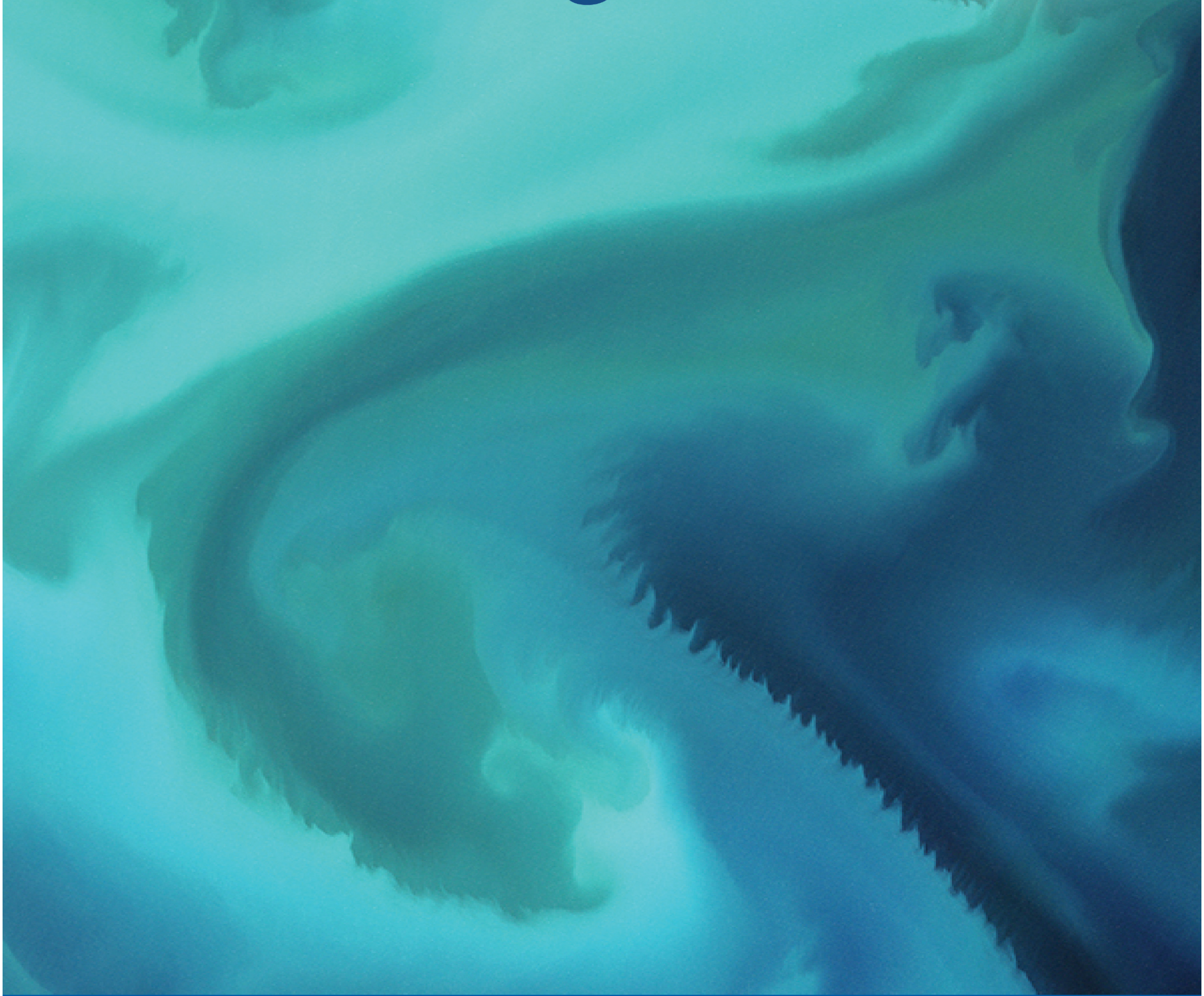
OCEAN Challenge

The Challenger Society for Marine Science



Making sense of marine ecosystems • SCOR is 60 not out! • Humboldt's legacy to oceanography • Why we need to track organic carbon from Arctic sea-ice before it disappears

Vol. 23, No. 1

OCEAN Challenge

The Challenger Society for Marine Science

Volume 23, No.1, 2017
(published 2018)

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.

NB *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

ADVERTISING

For information about advertising, please contact the Editor (see inside back cover).

AVAILABILITY OF BACK ISSUES OF OCEAN CHALLENGE

For information about back issues, please contact the Editor (see inside back cover).

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

For information about Council members see the Challenger Society website

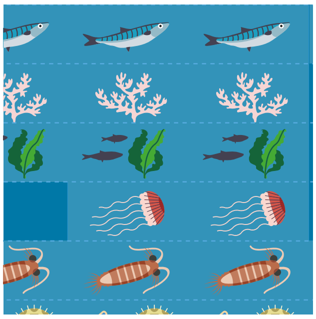
ADVICE TO AUTHORS

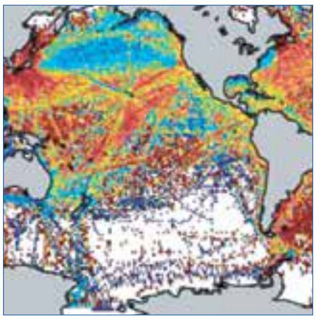
Articles for *Ocean Challenge* can be on any aspect of oceanography. They should be written in an accessible style with a minimum of jargon and avoiding the use of references.

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

Angela Colling, Aurora Lodge, The Level, Dittisham, Dartmouth, Devon, TQ6 0ES, UK.

Tel. +44-(0)1803-722513 **AngelaMColling@gmail.com**





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

The cover and heading graphics were designed by Ann Aldred.

The cover image is a true-colour image of the Barents Sea, obtained though the Sentinel satellite mission, by courtesy of ESA.

CONTENTS

Winners of the 2018 Presidents' Photographic Competition

This prize is awarded at the biennial Challenger Society Conference, with the winner being chosen by the new and outgoing Presidents of the Society. This year, the two photographs below (described by the photographers themselves) were judged equally worthy of the prize.

Overfishing is one of the biggest threats to the health of our oceans. Sustainable management by local people could find a balance between population needs and the availability of marine resources

by Angela Bahamondes Domínguez

(Photo taken on Chiloe Island, Chile)

Leaving Brighton for an 'aerial survey' of the new wind farm

by Alice Marzocchi

(The Rampion Wind Farm is the first offshore wind farm on the south coast. Once fully operational, the farm should generate enough electricity to power almost half of the homes in Sussex)

The Challenger Society for Marine Science

Message from the Editor

Welcome to Volume 23 of *Ocean Challenge*, and a special welcome to new members who joined when registering for the Challenger Conference. Climate change is the underlying motivation for much of the work described in this issue. The articles illustrate how understanding, and perhaps ameliorating, the effects of climate change, depend on science addressing the complexity of the atmosphere–ocean system, and bringing together people from many specialisms. One of the two feature articles, by Thomas Brown and Lindsay Vare, looks at an innovative technique developed to provide a clearer picture of the challenges that Arctic ecosystems face as sea-ice cover declines. The other, by the late Gerhard Kortum, considers the oceanographic legacy of a 19th-century scientist who would be very much at home in the interdisciplinary science of today – Alexander von Humboldt.

Angela Colling

Some highlights of the 2018 Challenger Society Conference

For the first time, the Challenger biennial conference was held in Newcastle. Also for the first time, delegates were addressed by royalty – His Serene Highness, Prince Albert of Monaco, a champion of the environment, whose great-great-grandfather was a famous oceanographer.

