hands. In November, the samples began to contain radiolarians: this became the pivotal moment that cast the die for his future career. Over the next few months he described some 100 new species of radiolarians, and the following April he returned to Jena with 12 crates of samples and began preparing to work on the collection for his Habilitation (the German licence to take on and teach students at a university). He successfully presented the work in 1861, in Latin.

While Haeckel is known to have read Darwin's *Origin of Species*, he apparently made no reference to it in this initial work. Robert Richards, Haeckel's biographer, surmises that this may reflect caution, unusual in Haeckel's case, as Darwin's theory was then probably still regarded with scepticism by influential scientists in the German community. The following year Haeckel published the two-volume *Die Radiolarien*, and in this he incorporated Darwin's ideas on evolution into the discussions. It was some 672 pages in length with 35 beautiful and skilfully drawn images, engraved onto copper plates for printing. Richards, in his biography of Haeckel (see Further reading), describes how he made careful measurements and then made models using potatoes with rods skewered into them so he could get the correct perspective for the final drawing.

Haeckel's watercolour of Capri, painted in 1859

Haeckel's science

Haeckel's total output was colossal, as diverse as it was extensive. Four works stand out as milestones: *Natürliche Schöpfungsgeschichte* (1868), three of the four Volumes he prepared for the reports of the HMS *Challenger* Expedition (1882–88), *Kunstformen der Natur* (published as a series of lithographs over the period 1899 to 1904) and *Die Welträthsel* (1899), all profoundly different in nature and content. Following his Habilitation in 1861 for his work on radiolarians, Haeckel's scientific career can be considered as three distinct phases.

1866–1879: Intensive output of major texts covering a wide range of topics including, and tying together, morphology, evolution and embryology.

1879–1889: Taxonomic work, notably the analysis of samples from the *Challenger* Expedition.

1899 onwards: Work of generally wider public interest.

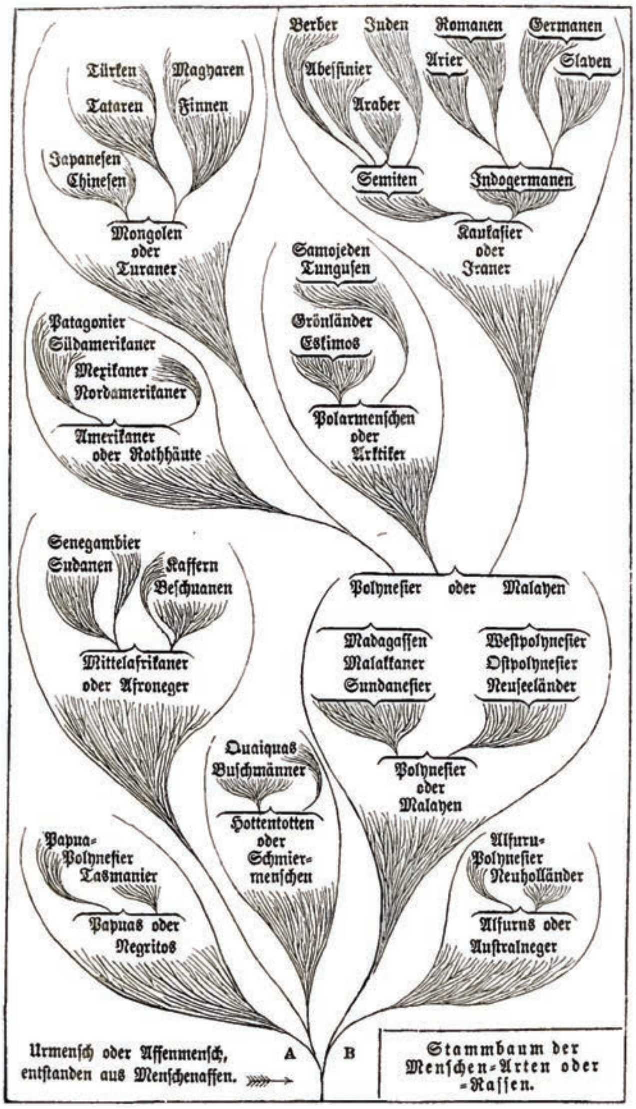
Haeckel's original sketch of the radiolarian* Rhizosphaera trigonacantha*, which appears in his 1862 publication* Der Radiolarien*, as part of Plate 25

1866 to 1879

Natürliche Schöpfungsgeschichte (*The Natural History of Creation*) had been preceded in 1866 by *Generelle Morphologie der Organismen*, which was an extensive two-volume text, a shade over 1000 pages long, written in just 12 months following the sudden death of Anna, his young wife. The work was not widely read, and to some extent *Natürliche Schöpfungsgeschichte* was written to remedy this. The book was translated into English as the *History of Creation* (1884), the word 'Natural' being omitted from the title, apparently at the suggestion of the English zoologist Ray Lankester in order 'not to frighten the pious English'. The book dealt with Darwinian and Lamarkian evolutionary theories, among a host of other topics.

Darwin developed his thoughts on the evolutionary mechanism in large part from animal breeding, with some supporting evidence from palaeontology, although that subject was in its infancy during his time. Haeckel added a further strand by introducing evidence from embryology. A major principle that Haeckel brought forward was what he referred to as the Biogenetic Law, better known by the catchphrase 'ontogeny recapitulates phylogeny'. The principle maintains that the embryo progresses through a series of developmental stages similar to that which the species has encountered during its own evolution. Although the validity of the concept continues to be debated, in the broad sense, Haeckel's fundamental point that there are important similarities between different vertebrate embryos is now known to be correct. As we will discuss later, the way Haeckel handled the matter got him, and the concept, into pretty hot water.

Haeckel's stem tree of the nine human races, with their varieties and the ape man at the source
From Natürliche Schöpfungsgeschichte *(1868)*



Natürliche Schöpfungsgeschichte and *Generelle Morphologie der Organismen* are where Haeckel laid down many of the fundamental principles in biology. Many of them stand to this day; for example, separate functions of the nucleus (reproduction) and the cytoplasm (energy generation and storage). Haeckel used phylogenetic trees extensively in portraying his ideas about the courses of evolution. In one, he proposed the separation of living organisms into three major strands, adding an extra one to Linnaeus' original Plant and Animal Kingdoms. The third – which he termed the Protista (*see below left*) – did not gain acceptance at the time, but a hundred years later the broad notion of major groupings of organisms outwith plants and animals has gained general acceptance and the terms Protista and protists are now firmly established in our scientific thinking and vocabulary.

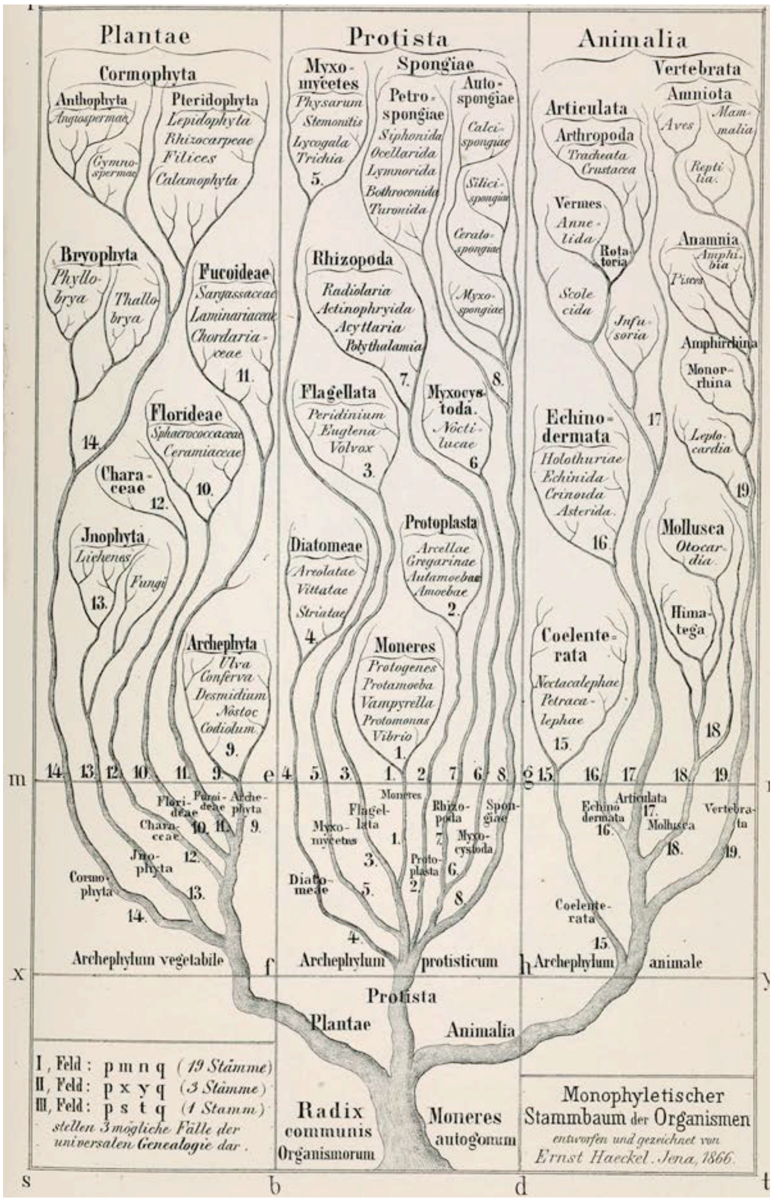
Darwin and Haeckel, along with other scientists of the time, argued passionately for the concept of evolution of species. Inevitably, if this general principle is accepted, one has to confront the problem of evolution in the case of man, clearly a potentially inflammatory issue. However, Haeckel with his longstanding preoccupation with patterns and his somewhat reckless nature, marched into this without much caution. He placed the various races of *Homo sapiens* into the same type of structure that he used so well to define the relationship between other forms of life. In his normal usage of the dendrographic stem tree, the extant species are the twigs at the end of the branches and not intermediates in the evolutionary process. However, his figure (*left*) can be read a number of ways and there is no shortage of critics who saw the diagram as an evolutionary ranking of contemporary races of man.