At the conference dinner, Challenger Society Fellowships were awarded to Stephanie Henson, Yvonne Firing and Phil Godwin (all from the National Oceanographic Centre, Southampton) and Xiaoming Zhai (University of East Anglia). The new Woodward Fellowship in Nutrients and Nutrient Cycling, made possible by Malcolm Woodward (see pp.6–8), was awarded to Sian Henly (Edinburgh University) (*below right)*.

The Norman Heaps prize for the best early -career oral presentation was awarded to Stephanie Allen, for her talk on 'Inferring the inter-annual control of plankton communities across the North Atlantic'. The Cath Allen prize was awarded to Lewis Wrightson (University of Liverpool) for his poster on 'Quantifying the impact of climate change on marine diazotrophy: insights from IPCC climate models?'

The Society's most prestigious Award, the Challenger Medal, was presented to Professor Mike Meredith. Mike is a physical oceanographer at the British Antarctic Survey in Cambridge, where he leads the Polar Oceans team. As well as physics, his research encompasses chemical oceanography, palaeoclimate and genetics. The next issue of *Ocean Challenge* will contain an article by Mike based on his stimulating Medallist's lecture.

The joint winners of the Photographic Prize were Angela Bahamondes Domínguez and Alice Marzocchi (*see opposite*).

At the Challenger Society AGM, held during the Conference, Rachel Mills passed the *Challenger* gavel to incoming President Rob Upstill-Goddard. Rachel is remaining on Council as Immediate Past President.

Newly appointed to Council are Judith Wolf, Alessandro Tagliabue, Sophie Wilmes and Jackie Tweddle. Mattias Green has taken over from John Bacon as Hon. Secretary, but John remains on Council as Technical Advisor. Edward Mawji remains as Hon. Treasurer. For areas of responsibility of Council members, information about the Society's prizes and awards (Including Fellowships), and how to apply for Stepping Stones Bursaries and Travel Awards, see challenger-society.org.uk/ where you can also find abstracts from the Conference.

Ed.

Below *Outgoing President Rachel Mills introducing Challenger Medallist, Mike Meredith to His Serene Highness Albert I of Monaco.* ***Right*** *Incoming President Rob Upstill-Goddard, alongide Malcolm Woodward presenting Sian Henly her Fellowship certificate at the conference dinner.*

Challenger Conference 2018

New Science at Newcastle

Corinne Pebody

The 2018 Challenger Conference was an excellent event bringing together awe-inspiring science and scientists. As ever, this biennial conference was a unique mix of early-career scientists and field leaders where all are listened to with equal respect. This blend offers a safe space in which to present data, promote discussion and even fly some fresh and slightly left-field ideas.

The diversity of subjects covered was fantastic and after a few mix-ups with the talks on Tuesday, things quickly settled down for the rest of the week. Indeed, the only difficulty was which of the parallel sessions to go to, and the innovative session titles cunningly encompassed talks from different disciplines. All were delivered with clarity and authenticity, challenging us with new ideas – perfectly fitting the ethos of a Challenger conference.

The topics covered ranged from physics ('lite' – for us biologists) to plastics and scum. No subject was too tricky to tackle. We explored systems from the micrometre to the planetary scale in a plethora of paradigms, tested to the full. Personal favourites were sinking strontium in the form of celestite in acantharian cysts. These episodic events are a fascinating example of the large impact of small organisms – a useful thought for all of us. A great talk from Beth Scott highlighted the importance of looking at a problem from the right angle; she discussed the impact of tidal energy extraction versus the impact of not using renewables. Are we more damned if we don't than if we do?

Laura Hobbs found that the slightly early calanoid catches the micro-zooplankton – but not if there are too many calanoids too soon. Eleanor Frajka Williams explained the Atlantic Meridional Overturning Circulation (AMOC) in an excellently accessible way. Geraint Tarling painted a rather poignant picture of the social interactions of krill – how, despite their swimming to stay together, fluid dynamics pushes them apart, thus limiting their swarm size. Everyone say 'Ahh!' This was one of many talks that showed that humour and clarity are not mutually exclusive.

The posters were displayed near the plentiful supplies of tea and coffee and were a complementary mix of instrument development, scientific results and invitation for comment. Many of the authors diligently stayed on after the sessions to discuss their posters with the many curious among us. Again some super smart ideas freely shared and questions welcomed.

The posters and talks all promoted the exchange of views – challenging or strengthening ideas – and the exploration of collaboration by diverse parties. The opportunity to meet up with potential collaborators from other institutions is one of the many great things that can 'just' occur at Challenger. Snippets from papers that would not be happened upon in 'normal' reading, pop up in posters and presentations. These promote ideas, provide discussion and seed future research, beneficial to us all. This longer term, indirect blossoming was in addition to the direct offers of *post doc* posts or occasional open statements of availability for employment. Impressive talks remain in one's mind ready for recall at future interviews or science discussions. Challenger truly is a case of the whole is greater than the sum of individual parts.

The conference dinner started with a welcoming drink in an informal setting where we gathered to chat, before moving on to the meal, which consisted of generous courses of attractive, tasty but unfussy food, all sponsored by Sky News. Sky demonstrated the film they produced to highlight the issues of plastics and sustainable purchasing, and there was a little harmless name-dropping which added to the fun. Again this collaboration demonstrated the power of people working towards a common goal. Committed individuals coming together from different backgrounds – commercial or academic – really do make a difference.

The poster hall, delegates and the tireless registration team

Alan Jamieson gave an extremely entertaining host's speech – the way he described his recent science-related activities was very much at odds with the image of scientists in white coats, imprisoned in sterile laboratories. The variety, vivacity and veracity of science does not equate to dullness – far from it!

The evening ended with coffee and the awarding of the Challenger Medal and Challenger fellowships. Oceanography involves so many impassioned, intelligent, driven and thoughtful people you would be forgiven for thinking it difficult to select individuals as outstanding. Yet the awards went out to some amazing scientists for a variety of excellent reasons, to the applause of all.

For the institution hosting the conference there is a lot of behind the scenes solid graft to bring it all together and Newcastle University were unstoppable. Despite one or two glitches thrown up by the new booking system all delegates got in and the conference staff were super supportive sorting out registrations and accommodation with little drama and plenty of patience and humour. The lecture theatres had excellent acoustics and the IT systems worked for all the sessions I attended.

Newcastle itself is an unassuming gem of a city. The focus on pedestrians made it easy to walk through to the many excellent destinations close to the city centre – I'm sure there were plenty further away, I just never got the time to explore them. Chinatown, the shopping centre, restaurants and central areas generally are pleasant and friendly, and even on a week night have a nice hum. We needed another week to be able to do justice to all the touristic opportunities and I particularly want to go back to see the Life Science Centre, run by the NHS and Newcastle University, which is in a fantastic building.

On the final afternoon, Prince Albert of Monaco gave a well received talk. His genuine understanding and interest in oceanography showed through, as did his considered concern about climate change and our responsibilities as both scientists and consumers.

It was a super successful conference and the presence of Prince Albert of Monaco was the royal icing on the cake. Thank you to Challenger, Newcastle and all the many people who went the extra nautical mile.

Corinne sampling for dissolved inorganic carbon at the Porcupine Abyssal Plain Sustained Observatory earlier this year.

Corinne Pebody works at the National Oceanography Centre, Southampton, as part of the Porcupine Abyssal Plain Sustained Observatory (http://projects.noc.ac.uk/pap/) team. She is interested in both scientific and creative writing.