Haeckel blundered into a further and even more contentious area. Artificial selection of progeny was to a large extent used by Darwin to give insight into natural selection. Haeckel attempted to illustrate this in the case of man by attributing the legendary vigour of the Spartans and the North American Indians to their supposed practice of killing deformed and defective newborns. This in turn led to accusations that Haeckel, and to a lesser extent Darwin, laid down the racist philosophy of the Nazis which gave rise to the holocaust. There are associated claims that Haeckel was profoundly anti-Semitic. Equally strong counter-claims are made of Haeckel's positive attitude towards the Jewish intellectual community. The problem one faces with these controversies is that Haeckel wrote so much, on such diverse matters, and in such a frank style, that it is possible to construct almost any view from his words. However, reading *Die Welträthsel*, which he regarded as a summary of his philosophies (*see later*), one is not left with an impression that it is the writings of a racist.

The three 'sandals'

Haeckel had a lifelong interest in patterns and it links his art and science. While the elasticity of comparing patterns does not always sit comfortably with the more rigid principles of science, it very much appealed to him. There is in embryology and other areas of morphology no fixed image, rather a spectrum of forms, and thus considerable scope for selection and adjustment of proportions and detail that can simplify the telling of the tale. Haeckel operated, apparently comfortably, on this fuzzy boundary. There is a division of opinion as to how often, and to what extent, he could be found, from a scientific standpoint, operating on the wrong side of the boundary. In the first edition of *Natürliche Schöpfungsgeschichte* he was clearly caught where he should not have been. In putting together the arguments in support of his Biogenetic Law he showed images of an early developmental stage – the so called 'sandal' stage – of three vertebrates: the dog, chicken and turtle. The attendant comment in the text ran: 'If you compare the young embryos … you will not be in a position to perceive a difference'. Although the three images were claimed by Haeckel to be from the three quite different vertebrates, they were in fact electrotype copies made from of a single woodcut. It was an outrageous piece of folly as it was clear that it would be spotted, and it was almost immediately by Ludwig Rütimeyer, an anatomist at Basel University. Rütimeyer clearly could not resist observing that indeed you would not be able to discern any difference as they were in fact the same image. In the following edition of *Natürliche Schöpfungsgeschichte* Haeckel replaced the three images with a single image along with the statement that 'It is all the same whether we describe the embryo of the dog, chicken or turtle, or any other of the higher vertebrates. For the embryos ... at the represented stage cannot be distinguished' – not a *mea culpa* by any measure. However, much later, in 1891, he did recognise his folly, which he referred to as 'a highly rash kind of madness'.

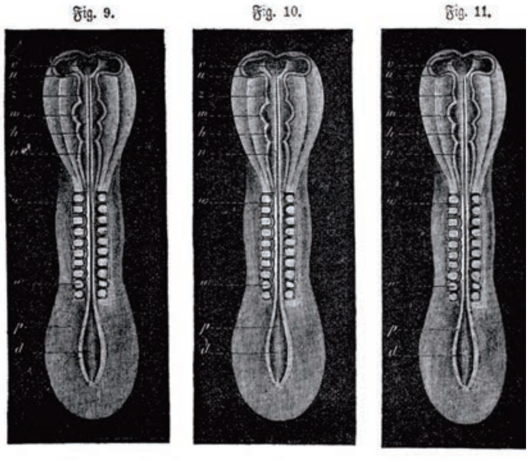
In addition to the 'three sandals', there are other subtle and debateable liberties with embryo images pointed out by scientists who were not prepared to buy into Haeckel's Biogenetic Law, and there was no shortage of them in Germany alone. Foremost amongst his critics was Wilhelm His, Professor of Anatomy and Physiology at the University of Basel. Without doubt His had an agenda. He held a totally different view of the mechanism of embryo development from that portrayed by Haeckel – one that did not fit with the Biogenic Law – so would have been anxious to discredit it. Further, in common with embryologists of the time, His was very protective of his turf, regarding embryology as a closed shop, and certainly intrusions by non-card-carrying gadflies, such as Haeckel, were not to be welcomed.



Haeckel's three-branched phylogenetic tree, with his new branch for Protista

Although Haeckel had made some amendments to his initial claims, and although further research has implied he was probably more right than wrong, the damage was done and accusation of fraud stayed with him and is maintained by some to this day. A remarkable example of efforts to proscribe Haeckel's work in modern times was a bill put forward to the Arkansas legislature in 2001. This proposed that it

Fig. 9. Fig. 10. Fig. 11.



The three 'sandals' from the first edition of **Natürliche Schöpfungsgeschichte** should be illegal for the state or any of its agencies to use state funds to purchase for schools or libraries books that contain false or fraudulent claims. Haeckel appears on the list. In addition there is a piece of folklore, much cycled in the Creationist literature, that in 1874 Haeckel was tried and found guilty of fraud by a court of his peers at Jena University. Richards, in his scholarly biography of Haeckel, reports that there is absolutely no evidence for this, and arguments to the contrary would appear to be pure sophistry.

Following the publication of *Natürliche Schöpfungsgeschichte*, Haeckel continued his study of embryology focussing on the calcareous sponges, and in particular the process of blastula* formation. This research was extensive, and beautifully detailed in a multivolume work – *Die Kalkschwämme*.

*A blastula is a sphere of cells produced during the development of an embryo.

1879 to 1889

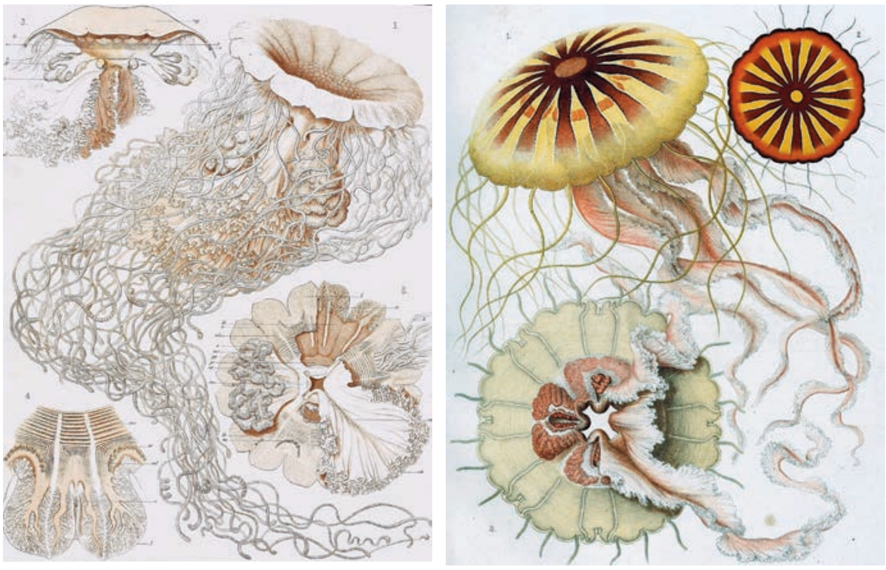
At some point, presumably in the late 1870s, Haeckel was invited to prepare reports for four collections of marine organisms acquired during the 1872–76 *Challenger* Expedition. In addition to his great love, the radiolarians, the collection included samples of deep-sea medusa, a related group – the siphonophores – and a group of sponges, the Keratosa. So far, we have been unable to locate the correspondence or any text covering the details of his brief. The articles appeared in the *Challenger Reports* over the period 1882 to 1889 and constituted the main part of Volume 4, and the complete Volumes 18, 28 and 32; they totalled some 2300 pages and 231 plates. The plates were lithographs prepared from sketches made by Haeckel, and the engraving and subsequent printing were undertaken by Eduard and Adolf Giltsch (father and son). The *Challenger Reports* contain by far the largest, and in many respects the finest, collection of plankton images made by Haeckel. Although a significant number of copies of the *Reports* were printed and distributed, their whereabouts is not well known or documented, and as a consequence the availability of images contained in them has been restricted to a privileged and informed few. In a move to make them more readily available, the images Haeckel drew for the *Reports* have been placed on the internet, and a selection of them, together with a back story, has been published by Prestel under the title *Art Forms from the Abyss* (*for more information, see the box at the end of the article*).

In the work Haeckel prepared for the *Reports*, the radiolarians accounted for nearly 90% of the text and two-thirds of the total set of plates. Haeckel described some 3000 new species of radiolarians. There are question marks over the validity of his classification – in part this is due to his primary separation of the group into four 'legions'; the consequence of this was that it gave rise to an excess of groupings at the lower taxonomic levels. Further, Haeckel was frequently presented with fragments of organisms for which he had to use his experience and imagination to assemble whole organisms – inevitably this gave rise to the creation of false forms. If we put this aside, and judge his images as they stand, the images of radiolarians are surely unique. A frequent comment from non-specialists is that they are unworldly, as indeed they are, for they are of another world – a world we share with them but understand poorly, and for which few have an intuitive feel – the world of the microorganism, quiet, minute, incredibly active and phenomenally powerful. The siphonophores are equally alien in their own way – almost creatures of a Tolkien world – inscrutable and threatening and, as with their cousins the medusa, their good looks mask a very nasty creature endowed with a powerful, and in the case of some medusa (e.g. the box jellyfish), a lethal sting.

1899 onwards

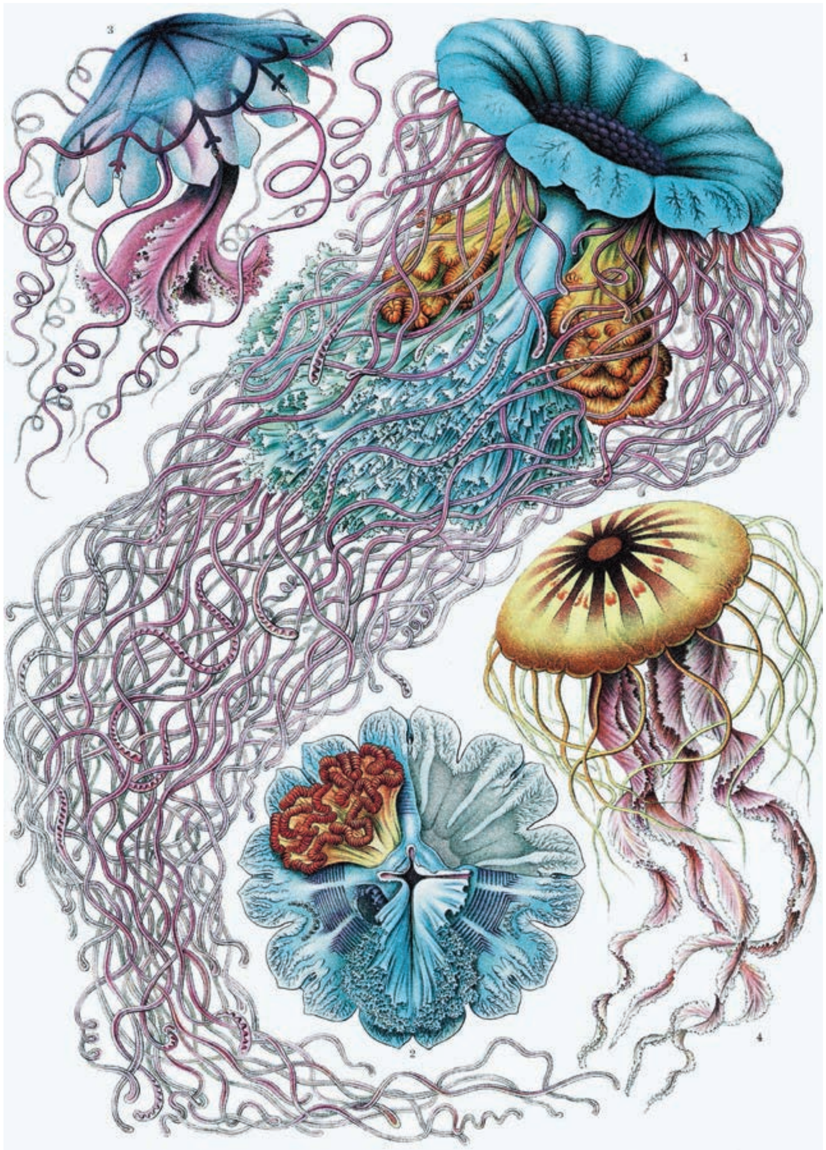
The late 1890s saw Haeckel turn to work of a wider public interest. In 1899, he began the publication of a series of lithographs, collected under the title of *Kunstformen der Natur (Art Forms in Nature)*. This drew extensively on his earlier published taxonomic studies on marine plankton, *Die Radiolarien* (1862) and *Das System der Medusen* (1879); the latter was the first in a series under the collective title *Monographie der Medusen*, a subsequent volume being published in 1881. He also drew upon the illustrations in the three volumes on planktonic groups he had prepared for the *Challenger Reports.* All of these were redrawn and re-assembled for the new publication. There were a number of reasons for this. The originals were created for a taxonomic text, whereas *Kunstformen der Natur* was targeted at a wholly different audience. Further, the limestone slabs from which the original lithographs had been printed would have been recycled, so inevitably new images would have had to be engraved. Haeckel used this as an opportunity to recast and reassemble his designs. Part of the correspondence between Haeckel and Adolf Giltsch has been preserved and it is evident from this that the Giltschs exploited the medium of lithography to its full. Haeckel's sketchbooks have also been preserved, and in the case of Haeckel's iconic image of the medusa *Desmonema* we have a visual record of its evolution *(see opposite*). The top left-hand panel shows the original sketch of *Desmonema* that Haeckel produced for the illustrator, and the adjacent panel shows Eduard Giltsch's published lithograph derived from it, plus his image of the medusa *Polybostrycha* (also named *Chrysaora*). These were published in 1879 as Plates 30 and 31 in *System der Medusen*. A decade later, when Haeckel began the lithographs that were to be gathered together in the series *Kunstformen der Natur*, he combined and redrew these two images (*lower left-hand panel*) as Plate 8 – in this case, the lithograph (*lower right*) was made by Adolf Giltsch. Thus, the final image named *Desmonema* is in fact a composite of two species of medusa.

Initial sketch of Desmonema *from Haeckel's notebook*



Lithographs (Plates 30 and 31) produced by Eduard Giltsch for System der Medusen*, published in 1879*

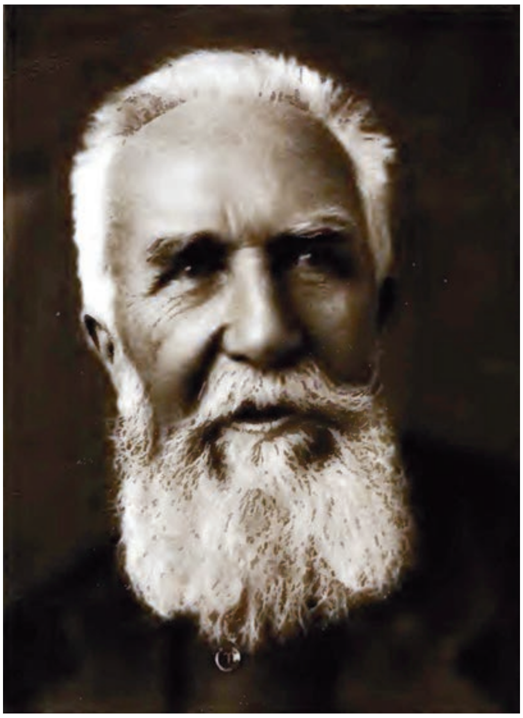
Revised layout by Haeckel combining Plates 30 and 31 for Kunstformen der Natur



Final combined iithograph of Desmonena *produced by Eduard Giltsch for* Kunstformen der Natur

***Evolution of the iconic image of* Desmonena**

The images from *Kunstformen der Natur* have been used in a wide range of designs, from major architectural structures to table napkins. The image collection is still used in art schools as a source book. The full set of images from this work and those from *Die Radiolarien* have been published by Prestel under the titles *Art Forms in Nature* and *Art Forms from the Ocean*. The publication of *Art Forms from the Abyss* (the images produced for the *Challenger Reports*) all but completes the modern facsimiles of Haeckel's plankton images; there remain 40 images published in 1879, which form part of *System der Medusen*.



Photograph of Haeckel by Lichtkunst in Was wir Ernst Haeckel verdanken (What we owe to Ernst Haeckel), a series of essays published in 1914 to celebrate Haeckel's 80th birthday

The same period of Haeckel's life, the turn of the 1800s, saw another significant product, *Die Welträthsel* (published in 1899), again directed at a wider public. The book was a phenomenal and unqualified success: it was published in September and there were two further printings before the year was out. 40 000 copies were sold in the first twelve months alone. The book was translated into English under the title *The Riddle of the Universe*. Even though it is now over 100 years since its first publication, it is still thought-provoking and eminently readable.

As seems inescapable with Haeckel, the book provoked controversy. He starts the book by laying down what he regards as two undisputed and fundamental laws of nature – the Law of Substance and the Law of Evolution – and from these he builds what he refers to as his monist philosophy. In brief, it contends that the cosmos, life included, contains just two basic things – energy and matter – and that there is no non-material component of living things. This, as much of the book, confronts a number of aspects of western religious doctrines head on). One issue he discusses at great length is the concept of the soul, devoting four chapters within the book to it. Haeckel does not deny the existence of the soul, but recasts it in an alternative form. The important distinction between Haeckel's notion and that of the western Church and other cultures, is that Haeckel saw the soul as an anatomical rather than a spiritual feature and one, moreover, that is present in all living organisms. From his materialist standpoint, he would not accept the soul as some immortal spiritual entity; he recasts it as a store of information and learning within the organism. He coins the term psychoplasm for the place where this information was stored in the cell; a notion he invented as there was no direct evidence for its existence. One could take the view that he has simply replaced one mystical entity for another; conversely one might argue that DNA and the genetic code are to some extent a latter-day realisation of this idea. As Mendel's work lay hidden until 1900, Haeckel, like Darwin, could have had no insight of hereditary mechanisms.