The Ocean Tide and the Port of Liverpool

Open to anyone interested in the tides and the Port of Liverpool

Saturday 11 May 2019, 10.00 a.m. to 2 p.m.
Merseyside Maritime Museum, Albert Dock

A free meeting marking the 100th anniversary of the world-famous Liverpool Tidal Institute

organised by the National Oceanography Centre and the University of Liverpool, in association with the Centre for Port and Maritime History and the Liverpool Institute for Sustainable Coasts and Oceans

Welcome and brief history of the Liverpool Tidal Institute *Philip Woodworth* • The science behind the ocean tide *David Pugh* • Opportunities for the UK in tidal energy *Judith Wolf* • The tides and the banks of the Mersey *Andy Plater* • The tides and the oceanography of our neighbouring seas *Jonathan Sharples* • The large Mersey tides and the Port of Liverpool *Simon Holgate* • Tides and the Earth's climate *Chris Hughes*

Pease register if you intend to come:
https://www.eventbrite.co.uk/e/the-ocean-tide-and-the-port-of-liverpool-tickets-50182272528
Please see this website nearer the time for any changes to the meeting programme.

From 1.00 to 4.30 p.m. there will be a Tide Prediction Machine Exhibition at the National Oceanography Centre, 6 Brownlow Street, Liverpool, where you can see the machine that was used to make tidal computations for the D-Day landings in World War II. The exhibition does not require registration – just come along. For more information see http://www.tide-and-time.uk/ and http://www.bidstonobservatory.org.uk/tide-prediction-machines/. There are also plans (details to be announced) for activities at Bidston on that day.

Look out for further events to mark this very special anniversary!

Malcolm Woodward: pushing the boundaries

A remarkable career making measurements at sea

In 2016, the Challenger Society awarded Honorary Lifetime Membership to Malcolm Woodward, leader of the Nutrient Facility at Plymouth Marine Laboratory, in recognition of his huge contribution to the world-wide marine science community. For me, time at sea on the RRS *James Cook* over Christmas, New Year and January 2017/18 – with a great team of scientists, including Malcolm – was a great opportunity to capture his story and find out about a career that spans nearly 40 years.

Rachel Mills *(Challenger Society President, 2016–2018)*

Malcolm grew up in Torquay, and has always lived by the sea. Marine science wasn't a common career track in the 1970s – it was a small field and there wasn't much choice of where to go to university. Malcolm got offers to study in Liverpool and London but he chose Bournemouth College of Science and Technology, which was far enough away from home but right by the ocean. He graduated with a London University external joint Honours degree in Chemistry and Zoology, tough at the time but in the long term, invaluable. At Bournemouth he learnt that he preferred the practical side of chemistry and was not over-keen on the theoretical, obscure aspects of physical chemistry, but he loved building things, making experiments work and solving problems and, in particular, he loved the ocean.

*Malcolm (right), with Rachel Mills, and Alessandro Tagliabue (Cruise PSO), on the RRS **James Cook** during the FRidge North Atlantic cruise, Christmas 2017*

In 1977, Malcolm heard about two jobs being advertised at the Institute for Marine Environmental Research (IMER), now Plymouth Marine Laboratory (PML): one was a biology role in the plankton group, and the other a chemistry post. Malcolm's initial thought was that he preferred the biology job, but Fauzi Mantoura interviewed him and appointed him as a chemist.

Early work at IMER

Malcolm's first experience of work at sea was very soon after starting at IMER and involved a series of regular three- or four-day surveys of the Bristol Channel with Bill Brown and Mike Jordan. At the time there were national plans to harvest energy from the Severn Estuary by means of a tidal power array between Minehead and South Wales; Malcolm's role was to carry out sampling as part of the scientific baseline surveys of particle loading, nutrient and chlorophyll concentrations, from on board the RRS *John Murray* or the 'Orange Banana' as she was 'affectionately' known – quite possibly the worst-coloured ship ever (see http://www.shipspotting.com/gallery/photo.php?lid=1287836)! These surveys left from the NERC ship base in Barry; like many of us, Malcolm stayed in the Barry Hotel, drank in *The Pixie*, and ate hot curry when the pub closed, and each morning on the way to the ship, walked past decommissioned steam trains, laid up rusting outside Barry Docks. There were many more cruises in and around the Celtic Sea on the *John Murray* over the first 10 years of Malcolm's career.

Strictly speaking, Fauzi had employed Malcolm as an organic chemist, and the first project was to build and deploy the first sea-going analyser for dissolved organic carbon (DOC). Malcolm was like a kid in a candy store; he got to build things and do practical chemistry, and he loved working with the team of scientists at IMER: Fauzi, Tony Bale, Alan Morris, Robin Howland, John Stevens and Reg Uncles. The DOC analyser was a success and the first samples analysed were those that were collected monthly, taken on a transect down the River Severn and its estuary by South West Water, who took the samples using a bucket lowered from a helicopter! The result – Mantoura and Woodward (1983)* – is a seminal paper, which has been cited hundreds of times. It describes the conservative behaviour of DOC in the estuary, which has huge implications for carbon cycling in the oceans.

After this project, Malcolm began working in 'proper' organic chemistry and began using an early gas chromatograph for a seasonal survey of volatile organic compounds in the River Tamar and estuary, especially focussing on the outputs from the Naval Dockyard and wash off from the Tamar road bridge at Saltash. Together, the team at IMER did a large number of river surveys from the flat-bottomed *Tamaris*, an adapted landing craft. They surveyed up the Tamar, slept on board with the DOC analyser still running, and surveyed back downstream the next day (with essential pub stops to allow the sample backlog to catch up). Outings to the River Dart and the River Fal really nailed the freshwater–brackishwater interface and described it for the first time.

Parallel to the DOC work Malcolm also started his first forays into nutrient analysis. Ammonium was not routinely mea-

*Mantoura, R.F.C. and E.M.S. Woodward (1983) Conservative behaviour of riverine dissolved organic carbon in the Severn Estuary: chemical and geochemical implications. *Geochimica et Cosmochimica Acta,* **47**(7) 1293–309. doi: 10.1016/0016-7037(83)90069-8 sured at IMER, or indeed anywhere else, so he spent a happy nine months learning about segmented flow colorimetric analysis and worked with Fauzi on a method for the reliable analysis of ammonium through the full salinity range of the Tamar estuary. That method, and derivatives of that method, are still widely used today. Indeed, that automated colorimetric technique for analysing ammonium was still one of the autoanalyser methods being used by Malcolm on the RRS *James Cook* during the 2017/2018 Atlantic cruise. The early colorimetric analysers had essentially the same glassware, connectors and tubing as now but the colorimeters were very simple with a light bulb and glass flow-cell for detection, large upright chart recorders (computers, what computers?) and a very basic auto-sampler with a timing mechanism. These machines needed a lot of looking after and this intensive work sowed the seeds for his future career path.

Broadening horizons

The group at Plymouth was now expanding its science and fields of research – in the early days, IMER was mainly a coastal laboratory, with cruises in the Severn Estuary, Carmarthen Bay and the Celtic Sea, never far from land and always on the smallest of the NERC ships. With the arrival of Nick Owens and Peter Burkill in the lab in the early 1980s, the scientific horizons broadened, and with the addition of the newer, larger RRS *Challenger* to the NERC fleet, bigger experiments could be carried out by a larger IMER team, further offshore into the Atlantic and North Sea.

By this time, Malcolm was getting more into nutrient measurements, and a big breakthrough was adapting and developing a new method for analysing very low (nanomolar) concentrations of nitrate and nitrite in oligotrophic (low-nutrient) waters. Previously these concentrations were below the detection limits of colorimetric autoanalysers. The early nanomolar methods were pretty scary – gas pressurised systems with boiling concentrated sulphuric acid to reduce the nitrate meant that by the end of the cruise Malcolm's clothes were full of holes from the acid burns – but the data were extraordinary and ground-breaking. Nick and Malcolm became close friends and they started the nitrogen cycling work at IMER with Nick working on development of the stable isotope mass spectrometer system for ^{15}N analysis and Malcolm now able to complement this, having the capacity to measure the nanomolar nitrate and nitrite concentrations in the oligotrophic oceanic regions.