In the latter part of the book, Haeckel dwells on the matter of ethics, making the point that our code of ethics arose as a social survival instinct by a process of natural selection, and not from religious texts. A similar case has been made more recently by Richard Dawkins in his book *The God Delusion*. Haeckel berates the Christian Church for its failure to command the cherishing of Nature and its creatures – contrasting it with the teachings of Buddha. He also deplores the lack of guidance and practice of personal cleanliness by the Church of his time. Haeckel notes that man as a social animal survives by managing two duties: care of himself and that of his neighbour. Here Haeckel manages to ruffle a few (British) feathers. He argues that the flaw in the Christian ethic is that it exaggerates the love to be given to your neighbour over that of your kin. He notes the oft preached 'Love your enemies, bless them that curse you ...', which he argues leads on to 'If any man will take away your coat, let him have thy cloak also'; he continues in what he terms the language of modern politics: 'When the pious English take from you simple Germans one after the other your new and valuable colonies in Africa, let them have the rest of your colonies also or, best of all give them Germany itself.' That, not surprisingly, got up the nose of the British establishment, and may explain why although the British papers reported his death, none, as far as we are able to determine, provided an obituary.

Whatever you may make of Haeckel, he was, without the slightest doubt, a complex, outstandingly talented and multifaceted man. This article just scratches the surface of his life and persona. Our feelings are well summed up in the concluding paragraph of Nick Hopwood's scholarly analysis of Haeckel's embryo images which, although dealing with just one aspect of Haeckel's science, makes points we would regard as having a general validity:

> Historical research can hardly expect to bridge the ideological chasm across which the recent controversy over Haeckel's illustrations has been fought out. But as well as unearthing and assessing evidence that all parties should take into account, it can show that if we only go beyond judging Haeckel to learn from the rich history of his plates, there are plenty of more productive questions to debate. Investigating further the fates of his pictures could help recover important dimensions of change since the 1870s. But the legitimacy of scientific images is still negotiated where didactic methods, research agendas, national politics, and science–religion disputes meet in media controversy. Paradoxically, it may be just as Haeckel's embryos are removed from textbooks that they have most to teach.

Further Reading

Copies of essentially the full set of Haeckel's published work can be downloaded from the Biodiversity Heritage Library collection – the following link is to the full catalogue for Haeckel: http://www.biodiversitylibrary.org/search?searchTerm=Ernst+Haeckel#/titles. By far the best account of Haeckel's life and work is the scholarly biography by Robert J. Richards (*The Tragic Sense of Life – Ernst Haeckel and the Struggle over Evolutionary Thought*, 551pp., published by the University of Chicago Press) – we have drawn very heavily upon this account of Haeckel.

Second-hand copies of the English translation of *Die Welträthsel* (*The Riddle of the Universe at the Close of the Nineteenth Century*, to give the book its full title) can be found in the catalogues of various second-hand booksellers, and pdfs can be downloaded from a number of sites. This book gives an insight into Haeckel's views on science, nature and philosophy. An extensive analysis of Haeckel's use and misuse of images, *Haeckel's Embryos: Images, Evolution and Fraud* by Nick Hopwood (392pp., 2015) has been published by the University of Chicago Press. The accusations of Haeckel's racism and anti-semitism, and aspects of Nazism philosophy that can be attributed to him, are described in the book *Haeckel's Monism and the Birth of Fascist Ideology* by David Gasman (482pp., published by Peter Lang, 1998). Critical analyses of Gasman's arguments on Haeckel's purported racism have been made by Richard Richards and are available on the internet: 'Myth 19: That Darwin and Haeckel were complicit in Nazi biology' http://home.uchicago.edu/~rjr6/articles/Myth.pdf, and 'Ernst Haeckel's alleged anti-semitism and contributions to Nazi biology' http://home.uchicago.edu/rjr6/articles/Haeckel--antiSemitism.pdf.

Acknowledgements

We thank the publisher Prestel for permission to use the images of the Jena theatre, Haeckel's painting of Capri and the reproduction of the radiolarian image from Haeckel's sketchbook – all taken from their publication *Visions of Nature* by Olaf Breidback. The images illustrating the evolution of Haeckel's iconic *Desmonema* composite have been taken from Prestel's publication *Art Forms from the Abyss.* The portraits of Goethe and Darwin, and Haeckel's three-branched dendrogram, have been downloaded with permission from the Wellcome Image Library. We are indebted to Professor Chris Richardson for a very thorough reading of the final draft of this article.

Dylan W. Evans gained his Ph.D at the School of Ocean Sciences at Bangor University. He is a Director of Samaki Ecology, and fisheries specialist for two international organisations. His work from Arctic to equatorial latitudes includes establishing marine reserves in Africa, brokering finance for governments, and managing the ecological restoration of remote high-biodiversity islands in the Indian Ocean. He is currently securing finance for CAIS, a Welsh charitable organisation that helps people to find their way and meaningfully fulfil their lives while recovering from addiction.
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Edith Gruber is a lecturer in German at the Coleg Cymraeg Cenedlaethol in the School of Modern Languages and Cultures in Bangor University. Her Ph.D thesis evaluated the role of Albert Schulz as a cultural mediator between Wales and Germany in the 19th century, and investigated the fundamental paradigm shift that occurred in this period, exemplified by the dispute between Schulz and his critic Ernst Susemihl. The paradigm shift resulted in late Romantic gentleman amateur scholars being gradually ousted from the contemporary academic discourse by modernist academic professionals.

Peter J. L. Williams has retired from Bangor University, but not from oceanography. Retirement has enabled him to spend more time on other interests, including designing and building stage sets for a local amateur dramatic society. He has also put together two exhibitions on the influence of plankton illustrations in art and design.

Haeckel's Art Made Available to All

In a move to make Haeckel's beautiful images more readily available, a group of Haeckel enthusiasts from Bangor University have put together high-quality images of the illustrations of medusa, siphonophores and radiolarians which Haeckel drew for the *Challenger Reports*. They can be viewed on the internet at http://haeckel.bangor.ac.uk/. This work was undertaken with the help of a grant from the Challenger Society. Some 55 of the images, along with a back story, have been published by Prestel under the title *Art Forms from the Abyss,* which will sit alongside *Art Forms from the Ocean* and *Art Forms from Nature,* also published by Prestel. For more information about these books see overleaf.

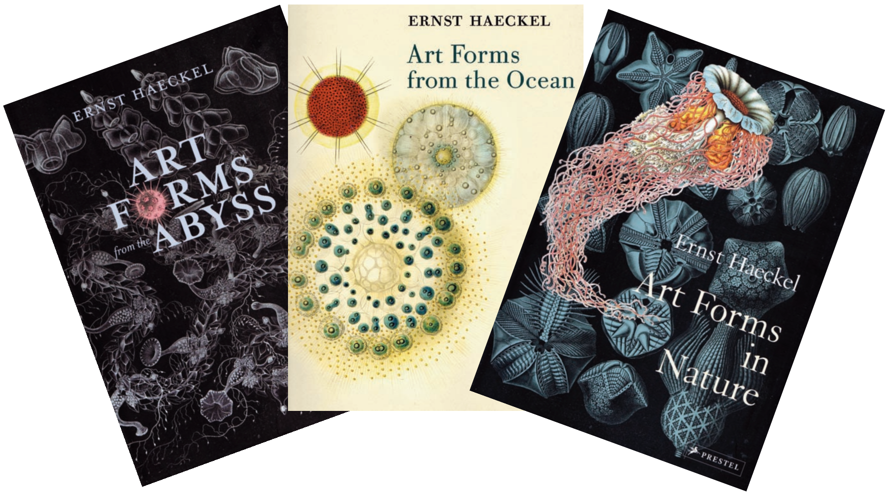
Art in the service of science

If you have been intrigued by the preceding article, you mght like to study Ernst Haeckel's images in more detail. A large proportion of these can be seen in three books published by Prestel. The titles of the books echo that of Haeckel's own *Kunstformen der Natur*, first published in 1899. The 100 plates from this book are found in *Art Forms in Nature*, accompanied by two essays by Olaf Breidbach ('Brief instructions to viewing Haeckel's pictures') and Irenäus Eibl-Eibesfeldt ('The artist in the scientist'). Perhaps the most beautiful of the images reproduced here are of marine animals (many first described by Haeckel himself), although there are also fine drawings of land plants and animals, including ferns, hummingbirds and antelopes.

Within *Art Forms from the Ocean* we find the 35 plates from Haeckel's 1862 publication *Der Radiolarien*. These are introduced by a wide-ranging essay by Olaf Breidbach, introduced by this extract from a letter from one of Haeckel's admirers, Max Schulze:

> *The atlas ... is the loveliest artistic achievement ever in a scientific work on the lower animals. I do not know which I should more admire about it: Nature, which created such diversity and beauty of forms, or the artist's hand which has captured such splendour on paper without tiring in the execution of its hugely difficult task.*

In the section about Haeckel's visit to Italy in 1859–60 we learn of two events which were to have great influence on his work: in Florence, he bought a microscope which, with its water immersion lens, permitted a magnification up to 1000 times; then, while in Naples, his enthusiam for drawing was rekindled when met the artist Hermann Allmers.



Haeckel returned to radiolarians later in his career. 1897 saw the publication of the second part of *Der Radiolarien* (in which he presented a natural history of the organisms). Then, for the *Challenger Reports* (published between 1877 and 1895), he was in charge of the section on radiolarians, as well as those on medusae and siphonophores. It is these three groups that are the subject of *Art Forms from the Abyss*. From all accounts, Haeckel could be rash and impetuous but, as the images in this and the other two books show, alongside his artistic talent he also possessed the ability to tackle extremely long and daunting projects with great care.

Ed.

Art Forms from the Abyss
Text by Peter J. le B. Williams, Dylan W. Evans, David J. Roberts and David N. Thomas (2015)
(ISBN 13: 978-3-7913-8141-1)
see also http://haeckel.bangor.ac.uk/

Art Forms from the Ocean
Text by Olaf Breidbach (2015)
(ISBN 13: 978-3-7913-8141-1)

Art Forms in Nature
Text by Richard P. Hartmann, Olaf Breidbach and Irenäus Eibl-Eibesfeldt (2005)
(ISBN 13: 978-3-7913-1990-2)

All published by Prestel

Book Reviews

Of seasilk, shells and slaves

Spirals in time: the secret life and curious afterlife of seashells by Helen Scales (2015) Bloomsbury, 304pp. £16.99 (hard cover, ISBN 13: 9-78147291136-0).

In spite of the phenomenal revolution in on-screen information, talk of the death of books has been exaggerated and for good reason. A printed book does not suffer from trailing cables or depleted batteries, but perhaps the biggest factor is its tactile quality: books tempt you to pick them up and open their pages. So it is with seashells, as few people can resist the temptation to examine shells on a beach. Even fewer of them, however, would know the intriguing stories behind the extremely diverse world of shell-making organisms.

In *Spirals in time*, Helen Scales takes us on a journey into their often strange lives. Peppered with entertaining anecdotes, the book describes a sample of the estimated 50 000–100 000 molluscan species, a diversity only eclipsed by arthropods and unmatched in the marine environment. Seashells are not solely produced by molluscs, but molluscs do comprise a major proportion of shell-makers. One of the puzzles Helen Scales unravels is why many mollusc shells are highly coloured and patterned yet the species involved may have no sight. Camouflage seems unlikely to be the reason as some species spend their lives buried in the sea bed. It turns out that patterning is a marker used in shell production or repair, telling the 'blind' individual where they are up to in the process.

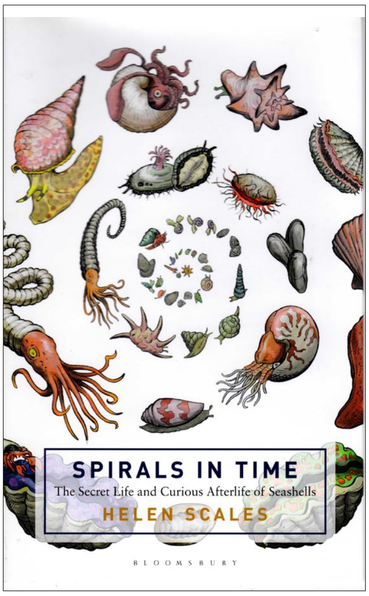
There is a chapter devoted to the story of golden sea-silk, a material I thought belonged to the realm of mermaids. A product of the byssus* of noble pen shells, it is still spun today on an island off the coast of Sardinia, a living fossil of an industry. Another revelation was the extent to which shells were exchanged in the slave trade: at its height, 150 000 cowrie shells could buy you an adult male slave. Shellfish have other more enlightened uses, nutrition being the main one. More recently, there has been research into the powerful toxins carried by cone shells which may offer a cure for such neurological diseases as Parkinson's. All the more reason why we should halt the acidification of the oceans by our CO_2-emitting

*Filaments secreted by many species of bivalves to attach themselves to a solid surface.

culture as this presents by far the biggest threat to all shell-making communities.

In spite of the visual richness of the subject, this book does not attempt to be yet another illustrated guide to shells, although there is a colour plate section and line drawings explaining Raup's principle of spirals. Instead, we get a compact almost pocket-sized book, complete with a useful glossary and index, which sets out to tell some of the shell-makers' life stories as well as the overlaps with our own human story. It will appeal to both the scientifically literate and the interested beachcomber whose curiosity has been stimulated by peering into another world.

Gerry Bearman
Science editor
sometimes adrift off Cornwall



The first zoologist

The lagoon: how Aristotle invented science by Armand Marie Leroi (2014) Bloomsbury, 501pp. £25 (hard cover, ISBN 13: 978-1-4088-3620-0); £9.99 (paperback, ISBN 13: 978-1-4088-3622-4); £9.99 (ebook, 978-1-4088-3621-7).

The introduction to this book, 'At Erato', refers to the bookshop in old Athens where the author first began to be drawn to Aristotle. Although not then interested in ancient philosophy, he was prompted by the title – *Historia Animalium* – to pick up a volume of a set of the *Works of Aristotle* translated into English by J.S. Smith and W.D. Ross. He opened it, read what Aristotle had written about shells, and began a long journey to the completion of this beautiful book. The bookshop reference is a clue to the author's great love of words and writing; for me, he has the skill of writing in a relaxed and engaging manner, while at the same time remaining extremely precise.

According to D'Arcy Thompson, who published a translation of *Historia Animalia* in 1910, the 'lagoon' of the title is in fact a sheltered bay which extends via a narrow strait into the centre of the island of Lesbos. Today, this nutrient-rich and highly productive body of water is called Kolpos Kalloni, but in Aristotle's time it was known as Pyrra. Aristotle lived on Lesbos for only two years, but this period of his life seems to have influenced him immensely, and may explain why a large proportion of the animals he was most fascinated by live in or by the sea.

On Lesbos Aristotle met a young man who was also interested in the study of living things, and who became his closest collaborator. Just as some see Aristotle as the father of zoology, Theophrastus (the name that Aristotle gave him) is often thought of as the father of botany. In fact, Theophrastus also wrote on animals, and Aristotle is known to have written at least one book on plants, but in both cases the works have been lost.

The author describes his book as 'an exploration of the ... beautiful works that Aristotle wote and taught at the Lyceum' (the school he set up in Athens). Aristotle had turned his back on the more abstract preoccupations of his own teacher, Plato (and hence also of Socrates). Although he was 'an intellectual omnivore', the subject that most fascinated Aristotle was biology. He invented the science, and the author makes a good case for his having invented science itself.

Leroi considers that Aristotle was at heart a comparative zoologist. He studied how animals were put together, where possible by direct observation, and tried to work out *why* they were as they were. Further, he devised what today we would call a taxonomy, one that was the starting point of our own.

Sadly, none of Aristotle's own drawings have survived, so the illustrations (many based on Aristotle's own texts) were all made post-1500. These serve the purpose, but some have not reproduced well, and it's a particular shame that the map at the front is hard to interpret (I resorted to an atlas).

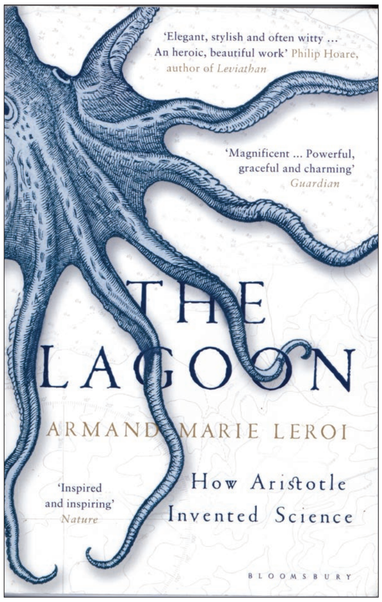
Although there is a clear structure to the book, it can be pleasurably dipped into, as it is made up of mostly short chapters grouped together in sections. These have evokative titles such as the Dolphin's Snore, The Bird Winds and The Soul of the Cuttlefish. As these suggest, discussion of Aristotle's ideas and way of thinking is woven into descriptions of Greek natural history and culture, today and in Aristotle's time. The book also explores how Aristotle's ideas have influenced and been co-opted by later scientists. One of the most entertaining chapters, in a section called The Stone Forest, descibes an vicious quarrel (of a type that might be recognised by any modern academic) where the views of both protagonists resulted from their interpretations of Aristotle's writings.

Darwin himself didn't appreciate Aristotle until a few months before his death, when he was sent a copy of *The Parts of Animals* by William Ogle who had just translated it into English. Darwin wrote back saying '... I had not the remotest notion what a wonderful man he was. Linnaeus and Cuvier have been my two heros ... but they were mere school-boys to old Aristotle.'

Reading this book made me wonder what Aristotle would have achieved were he working in science today – but perhaps that would be missing the point. Thinkers have been 'standing on the shoulders of giants' for millennia, rather than the hundreds of years I had previously imagined. As the author says, although today's scientists have all but forgotten about Aristotle, his way of thinking has come down to us through previous generations of scientists.

Despite the clarity of the writing, and the charm of the style, the book can't be described as an 'easy read' for the average marine scientist. I had to look up terms not commonly encountered in oceanography, and I had trouble remembering ancient Greek names and words so needed to check back occasionally. But it was very much worth the effort, and I would urge anyone interested in biology, and in how ways of thinking have evolved, to read this thought-provoking book, which deals with complex arguments with a light touch.

Angela Colling
Editor, *Ocean Challenge*



Geology versus Genesis

The Earth: from myths to knowledge by Hubert Krivine (translated by David Fernbach) (2015) Verso Books, 304pp. £20.00 (hardback, ISBN 13: 978-178168-799-4); £12 (ebook, 978-178168-798-7).

This unusual book presents a historical account of the battle between science and religion over Earth's place in time and space. This is an interesting topic because, together with evolutionary biology, there is no scientific discipline that is so at odds with religious dogma as geology. The vast stretches of time which have passed since Earth formed from the solar nebula, and the comparably insignificant amount of time which humanity has spent on this planet, are both incompatible with the special status of our species proposed by various Creation myths. Similarly, the insignificance of our planet in the heliocentric model of the solar system and in the wider universe is also difficult to reconcile with many religious world views. Sadly, despite the astonishing successes of mathematics and science, fundamentalist religion is on the rise and science is on the defensive. Furthermore, in the absence of logical arguments and scientific experiments, religious disputes are often settled with weapons and violence, as we can see on our television sets every day. Thus, Krivine's book covers a timely and important topic. Unfortunately, the execution is not perfect.