Malcolm with Pascal Salaun (Liverpool University) on the RRS James Cook *in January 2018*

A knack for logistics

Malcolm's first big open ocean cruises were in 1986 as part of the Indian Ocean Expedition, with Peter Burkill as Principal Scientist. There were two cruises investigating biogeochemical cycling in the north-west Indian Ocean and the upwelling region off Oman. This is when Malcolm realised his skill for logistics and organising people. Shipping of chemicals was very different from today and all of the chemicals were sent out in a single container, within the then regulations. By the time the container arrived in the Seychelles, having been baked for six weeks in the sun on a container ship, all of the preweighed phenol had been ruined in the vials. A hastily arranged visit to the Victoria hospital in the Seychelles (where the cruise began) to replenish the stock of this essential chemical was enough to ensure Malcolm was very careful never to have to take advantage of health care in this region.

The cruise ended in Oman, where extraordinary bureaucracy meant each traveller needed 18 passport photos to enter the country, which had not yet opened up to tourism – but for Malcolm this was just another logistical problem to be dealt with. It was here that the challenges of working at sea, getting analysers operational and keeping them that way, plus the enjoyment of seeing different oceans and cultures, made sure that there would be no career changes for Malcolm.

The birth of the PML Nutrient Facility

There was a follow-up Indian Ocean cruise in 1994, and by then Malcolm had assumed responsibility for all the nutrient analyses at IMER, taking on the four-channel Technicon analyser for nitrate, nitrite, silicate and phosphate, which complemented the ammonia, DOC and the new nanomolar methods for nitrate and nitrite that he already worked with.

The Plymouth Nutrient Facility was born, and with it a desire to improve techniques and handling of samples, and then to improve the data quality outputs and reliability of the analyses. Involvements with major programmes grew, and early EU projects like EROS (European River Ocean System) introduced Malcolm to the global community, and there followed numerous collaborative cruises like CYCLOPS (2002), which was the phosphate-release experiment in the ultra-oligotrophic eastern Mediterranean. Involvement with UK programmes, underpinning the crucial nutrient analyses and running the scientific cruise logistics, as with the NERC UK Shelf Seas programme, has continued right up to the present day, with FRidge on the Mid-Atlantic Ridge.

AMT cruises

Nutrients and cruise logistics for the AMT (Atlantic Meridional Transect) programme took up much of Malcolm's time in its early years (1995 onwards), as there were then two cruises per year using the RRS *James Clark Ross* and her transit to and from the Falklands, transporting staff and equipment for the British Antarctic Survey. The early ideas and eventual inception of the AMT came from 'Met Obs meetings' which were named after meetings to discuss metereological observations when at sea, but were then held regularly in the basement of the IMER building (usually involving a bottle of wine or two at the end of the week). There in 1994 Jim Aitken, Roger Harris, Tony Bale, Dave Robins and Malcolm discussed and developed the idea for using the RRS *James Clark Ross* transit to sample the whole length of the Atlantic Ocean for the very minimal cost of staff time and consumables, just adding a couple of days' ship-time costs to achieve a full Atlantic transect. This Atlantic Meridional Transect has to be the best value science that has ever been funded in the UK.

In all, Malcolm has completed six whole AMT legs and five partial transects. Partial transects involved flying to the Falklands to set up the ship and train the scientists, leaving the ship at Montevideo and flying home. Or he would go to Grimsby to set up, the ship would call into Portsmouth to pick up aviation fuel for BAS aircraft and he would jump off and head home.

Malcolm was Principal Scientist for AMT11. It was funded with only 42 hours of science time that was eked out over the 40-day passage. Each day he would oversee two CTD deployments, zooplankton netting, and an optics dip to look at the optical properties of the surface ocean. The importance of ocean colour was of huge interest to NASA and they part-funded the early AMTs to help ground-truth the new *SeaWIFS* satellite data.

AMT was by then an international activity and Carol Robinson led the NERC consortium that funded AMT13 through to AMT18, on which Malcolm was again the Principal Scientist. Tim Jickells was the Principal Scientist for AMT12 and he requested that Malcolm sail with him to oversee nutrient measurement right across the oligotrophic ocean gyres. Malcolm upgraded all of his kit and delivered great data under all sea conditions.

Raising standards

Malcolm now works with the global marine community and is recognised world-wide as one of the leaders in the field – he has led the PML Nutrient Facility for over 22 years. He is proud of everything he has built up but most of all he wants to get good numbers and good data, and share this knowledge with scientists around the world. His mantra is about attention to detail: 'It is the many small changes and improvements you can make to cleanliness, handling, sampling, reagents, tubing etc. that make the difference,' he says. 'Lots of very small improvements add up to a large improvement in the overall quality of the analysis. There is rarely any one big thing, but everyone can make small cumulative changes and improve the quality of their analyses.'

Participating in the GEOTRACES programme and the UK cruises at 40°S (2010 and 2011) between Cape Town and Montevideo, with Gideon Henderson as the Principal Scientist, really challenged this attention to data quality and to the sharing of data. Rigorous comparison of data from cross-over stations and peer scrutiny of numbers is really important, and through Malcolm's efforts as part of a similarly minded team, reference materials are now regularly used by nutrient chemists across the globe. Reference materials are the key to good analyses but they are very expensive – Malcolm co-chairs an International SCOR (Scientific Committee on Ocean Research) Working Group (No. 147) whose aims include making low-cost reference materials which are now more widely available at a lower price. Malcolm oversaw the collection of nearly a tonne of Atlantic seawater last year on the ZIPLOc cruise (zinc, iron and phosphate in the Atlantic Ocean) with Claire Mahaffey as the PSO. He helped filter, cook (to 80°C), store and package this water and sent it to Japan for processing. There are now two sets of certified nutrient reference materials for deep and mid depth Atlantic seawater available from JAMSTEC (the Japan Agency for Marine–Earth Science and Technology) who are co-ordinating the sales on behalf of the SCOR working group.

Through his international working group, Malcolm has coordinated nutrient training workshops for scientists from developing countries – training young scientists from South Africa, India, China, Argentina and Mexico in the art of nutrient analysis and helping them with their lab and analytical techniques. This international effort to get the quality of analysis and data in all regions to the same level is an absolutely essential part of moving international science forward, so enabling the comparison of nutrient datasets in the future. Attention to data quality becomes even more important as we try to measure changes in the deep and upper ocean nutrient inventory in a warming planet – we can only do this effectively if our data are intercalibrated accurately. Malcolm and his group are looking for ideas for funding to maintain this international effort in the future.

Malcolm at the launch of the hull of the new polar research vessel, **Sir David Attenborough**, *in July. Malcolm represents UK marine chemists on the Scientific User Consultation team helping advise on the design and specification of the scientific areas on the new ship.*

Malcolm assures me that he still is fiddling with his techniques and trying to make them better. 'You have to question what you do, examine your data with a critical eye and learn from the best,' he says. He's picked up tricks from Cliff Law and Phil Boyd while visiting New Zealand as an international visiting scientist (2005 and 2006) and they shared ideas – Malcolm now uses 'nitrogen pillows' (known as Tedlar bags) to supply gas to his analytical system rather than bulky and hazardous pressurised gas systems, and with much better results. He also participated in the New Zealand South Pacific GEOTRACES voyage whilst there. As for the number of cruises he has been on, well, it's somewhere over 80, and one day they should be documented.

Malcolm is now regularly sought after to advise on techniques, to train up scientists, and advise on the development of new kit. This keeps him busy and he also has a number of projects lined up for the future (e.g. the ORCHESTRA and PICCOLO programmes in the Antarctic). He still has lots of enthusiasm and drive but somewhere down the line maybe he will want to do something different.