The text is really a rather disjointed combination of two books: a short one (46 pages) about the age of the Earth, and a long one (102 pages) about heliocentrism. The second part goes into considerably more detail than the first. Being a geochronologist, I would obviously have preferred a more balanced approach. The discussion of the Earth's age is largely limited to the contributions of physicists such as Kelvin, Rutherford and Boltwood. 20th century geochronologists such as Holmes and Houtermans barely get mentioned, and the current state of the art in geochronology is not discussed at all. There is no mention of the Hadean Jack Hills zircons* or the age of the Moon. The fascinating chronology of meteorites, which forms the basis of the preferred age of the Earth (an incredibly precise 4564.7 ± 0.6 million years) is summarised in a measly two pages. Part two of the book is more thorough. It recounts the well known history of Ptolemy's epicycle theory, the Copernican revolution, Galilei's forced retraction of the Copernican model, Giordano Bruno's execution, and the eventual acceptance of heliocentrism with the development of Newtonian mechanics. The narrative follows a chronological order and is accompanied by many clear illustrations. The story is told from a European perspective, although there are a few sections which briefly mention parallel developments in the Middle and Far East.

The author's goals are ambitious, combining (1) a scientific treatise on the age and orbit of the Earth, (2) a historical account of the ongoing battle between science and religion, (3) a critique of postmodernist philosophy and (4) a case for mathematical physics being the most rigorous of the natural sciences. But in juggling all these balls together, Krivine struggles to follow a clear story-line and this may make the text somewhat inaccessible to the uninitiated. In spite of those imperfections, there is a lot to like about the book. The author's objectives are noble and there is much that will be of interest to the scientifically literate reader. The extensive and detailed endnotes and appendices are a treasure trove of interesting trivia. Mathematically inclined readers will enjoy the detailed equations and case studies at the end of the book. But I don't think that the text will appeal to the postmodernist intellectuals and religious people who would benefit the most from a well written account of the battle between geology and astronomy on the one hand and religious dogma on the other. That book still needs to be written.

Pieter Vermeesch
Department of Earth Sciences
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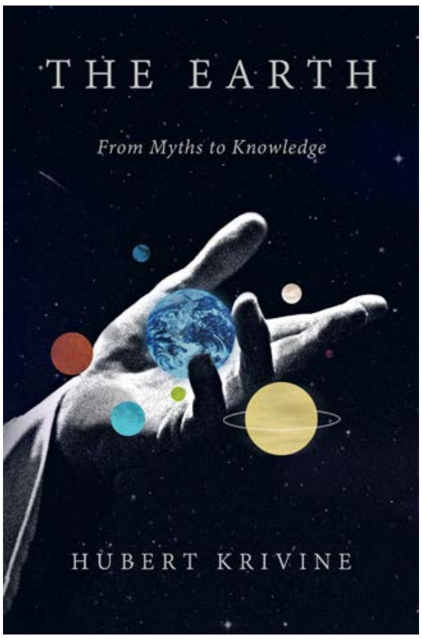
*These zircons, from a range of hills in Australia, are amonst the oldest minerals on Earth.



The multidisciplinary world of icebergs

Icebergs: their science and links to global change by Grant R. Bigg (2016) Cambridge University Press, 240pp. £79.99 (hardback, ISBN 13: 978-1-107-06709-7).

Humans have long encountered icebergs. Inuit people must have been aware of icebergs for millennia. Modern European experiences may date from the Viking colonisation of Iceland and Greenland by around 1000 AD, with frequent iceberg encounters most likely off Greenland in particular. With the Age of Discovery, from around 1500, came exploration far to the north and south, and encounters near Antarctica for the first time.

Iceberg encounters can of course be hazardous. Over the last 350 years, there have been many recorded collisions between ships and icebergs. Icebergs thus acquired a notorious reputation. Meanwhile, generations of scientists have been gathering a wide range of observations, leading to today's understanding of icebergs and their wider role in the Earth System. One of the world's foremost iceberg researchers, Grant Bigg, has brought these diverse stories together in his new book, underpinned throughout with multidisciplinary science.

The book begins by recounting the likely story of the iceberg that sank RMS *Titanic* in April 1912, leading on to a review of the aforementioned human encounters with icebergs. Part I then covers the science of icebergs, while Part II addresses a wide range of iceberg impacts. Multiple links between Parts I and II emphasise the science that underpins our understanding of the impacts.

Part I takes us through the glaciological origins of icebergs, their physics (dynamics and thermodynamics), and their interactions with the ocean and the sea bed. Starting with the ice sheet, ice is slowly delivered to a marine glacial terminus or an ice shelf front. Here takes place the complex and poorly understood process of iceberg calving. Bigg clearly presents calving as the consequence of stresses in a glacier or ice shelf, becoming more likely with deeper crevasses and thinner ice streams. He distinguishes the relatively small icebergs regularly calved from tidewater glaciers around Greenland from the sometimes colossal tabular icebergs that occasionally calve from ice shelves around Antarctica, explaining the physics of each.

Further novel aspects of iceberg science include various scouring processes whereby icebergs profoundly alter the sea bed, and the rich biogeochemical signatures found in and around icebergs, which have been demonstrated to locally enhance primary productivity where limiting nutrients are fluxed into the surrounding ocean. This effect may be important for carbon export at mid to high latitudes of the Southern Ocean.

Part II covers the evidence for icebergs and their influences through Earth history, reviews iceberg risk both past and present, revisits the tantalising prospects of icebergs as a vast freshwater source in a thirsty world, and concludes with prospects for icebergs in a future warmer world, looking forwards over decades to millennia.

Starting with Earth history, Bigg looks forwards from deep time. Whenever Earth has been sufficiently cold, icebergs have populated the oceans. In geological parlance, they have been with us since the dawn of the Oligocene, around 34 million years ago. Over the last few hundred thousand years, they played a starring role during the 'Heinrich Events' (HEs) when 'armadas' of icebergs were released from the northern ice sheets; as they melted, the icebergs released large quantities of ice-rafted debris, which accumulated on the underlying sea bed. HEs punctuated long periods of glacial climate, and were sometimes coincident with episodes of abrupt climate change. Bigg considers in detail the six HEs that occurred through the last glacial period, from H1 at around 12 000 years ago to H6 at around 60 000 years ago. While uncertainties are considerable, varying provenances of ice-rafted debris postulated for H1–H6 illustrate the complex waxing and waning of various ice sheets around the Northern Hemisphere.

The hazard associated with icebergs remains clear and present, although collisions nowadays are rare. However, the inexorable poleward expansion of shipping and offshore activities may yet see an increasing number of incidents, and Bigg covers a wide range of adverse impacts that have been recorded, and may yet arise. Readers may be surprised to discover that powerful tugs are capable of towing large icebergs to avert collision with a fixed offshore structure, and this capability may yet be extended to exploit even larger icebergs as a freshwater source. Bigg recounts the 1970s heyday of discussions on the transport of icebergs to arid regions, and the contemporary prospects. Although the idea has long been shelved, for a variety of reasons, technological advances and increasing pressures on water resources may yet revive interest in commercially viable iceberg harvesting.

Finally, Bigg outlines an uncertain future for icebergs, distinguishing between near future (21st century) and far future (later millennium and beyond). Competing changes are likely, with increased precipitation over ice sheets and acceleration of ice streams expected to increase calving rates, while glacial retreats around Greenland will reduce the number of marine terminations and hence the overall calving rate for that ice sheet. Episodic collapse of ice shelves around Antarctica may periodically result in the influx of large numbers of icebergs to the Southern Ocean, while basal melting beneath floating ice shelves is estimated to have recently increased in proportion to calving, as a mechanism for Antarctic mass loss.

As Bigg often notes, we have only a limited understanding of some key processes. For example, our knowledge of the sequence of events that lead to iceberg calving is still limited, while evidence that icebergs may exert considerable influence on biogeochemical cycles is just emerging. As a consequence, iceberg modelling in wider coupled contexts (e.g. ocean–iceberg–cryosphere, ocean–iceberg–biogeochemistry) is currently at a nascent stage. Through his book, Bigg thus provides us with a timely prompt to widen and deepen our understanding of this most fascinating, and overlooked, of natural phenomena.

Through much of the book, Bigg uses and cites his extensive research and experience on the subject, notable examples including: pioneer work on ocean–iceberg modelling in the 1990s; subsequent use of this modelling to associate Heinrich Events with freshwater forcing and responses of large-scale ocean circulation; innovative use of remote sensing to track selected giant icebergs around Antarctica; recent attribution of elevated chlorophyll to the passage of a giant iceberg in the Southern Ocean; and assessment of icebergs as a hazard to offshore operators.

Overall, Bigg's new book provides a unique overview, essential reading for the growing community of researchers interested in icebergs, including those seeking a more complete understanding of biogeochemical cycles, a more nuanced understanding of past changes at high latitudes as recorded in sediment cores, and more complete coupling of the cryosphere in Earth System models. This accessible book will further appeal to any polar oceanographer, mariner or tourist who has been captivated by up-close encounters with icebergs.

Robert Marsh
Ocean and Earth Science
University of Southampton

Revisiting a classic

Ocean waves and kindred geophysical phenomena by Vaughan Cornish (2015) Cambridge University Press, £26.99 (flexicover, ISBN 13: 978-1-10755-999-8).

My first reaction when invited to review this book was to express surprise that Cornish is still scientifically active. He isn't. Vaughan Cornish (1862–1948) was a privately funded geographer who wrote books and scientific papers on subjects as diverse as the building of the Panama Canal, and the relationship between scenery and poetry. This fascinating account of various natural wave phenomena was first published in 1934, and has been re-issued by Cambridge University Press in their series of reprints of classic texts.

Cornish was a life-long acute observer of waves in all their natural manifestations. The first part of the book is about observing ocean waves from the passenger decks of liners, by aligning the wave crests with the horizon. Part two describes waves in snow and sediments from places as diverse as northern Canada and Aberdovey. The final part reports observations of waves in rivers, notably progressive and standing waves around Niagara Falls, and the propagation of the tidal bore up the River Trent in Lincolnshire. Some of the author's observations are illustrated by 26 original plates. He is a close observer of patterns but not someone capable of delivering the basic scientific understanding.

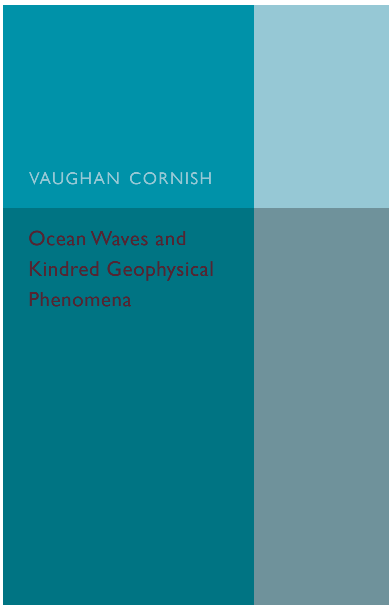
That role is brilliantly fulfilled by Harold Jeffreys in a 40-page annex summarising the mathematical theories and the underlying physics of the different wave processes. The book would have been worth reprinting for this alone. I am not aware that Sir

Harold, the doyen of geophysical mathematicians, ever published such a concise account anywhere else.

Reissuing these classics is cost-effective for the publishers: printing costs are low, presumably copyright has lapsed, and even a few sales make small and cumulating profits. For us, access to the pioneering thinking of early scientists can give a sense of both progress and direction.

Cornish's individual observations would be little use for modern data-rich investigations. Even he acknowledges the limitations of his solitary records of the Trent bore: 'Want of data obliges me to leave the matter here, but I suggest a further investigation of the phenomena ... by the kind of team work which has now become fashionable in scientific, as in other spheres of activity.' Welcome to modern oceanography.

David Pugh
National Oceanography Centre
Liverpool



Investigating the 'Investigators'

Discovering the North-West Passage: the four-year odyssey of H.M.S. *Investigator* and the McClure Expedition by Glenn M. Stein (2015) McFarland & Company, Jefferson, North Carolina. 388pp. £36.95 (flexicover, ISBN 13: 978-0-7864-7709-1); £20.44 (ebook, 978-1-4766-2203-3).

The exploration of the Arctic in general, and search for a North-West Passage in particular, involved major expeditions during the mid-19th century. Much was revealed during the steady progress of discovery but one major enigma remains: the fate of Sir John Franklin with the complement of 129 men from HMS *Erebus* and HMS *Terror* who were last seen alive in 1845. Much literature concerns their fate and the subsequent decade of searches which, ironically, resulted in the discovery of several North-West Passages as well as exploration of other extensive Arctic regions.

During this era, one of the most important exploratory voyages was that of HMS *Investigator*, commanded by Robert McClure, which spent four winters in the Arctic before being abandoned. Little modern literature, and only a few contemporary accounts, deal with the complexities and tribulations of the 'Investigators', as her complement came to be known. The voyage was significant as it was one of the few approaching the Passage from the west, through Bering Strait from the Pacific Ocean. Originally it was to accompany HMS *Enterprise*, commanded by Richard Collinson, but the ships separated in the Pacific Ocean. The motives for Captain McClure's failing to rejoin HMS *Enterprise* were not simple, as noted in an assessment of his character. *Enterprise* eventually spent three winters in the Arctic.

The author's research is extensive and relies much on original documents held in many repositories. His use of published sources is similarly comprehensive. Many quotations are given to illustrate and amplify particular points. The 'virtual Pandora's Box' of mystery and intrigue 'which spilled forth' from many journals and other writings (p.234) is well shown by direct quotations. I am content that the author has done excellent work in untangling these aspects of ambition and conspiracy, in as far as practicable.

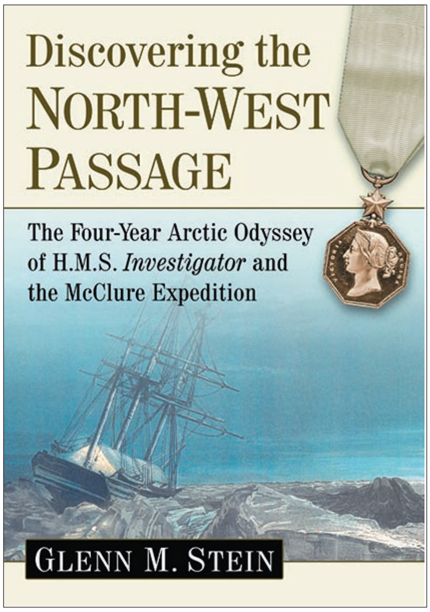
The text is, in general, easy to follow although some of the author's remarks are unexpected. A few examples are: the idea that water jetted from whales (p.67) indulges an ancient fallacy; 'knot per hour' (p.167) is a measure of acceleration not speed; anachronistic use of the term 'okay' (p.304) in a formal British memorandum of 1856 raises a question of accuracy of transcription of manuscript. Some of the modern synonyms for traditional terms seem superfluous; and measurements are not given systematically (despite a table of conversions in Appendix 1).

The descriptions by Johann Miertsching, a missionary interpreter who had a large degree of independence, are revealing, despite his having to reconstruct his journals after the originals were left aboard the abandoned vessel. The relative lack of contact with the indigenous inhabitants is a consequence of much of the expedition being beyond the northern extent of their usual range.

The 1853 summer was disastrous in Arctic history with the loss of six major ships. The circumstances leading to these events are discussed, noting the privations of the Investigators during four winters with inadequate fuel, starvation, scurvy, and outbreaks of 'lunacy'. The meeting of complements of several ships on Beechey Island, preparatory to ending this episode of the Franklin searches, was the culmination of the expedition. The return of Samuel Gurney Cresswell, with one of the 'lunatics', to Britain in 1853 was the earliest transit of the North-West Passage, although over the ice in the middle portion (it was not until 1906 that such a journey was accomplished by one ship). Captain McClure followed in 1854 with the survivors.

The bibliography with a list of other sources is extensive and to be commended, as is the index. Illustrations for such a work are difficult to obtain; those provided, all monochrome and not listed, are a useful supplement to the text. There are only three maps (half-page) and a chart; perhaps some more local ones would have helped the geographical understanding. Footnotes and bibliography are detailed and very well referenced. The adaptation and improvement of sledging techniques as experience in the Arctic increases is decribed, and notes on sledging journeys and map features are useful appendices. Tribute to earlier writers, particularly A.G.E. Jones and R.J. Cyriax, is generous.

The author is a specialist in the Arctic Medal and related decorations. These form a sub-theme throughout the work, quite intimately connected with the text. The lists of honours and awards, combined with concise biographical details, of all the *Investigator* men is good to see in the seven appendices. A final appendix



describes the origin and development of the Arctic Medal, which became the basis of the modern Polar Medal.

The Epilogue is timely, giving details of the finding of HMS *Investigator* during a recent (2014) search by Parks Canada, very close to where she was abandoned at her moorings over a century and a half earlier. It provides a satisfactory conclusion of the book, which has taken much time and effort to write.

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Rediscovering Humboldt

The invention of Nature: The adventures of Alexander von Humboldt, the lost hero of science by Andrea Wulf (2015) John Murray, 473pp. £25 (hard cover, ISBN 13: 978-1-84854-898-5); £9.99 (paperback, 978-1-84854-900-5); £6.99 (ebook, 978-1-84854-899-2); also available as a downloadable audio file (978-1-47363-718-4).

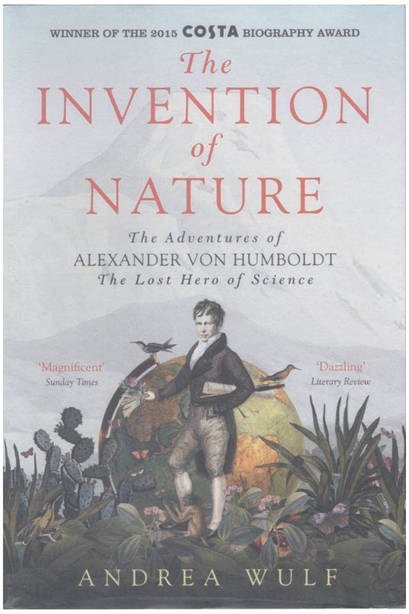
In the UK today, Humboldt's name recalls little apart from the Humboldt Current (the alternative name of the Peru Current) and perhaps some reference to his travels in Latin America. This book sets out to restore him to a wider readership in his rightful place as a major figure in the history of the natural sciences. More than simply an account of his life and works, it seeks to demonstrate the relevance of Humboldt's philosophy in the 21st century.