What's next?

Malcolm has always played hockey and now has ten international caps for Wales, scoring three goals for the Welsh Grand Masters team (his mother was born in Wales) in the Hockey World Cup in Australia in 2016, and following that up with another three goals in Barcelona, during the 2018 Grand Masters World Cup.

What happens when he retires? He has ideas to set up a gin distillery, but worries there may not be much to sell. We look forward to tasting Woody's Gin, and I predict it will be exceptional!

We need a plan for when we have to replace him – his is a fantastic job for the person with the attention to detail, ability to organise things and the energy and enthusiasm for a long career in marine science.

Rachel Mills, *January 2018*

Professor Roy Chester (1936–2018)

A tribute to a pioneering marine chemist

Roy Chester, Professor of Oceanography in the Department of Earth Sciences at Liverpool University from 1991 to 2001, died on 20 March 2018 after a short illness, aged 81. Roy graduated with a B.Sc in Geology in 1959 and was then awarded an Imperial Oil Company Scholarship for research into sedimentary geochemistry, gaining his Ph.D from Manchester University in 1963. In 1962 he came to Liverpool as an Assistant Lecturer in the Department of Oceanography, being promoted to Lecturer in 1965, Senior Lecturer in 1973, Reader in 1976 and Professor in 1987. He took over the established Chair of Oceanography from John Riley in 1989.

Roy had many research interests in the geochemistry of marine and lacustrine waters, sediments and marine aerosols. He published over 125 research papers, many of which were very highly cited. In the early 1970s Roy started working on deep-sea sediments and then, recognising the role of atmospheric deposition in supplying terrigenous clays to abyssal sediments, began a series of pioneering studies of atmospheric inputs to the ocean. His innovative work helped to create the whole field of research on atmospheric contributions to the oceans.

He developed a novel sampler, and his early work on the Saharan dust plume (with Harry Elderfield and others) set the scene for much that followed in this field. He began by considering the clay content of aerosols, but an important component of his research was his pioneering work on Saharan dust and other atmospheric particulate matter as external sources of trace metals and other chemical species to the Mediterranean Sea (with Peter Statham, Malcolm Nimmo and others). Scientists had realised that there had to be large quantities of Saharan dust entering the Mediterranean, but there were almost no measurements of the nature and amount of such inputs. Roy collected samples from some fixed stations in the western Mediterranean and during cruises through the Mediterranean. He made measurements of total and leachable trace metals, determining for the first time the nature of the major sources of trace metals for this important inland sea, and the relative contributions from Europe and from Saharan Africa. His novel methods for determining the solid-state speciation of trace metals were also important for understanding their solubility and biogeochemical impact in the oceans. Roy went on to show the importance of continental dust entering the Atlantic Ocean. The significance of his work was not just in understanding how these transport pathways operate, but also in the realisation that continental aerosols could be important for supplying fertilizing nano-nutrients, such as iron, to oceanic surface waters. Trace metal fertilization of the oceans remains a very active area of research and Roy would have been delighted that colleagues at the University of Liverpool continue to excel in this field.

As a teacher, Roy Chester was a firm believer in the principle of allowing cutting edge research to influence teaching. His collaboration with John Riley and Geoffrey Skirrow initially resulted in the research-level two-volume book, *Chemical Oceanography*, published in 1965, but realising that this was beyond the reach of undergraduates, he and Riley distilled the key components into the *Introduction to Marine Chemistry* published in 1971. This was a key resource for the BSc. teaching at Liverpool for many years and was widely adopted internationally as an accessible and authoritative overview of the subject.

Through his research and teaching Roy developed his description of the oceans as a unified system linked by a variety of pathways. He used this approach to develop his *magnum opus*, the textbook M*arine Geochemistry*, which ran for three editions (the third with Tim Jickells) and remains one of the most comprehensive and well-written marine chemistry textbooks to this day. Roy was keen to maintain its relevance and was talking to Tim Jickells about another edition only a few months before he died.

I remember Roy as an excellent colleague with a wonderful sense of humour. He led the Liverpool oceanographers through some difficult times but cared for all of the staff and was prepared to stand up for us when necessary. His Ph.D students and postdoctoral researchers benefitted from his careful and close supervision. Many of them were international students, and now hold academic posts all over the world.

Roy had more strings to his bow than most. He was a prolific novelist, penning murder mysteries and thrillers (including *The Toy Breaker*, *Pagan* and *Vengeance*), a member of the Mental Health Tribunal, and an active member of the Round Table. He was also a mad Liverpool fan, who never tired of ribbing me about my support for West Ham United FC and delighting in the inevitable thrashing that we got every season at Anfield! I missed Roy when he retired and will certainly miss him now.

George Wolff (University of Liverpool) with help from **Tim Jickells** *(*University of East Anglia), **Mike Krom** (University of Leeds) and **Martin Preston** (University of Liverpool)

Readers with connections with Oceanography at Liverpool might be interested in a special meeeting in May on 'The Ocean Tide and the Port of Liverpool'. For more information, see p.5.

John Wilson (1938–2017)

The interdisciplinary scientist whose innovative work shed light on cold-water corals

John Wilson worked at the boundary between geology and biology by studying modern shelf-sea environments, how these control the distribution of organisms living there and how these organisms became preserved in the fossil record. More specifically he focussed on those with calcareous skeletons such as molluscs and corals, their ecology and taphonomy (i.e. preservation/fossilisation), and how they contributed to the production of calcareous sediment on the UK shelf.

Born and educated in Edinburgh, John obtained a first class honours degree from Edinburgh University. After a year at Caltech he continued at Edinburgh with a Ph.D studying how bivalve molluscs became preserved in the intertidal sediments of the Solway Firth. Using an 'actuopalaeontological' approach, being pioneered by German workers such as Wilhelm Schäfer, he was able to demonstrate the differences between shell beds formed on tidal flats and those formed on the floors of tidal channels, and how different bivalve species were preferentially preserved in these sediments.

IOS and classic papers

Following his Ph.D in 1965, John obtained a lectureship for four to five years at Aberdeen before beginning his productive career at the Institute of Oceanographic Sciences (IOS), near Godalming, Surrey. Here he joined an active research group who were making major advances in the hydrography, sedimentology and ecology of the UK's shelf seas using innovative equipment such as side-scan sonar. At IOS John was one of the first to use manned submersibles to study deep-water coral reefs or thickets in waters 200–300 m down off the western shelf of the British Isles. This work led to a number of classic papers and his major contribution to our science. Fortunately, the videos and commentaries of some of his 1973 dives have been saved by colleagues working with the British Film Institute and can be viewed at http://www.lophelia.org/case-studies/pisces-and-rock-all-bank/pisces-videos.

In these pioneering submersible dives John made critical observations on how cold-water coral patches formed by *Lophelia pertusa* developed to form coral rings: large colonies expanding out from existing small fragments of hard substrate. The environmental controls on these formations (known today as 'Wilson rings') are still of research interest. Working in the cramped conditions in *Pisces* submersibles John's keen eye and observational skills were the vital ingredients that laid foundations for work on cold-water corals, which has been growing exponentially since the late 1990s.

Royal Holloway

With the closure of the IOS at Godalming in 1995, John moved to an Honorary Research Fellowship at Royal Holloway, University of London, where he carried out research on material collected during his many IOS cruises and assisted with teaching and Ph.D research supervision. A fortuitous meeting with André Freiwald led to fruitful collaboration on *Lophelia* reefs and thickets – most notably, the extensive Sula Reef on the Norwegian shelf.

Throughout his career John was always the most enthusiastic and supportive colleague and mentor. This enthusiasm for his subject was infectious and no-one who worked alongside John at sea or back in the lab will forget the passion he brought to his work and his sheer joy at seeing something new or unexpected for the first time.