Roughly speaking, the first two thirds of the book are concerned with Humboldt's adventures, both physical and intellectual, throughout most of Europe and, as an explorer, much further afield, whilst the remainder considers his influence, its decline following his death and its significance today. From the story of this busy and varied life it evolves into something approaching a history of the development of a unified view of nature, centred around Humboldt's beliefs and illustrated by their effect on his younger contemporaries and on some key figures in the conservation movement of the 19th and early 20th centuries.

Alexander von Humboldt was born in Berlin in 1769. From an early age he showed a marked interest in natural history; later on, descriptions of the South Sea islands imbued him with a romantic longing to visit the tropics. When at last the opportunity came, he was well prepared. In June 1799, on the eve of departure for Latin America with the French botanist Aimé Bonpland, Humboldt expressed his aim with a simple clarity: 'In a few hours we sail round Cape Finisterre. I shall collect plants and fossils and make astronomic observations. I shall try to find out how the forces of nature interreact upon one another and how the geographic environment influences plant and animal life. In other words, *I must find out about the unity of nature.*' (My italics)

Their famous expedition took Humboldt and Bonpland through much of the Spanish empire in the Americas, including present-day Venezuela, Colombia, Ecuador, Peru, Mexico and Cuba, during five years of intense activity. Humboldt did indeed fulfil his ambition to study the unity of nature – by observation, collecting specimens, measuring every property accessible to his instruments and, crucially, by correlating all this information across time and space. His investigations covered natural history, every branch of geography, both physical and human – ranging from climate and vegetation to commerce and industry – the Earth sciences, including meteorology and geophysics, as well as subjects closer to the humanities, such as ethnography and pre-Columbian history. A competent draughtsman himself, Humboldt valued and recorded his æsthetic impressions throughout these travels, describing his surroundings with the eye of an artist: 'those calm tropical nights of the Pacific, where the constellation[s] ... pour their mild planetary light through the ethereal azure of the sky, while dolphins mark the foaming waves with their luminous furrows.' The results of all these labours were published in more than thirty books over a period of almost as many years.

The hazardous journeying by canoe and on foot is well described by Wulf, but this reviewer would have welcomed a more detailed account of Humboldt's equipment and methodology in the field, particularly the surveying and navigational aspects. Again, there is only limited evaluation of his scientific achievements; for a fuller examination of their significance we must look back to Charlotte Kellner's biography *Alexander von Humboldt* (OUP 1963).



Humboldt undertook one more major expedition, to Siberia in 1829 at the invitation of Tsar Nicholas I. The remaining decades of his life were mainly occupied with writing, in particular *Cosmos*, his five-volume 'sketch of a physical description of the universe', which was designed for a wider public and published in 1845–62. This work represented the summation of his career for, besides aspiring to provide a complete picture of the known universe, it expressed his personal synthesis of head and heart. Very popular in its day – in the British Isles alone some 40 000 volumes had been sold by 1849 – *Cosmos* is still the best-known of his many publications. In the introduction Humboldt had written 'I venture, then, to indulge the hope, that [*Cosmos*] will not be wholly disregarded even at a future period.' He died in 1859, at the age of 89, leaving the last volume unfinished.

Humboldt made valuable contributions to the Earth sciences. His analysis of the propagation of earthquake waves laid a foundation for seismology, and his concept of vulcanism operating on a continental scale through processes deep within the Earth was a farsighted innovation, although the notion that his writings prefigured the theory of continental drift, as suggested by Wulf, surely goes too far. Humboldt's contributions to marine science were relatively few, and Wulf makes no mention of this area of his work, perhaps because he never gathered the results of his hydrographic research into a single publication.

Such individual accomplishments present only a fragmentary picture of Humboldt, whose own approach to nature was essentially holistic, continually making comparisons and seeking connections. To quote the best-known example, he explained the geographical determinants of climate, and hence the distribution of plant species. Although he mentioned the role of predation in limiting the size of animal populations, his idea of evolution was unexceptional for the time. But his vision went further: including humankind as part of nature, he was alert to the conflict between human activities and the natural environment. Humboldt described the impacts of deforestation and the draining of marshes on hydrology, soil erosion and climate. Such ecological insights and the warning notes they sounded made him unique in his time and formed the basis of his influence on later generations of naturalists and environmentalists. It is to this legacy that Wulf directs her focus in the rest of the book.

As examples of Humboldt's lasting influence, she discusses the careers of some prominent figures, including Charles Darwin, who wrote in 1845: 'I shall never forget that my whole course of life is due to having read and re-read as a youth [Humboldt's] *Personal Narrative*', and the German zoologist Ernst Haeckel (1834–1919), originator of the term 'ecology'. Three Americans complete her tally: Henry David Thoreau (1817–1862), the writer and naturalist, best known today as the author of *Walden*; George Perkins Marsh (1801–1882), an early advocate for the conservation of natural resources, and John Muir (1838–1914), known in the USA as 'Father of the National Parks'. All these individuals acknowledged their debt to Humboldt and led lives that echoed the pattern of his career: travelling, observing and making connections.

Cosmopolitan polymath, intrepid traveller, reluctant courtier, geographer *sensu latissimo*, linguist, populariser and international networker – these are all facets of one remarkable person. Humboldt was a man of many talents who also possessed the unfailing curiosity and enormous vitality needed to make full use of them. How successfully does Wulf capture this many-sided figure? She tells Humboldt's story with pace and style, setting him in the social and political context of his time and bringing to life an engaging personality with her sometimes breathless prose. Her trump card is an original theme running alongside the life of the 'lost hero': the uneven journey of his influence down the years and into the last century. The extensive notes and bibliography bear witness to the hard work involved in researching the story of such a complex and long-lived subject.

Wulf has certainly achieved her aim of 'rediscover[ing] Humboldt' for a new generation, although whether this fulfils her parallel objective of 'understand[ing] why we think as we do today about the natural world' is more debatable. That might require another book, focussing on the 20th century and without a central character. What we have already is an excellent historical study with an important message for the future. It was a pleasure to read.

John Phillips
MIlton Keynes

Cooperation is the key to conservation

Human–wildlife conflict: complexity in the marine environment edited by Megan M. Draheim, Francine Madden, Julie-Beth McCarthy, and E.C.M. Parsons (2015) Oxford University Press, 224pp. £34.99 (flexicover, ISBN 13: 978-0-19-968715-2), £70 (hard cover, 978-0-19-968714-5); also available as an ebook.

I have always believed that nature conservation is less about nature and more about people; if you get the people bit right, then nature is more likely to be conserved. Sounds easy, but the trouble with people is that they do not always share the same attitudes to nature, so what might be attractive, useful, and worthy of care to one, might be an ugly pest deserving destruction to another. I had the opportunity to bolster my belief through two BBC Radio 4 series which spanned five years. While we were making the 'Saving Species' series it became apparent that there was a need for a follow-up which took a leap into the complex world of human–wildlife relationships; 'Shared Planet' did just that, following the thread of how nature could possibly survive in the face of a growing human population and the encroachment of 'civilization' into what little wilderness remains on our planet. The obvious became clear: the fact is that the world is now a very small place and there are few parts of it that have not been directly affected by humans. As we surge towards a global human population of 9 billion it won't get easier for nature as it becomes increasingly squeezed into less and less space, while for some species the hour-glass of survival is rapidly running out of sand.

When it comes to the ocean we humans have treated it in two contradictory ways. On the one hand we have seen it as a huge repository of wealth in the form of food, a cornucopia never failing to supply us with whatever we called upon it to supply. At the same time we have treated it as a huge carpet under which we have swept our waste – out of sight out of mind, the sea can cope! We now know that the seemingly endless supplies of fish we took for granted are finite and threatened, and the endless pit that would swallow anything we wanted to put in it has reached its limit.

In order to understand how the marine environment is being affected and how we might repair it, we first have to understand our relationships with it, and how they differ between nations, societies, communities and individuals – it is not an easy thing to achieve. *Human–wildlife conflict: complexity in the marine environment* sets out to disentangle these relationships and how they change across time and place. Far from academic desk-top preaching, it provides real examples, successful and not-so-successful, to explain how we might go forward. Lessons, in the form of case studies, provide insights into challenges and the processes that have been followed to attempt to overcome them. The conflict is not simply between humans and nature; increasingly it is complicated by the interactions of the different human factions who may have conflicting religious, cultural or economic demands. 'Human–wildlife conflict' has classically been defined as a situation where wildlife impacts humans negatively (physically, economically or psychologically), and where humans likewise impact wildlife. However there is a growing consensus that conflict between people about wildlife is as important as conflict between people and wildlife. The Hawaiian spinner dolphins are an excellent example: swimming with dolphins has led to conflict between local communities, government and operators as a result of disputes over fishing grounds and economic interests peppered with ethical and legal debates. Cetaceans in general may be seen by some nations as 'another fish' to exploit; by others, as symbols of intelligence, icons of the wild and 'other-wordly'.

It is clear from the case studies in this book that clarity of language in laws and treaties, and understanding the 'other point of view', are essential if conflict is to be avoided, and that finding common ground is as much about social science as it is ecological science or economics. There is a lot packed within the three sections, nine chapters and almost 200 pages. The publishers say that *Human–wildlife conflict* will be 'essential reading for graduate students and established researchers in the field of marine conservation biology'. I would add special correspondents in environmental broadcasting, and indeed anyone who is aware of the shrinking planet and the expanding human population.

Kelvin Boot
Science Communicator