Outside his passion for his subject John was an avid collector of militaria, memorabilia from the White Star Line and the *Titanic* (his father was a nautical engineer who transferred his skills to build an oil refinery for the Burma Oil Company). John is survived by his wife Leta, his two sons, Angus and Bruce, and three grandchildren Jonathon, Hannah and Chloe.

Dan Bosence (Royal Holloway, University of London) and **Murray Roberts** (University of Edinburgh), with assistance from Leta Wilson.

Above right *John proudly holding up a sediment sample, and (**left**) adding weights to the Smith McIntyre grab, with Bob Spencer and crew, on RV* Surveyor*, in March/April 1971.* ***Right*** *John examining dredged coral aboard the RV* Victor Hensen*, on the Galicia Bank, in April 1997.*

(Photos taken on board RV Surveyor *by courtesy of Colin Pelton; photo to the right, by courtesy of André Freiwald)*

This obituary first appeared in Geoscientist, ***28****(6), 2018. The two photographs taken on board RV* Surveyor *are from 'Memories of John Wilson' by Colin Pelton, which can be found at oceanswormley.org.*

SCOR is 60 not out!

SCOR – the Scientific Committee on Oceanic Research – is now in its 7th decade. Many readers will have been involved in SCOR programmes, but others may know little about it, despite the tremendous role it plays in coordinating and integrating ocean science across the globe, and the substantial involvement of UK scientists throughout SCOR history. Below, Gideon Henderson explains how SCOR facilitates and supports marine science in the UK and internationally. The first of the two pieces that follow describes one of SCOR's Large Scale Ocean Research Projects – IMBeR (Integrated Marine Biosphere Research) – while the second describes the aims of one of the 18 smaller and more tightly focussed Working Groups – IQuOD (International Quality-controlled Ocean Database). *Ed*

SCOR: building international science

Gideon Henderson, Chair UK-SCOR
Department of Earth Sciences, University of Oxford

SCOR was founded in 1957 by the International Council for Science in recognition of the international and interdisciplinary nature of ocean science. It aims to promote international cooperation in planning and conducting ocean research, and it enables trans-national ocean research to flourish. Since its inception, SCOR has had a track record of taking new ideas and challenges from the bench (or perhaps more accurately, ship) and nurturing them into international scientific activities. Its programmes span the full range of ocean science – biology, physics, chemistry and geology – and lead to findings with broad implications for ocean policy.

SCOR activities fall into three groups. One involves the initiation and organisation of Large Scale Ocean Research Projects to make the most of important opportunities or tackle major challenges in oceanography that cannot be addressed by one nation. Such SCOR Projects include WOCE, TOGA, GLOBEC, JGOFS, IMBeR, SOLAS, and GEOTRACES, all of which have allowed significant step-changes in our understanding of the ocean.

A second SCOR activity is sponsorship of Working Groups, each dedicated to addressing a timely issue in a particular area of oceanography. SCOR funding allows a group of international experts to meet, over a period of four years, to address a specific set of questions or goals. Last year SCOR announced three new Working Groups: numbers 153, on floating litter and ocean transport, 154, on integration of plankton observing systems, and 155, on eastern-boundary-current upwelling systems. Each year there is a call for proposals, allowing any group of scientists to suggest a subject they consider suitable for a new SCOR Working Group.

The third SCOR activity is capacity-building, by expanding the range of oceanographic expertise in developing nations. Key to spreading expertise are SCOR Visiting Fellowships, which allow leading oceanographers to run courses in developing countries, and the jointly sponsored POGO–SCOR Fellowships, which allow young scientists from the developing world to spend up to three months at leading oceanography institutes.

SCOR's organisation of this suite of activities is efficiently led by an executive committee of ten scientists, and a one-person secretariat in the form of Ed Urban – SCOR's Executive Director. SCOR representatives from member nations meet annually to steer existing initiatives and consider future ones. The next Annual Meeting will be in September 2019, in Toyama, Japan.

SCOR activities are funded by a combination of national subscriptions and grants from national funding councils which support certain programmes. In the UK, 51% of the national subscription is contributed by the Challenger Society, who are therefore the responsible organisation for UK interaction with SCOR, and 49% comes from the Royal Society. Challenger Council has recently taken on direct responsibility for UK-SCOR business (previously undertaken by a UK-SCOR Committee that met annually) and now has SCOR as a standing item on its agenda to ensure regular consideration of the interaction of UK oceanography with SCOR. SCOR activities are also reported to the Royal Society, through an *ex officio* SCOR position on the Society's Global Environmental Research Committee.

UK scientists have played a strong role in shaping SCOR activities over the years, and continue to have a presence on project steering committees and in Working Groups that far exceeds that expected from a single nation. The UK recently provided the President of SCOR internationally (Peter Burkill, 2014–16), and UK scientists have chaired many of the major programmes including SOLAS (Peter Liss, 2005–2007) and GEOTRACES (Gideon Henderson, 2006–2012); IMBeR is currently led by Carol Robinson (*see overleaf*). The UK also presently has 15 full members on SCOR Working Groups, including four in Chair positions. SCOR sponsorship has given UK scientists an opportunity to pursue their scientific ideas and integrate them with those of other oceanographers across the world.

Two contrasting examples of SCOR initiatives are described in the pieces that follow.

IMBeR: Ocean sustainability under global changes for the benefit of society

Carol Robinson (Chair of the Steering Committee)
School of Environmental Sciences, University of East Anglia

The Integrated Marine Biosphere Research project (IMBeR; www.imber.info) is one of the international research initiatives sponsored by SCOR. Now involving more than 2000 scientists from more than 80 countries, it began in 2005 with the central goal of providing '*a comprehensive understanding of, and accurate predictive capacity for, ocean responses to accelerating global change and the consequent effects on the Earth system and human society*'. The 2005 Science Plan had four themes:

- Key interactions between biogeochemical cycles and marine food webs.
- Sensitivity to global changes (such as ocean acidification, increasing temperature, inorganic nutrient limitation, deoxygenation and increases in marine harvesting).
- Feedbacks within the Earth system including oceanic storage of anthropogenic CO_2 and the impact of deoxygenation on emissions of nitrous oxide.
- Responses of society

The interdisciplinary science within these four themes was progressed through the work of four regional programmes, several task-oriented working groups, and international networking and capacity-building activities.

During 2014 and 2015, IMBeR took stock of its accomplishments over the previous 10 years, and engaged the scientific community in producing a new 10-year Science Plan. This has a mission to promote integrated marine research and enable development and implementation of strategies for attaining ocean sustainability within and across the natural and social sciences, and provide society with the information and knowledge necessary to secure sustainable, productive and healthy oceans. The new Science Plan is divided into three themes or 'Grand Challenges' which cover six priority research areas and incorporate four key topics or 'Innovation Challenges' (Figure 1).

IMBeR Grand Challenges

The first Grand Challenge relates to developing whole-system-level understanding of ecosystems, including biogeochemical cycles and interactions with humanity. One research question within this challenge asks what the major linkages, interactions and dependencies between human and ocean systems are, and how they are affected by global change at a range of time- and space-scales.

The second Grand Challenge is to predict future states of the oceanic ecosystem, and the consequences of global change for marine ecosystems and human societies, by incorporating into models a system-level understanding of the drivers of change in marine ecosystems. An example research question within this challenge asks what levels of ecological, biogeochemical and social complexity are required to provide realistic projections of future states, including human well-being and livelihood.

The third Grand Challenge aims to improve communication and understanding between IMBeR scientists, policy makers and society to achieve improved regional and international governance, adaptation to and mitigation of global change, and transitions towards sustainability. An example research question within this challenge asks how natural science, social science and humanities research can be integrated into global change research so that it is useful to policy-makers and society in general.

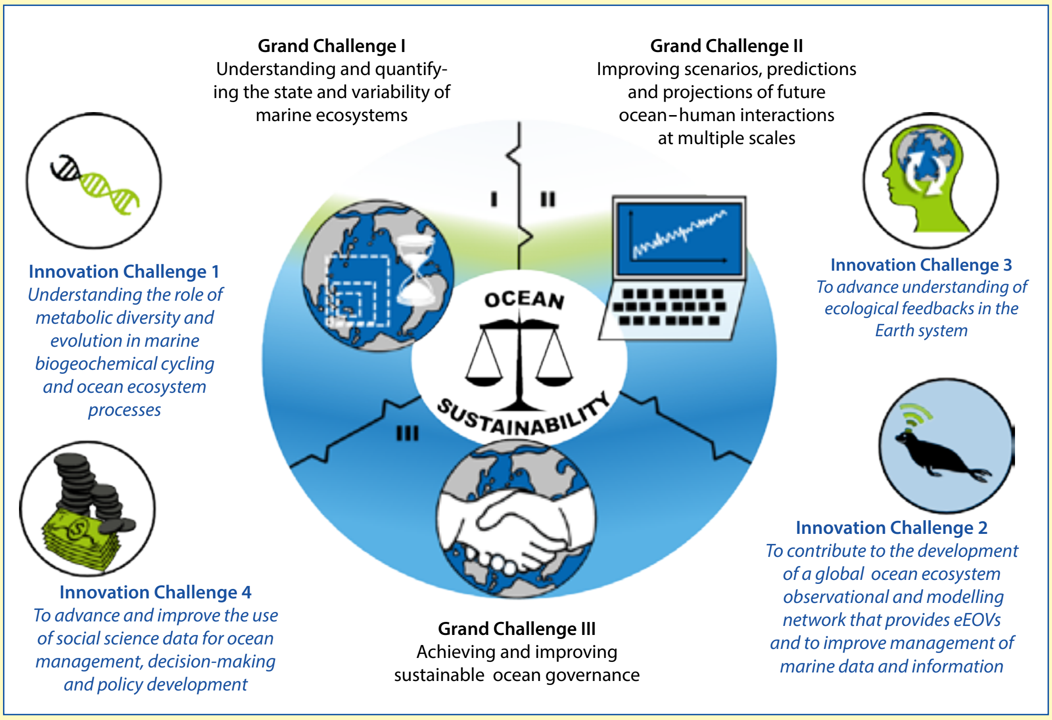


Figure 1 *The three Grand Challenges and four Innovation Challenges within the IMBeR 2016–2025 Science Plan. Note: An EOV is an Essential Ocean Variable, i.e. a quantity which is derived from field observations and which contributes significantly to assessments of the state of the ocean. An eEOV (Innovation Challenge 2) is a biological or ecological EOV.*

IMBeR Innovation Challenges

The Innovation Challenges are timely topics which we believe are tractable within three to five years and for which IMBeR is suitably placed to make a difference. The first Innovation Challenge asks how the diversity and evolution of marine organisms affect their resilience and their capacity to adapt to change. The second Innovation Challenge addresses the synthesis and integration of global datasets, and linkage of these datasets to ecosystem modelling. Innovation Challenge 3 asks how interactions between the ocean ecosystem and other components of the Earth system affect climate processes and how these interactions are affected by change; and the aim of the fourth Innovation Challenge is to progress the integration, analysis and synthesis of data and information collected at different spatial and temporal scales from across the range of relevant social and natural sciences.

Oversight of IMBeR activities is provided by an international scientific steering committee, and the day-to-day running of IMBeR is undertaken by teams at the International Project Office (IPO) in Bergen, funded by the Norwegian Institute of Marine Research and the Research Council for Norway, along with the Regional Project Office (RPO) in Shanghai supported by the State Key Laboratory of Estuarine and Coastal Research at the East China Normal University (Figure 2).

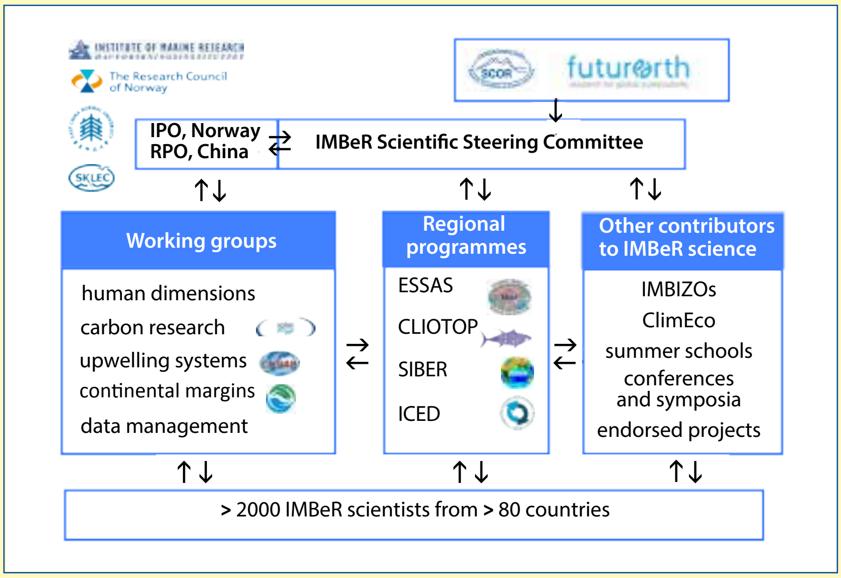


Figure 2 *The activities through which IMBeR facilitates networking and research*

Regional programmes

A large part of IMBeR research is completed through four regional programmes, each of which has a science plan overseen by a scientific steering committee. These are ESSAS (Ecosystem Studies of Sub-Arctic and Arctic Seas), ICED (Integrating Climate and Ecosystem Dynamics in the Southern Ocean), SIBER (Sustained Indian Ocean Biogeochemistry and Ecosystem Research), and CLIOTOP (Climate Impacts on Oceanic Top Predators). Some of the activities undertaken by these programmes during 2017 are given below.

ESSAS and ICED

ESSAS and ICED led the first comparative study of the ecological impacts of atmospheric and oceanic circulation on polar and subpolar marine ecosystems. The study highlights the effect of the strikingly different polar circulation patterns of the Arctic and Antarctic on the amount, thickness and duration of sea ice and the ecology of zooplankton, fish, seabirds and marine mammals.

Meeting the ever-increasing needs of the Earth's human population while maintaining biological diversity is one of the greatest challenges of our time. Despite bold international commitments, biodiversity continues to decline. One potential solution rapidly gaining momentum – as well as attracting opposition – is to incorporate the economic value of biodiversity into mainstream decision-making. ICED scientists and collaborators asked how well this approach is working for marine systems using examples from three contrasting regions, one of which was the Southern Ocean. These ICED case studies demonstrate that valuation can be useful but they also highlight the dearth of research exploring the ecological relationships which underpin the benefits that ecosystems provide.

SIBER

SIBER is co-sponsored by the Indian Ocean Global Ocean Observing System (IOGOOS) Programme, and focusses on understanding the effects of climate change and other anthropogenic forcing on biogeochemical cycles and ecosystems in the Indian Ocean. A major activity of SIBER is the Second International Indian Ocean Expedition (IIOE2, 2015–2020), which is motivated and sponsored by SCOR, the Intergovernmental Oceanographic Commission (IOC-UNESCO) and IOGOOS. The goal of IIOE2 is to advance understanding of interactions between the geologic, oceanic and atmospheric processes that give rise to the complex physical dynamics of the Indian Ocean region, and determine how those dynamics affect climate, extreme events, marine biogeochemical cycles, ecosystems and human populations.

CLIOTOP

The aim of CLIOTOP is to investigate key processes involved in the interaction between climate variability/change and human use of the ocean, and their effects on the structure of pelagic ecosystems and large marine species. A major output from CLIOTOP this year was the publication of a special issue of *Deep-Sea Reseach* including 27 papers on topics covering conservation biology, trophic ecology, fisheries science, climate change, and adaptive management. The introductory paper describes over a decade of CLIOTOP research which resulted in significant progress towards the goal of preparing both climate-sensitive predator populations and the human societies dependent on them for the impending impacts of climate change.

IMBeR working groups

In addition to the four regional programmes, six IMBeR working groups focus on ocean carbon cycling, ocean acidification, upwelling systems, continental margins, data management and human dimensions. One example is the ocean acidification subgroup of the carbon research working group (jointly organised by IMBeR and SOLAS, the Surface Ocean Lower Atmosphere study; http://solas-int.org/) which coordinates activities through the ocean acidification international coordinating committee (https://www.iaea.org/services/oa-icc). This working group also organises the Ocean in a High CO_2 World conference series and contributes to the global ocean acidification observing network (GOA-ON, http://www.goa-on.org/).

Other IMBeR activities

IMBeR also convenes open science conferences, biennial workshops (known as IMBIZOs: IMBIZO is the Zulu word for meeting or gathering) and biennial summer schools. IMBIZOs are targeted meetings which aim to lead to synthesis papers and dedicated journal special issues. For example, the first IMBIZO was held in Miami, USA, in 2008 and led to a special issue of *Deep-Sea Research* on the ecology and biogeochemistry of the mesopelagic and bathypelagic ocean. The latest IMBIZO – IMBIZO5 – was held in Woods Hole, USA, in October 2017, and position papers are currently being prepared aligned with the challenges of the new Science Plan on microbial metabolic diversity and evolution, critical constraints on future projections of marine systems and management strategy evaluation.

IMBeR has always aimed to contribute to training of the next generation of interdisciplinary marine researchers and practitioners, incorporating mentoring for early career scientists in all of its activities. In particular, we organise the biennial ClimEco (Climate and Ecosystems) summer schools. These are exceptionally popular; 200 applicants from 51 countries applied for the 65 places available at ClimEco5 in 2016. Students on the summer school spend a week attending lectures, participating in hands-on practical sessions and undertaking a group project related to predicting the socio-ecological impacts of global change. ClimEco6 was held in Indonesia in August 2018, and the next one will be in 2020. IMBeR has also recently initiated a network of early career researchers (Interdisciplinary Marine Early Career Network – IMECaN) to provide training, development, collaboration and leadership opportunities.

IMBeR communicates its activities through a website (www.imber.info), twitter account (@imber_ipo) and bi-weekly eNews Bulletins. To find out more about IMBeR activities, sign up to the eBulletin, apply for a place on the next summer school, or participate in one of our forthcoming conferences. The next IMBeR Open Science Conference (Future Oceans 2) will be held in Brest, 15–21 June 2019 (http://www.imber.info/en/events/osc/2019).

Further reading

Cavanagh, R.D., S. Broszeit, G.M. Pilling, S.M. Grant, E.J. Murphy and M.C. Austen (2016) Valuing biodiversity and ecosystem services: a useful way to manage and conserve marine resources. *Proc. R. Soc. B* **283** 20161635 doi: 10.1098/rspb.2016.1635

Hobday, A.J., H. Arrizabalaga, K. Evans, K.L. Scales, I. Senina and K.C. Weng (2017) International collaboration and comparative research on ocean top predators under CLIOTOP. *Deep-Sea Research II*, **140** 1-8. doi: 10.1016/j.dsr2.2017.03.008

Hofmann, E.E. and 10 others (2015) IMBeR – Research for marine sustainability: Synthesis and the way forward. *Anthropocene,* **12**, 42– 53.

Hofmann, E.E. and the IMBeR Scientific Steering Committee (Eds) (2016) *IMBeR 2016–2025: Science Plan and Implementation Strategy.* http://www.imber.info/resources/images/prosjekter/imber/IMBeR-Science-Plan-and-Implementation-Strategy-2017.pdf

Hunt, G.L. Jr and 16 others (2016) Advection in polar and sub-polar environments: Impacts on high latitude marine ecosystems. *Progress in Oceanography*, **149**, pp.40–81. doi: 10.1016/j.pocean.2016.10.004.

Steinberg, D.K. and D.A. Hansell (Eds) (2010) Ecological and biogeochemical interactions in the dark ocean. *Deep-Sea Research II* **57**(16) 1429–1592. https://www.sciencedirect.com/science/journal/09670645/57/16?sdc=1

The international Quality-controlled Ocean Database Initiative (IQuOD): subsurface temperature profiles

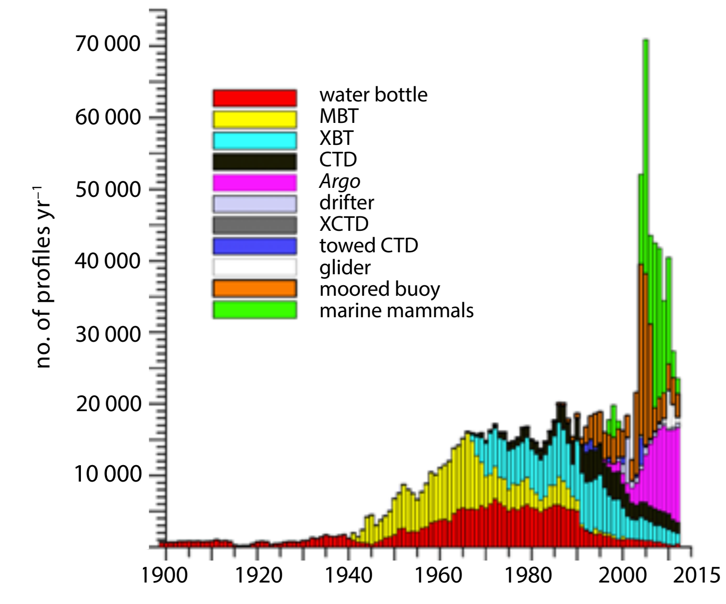
Matthew Palmer, Met Office, and Catia Domingues, CSIRO, Australia (Joint IQuOD Chairs) on behalf of SCOR WG148, IODE SG-IQuOD and CLIVAR IQuOD

The global ocean stores most of the excess heat energy accumulating in the Earth system as a result of human-induced greenhouse gas emissions. It is this accumulation of energy that is the fundamental driver of the various manifestations of climate change. As seawater warms, the ocean volume expands, raising global sea level. At regional scales, changes in ocean currents and physical water properties (temperature, salinity, density) can significantly influence geographical patterns of sea-level change, and also provide insights into changes in the global water cycle, particularly through changes in ocean salinity. In addition, the ocean's ability to integrate atmospheric signals, and propagate these relatively slowly, provides the climate system with 'memory', which is the foundation of seasonal and decadal forecasts around the world.

Why IQuOD is needed

To monitor variability and change in the ocean interior we rely on *in situ* observations, because unlike the atmosphere, the ocean depths are invisible to satellite-borne sensors. Over time, an increasing armada of observing technologies and platforms has become available (Figure 1), but the ocean is a challenging environment in which to collect *in situ* measurements, and most historical observations have relied on deployment of instruments from research and commercial ships. Routine measurements of the upper few hundred metres of the ocean only became available from the late 1960s. Ocean measurements extending to the sea floor still rely on dedicated research ships, including those in the GO-SHIP programme, with a typical cruise working 24 hours a day for several weeks or months to provide full-depth transects across an ocean basin (http://www.go-ship.org/RefSecs/goship_ref_secs.html).

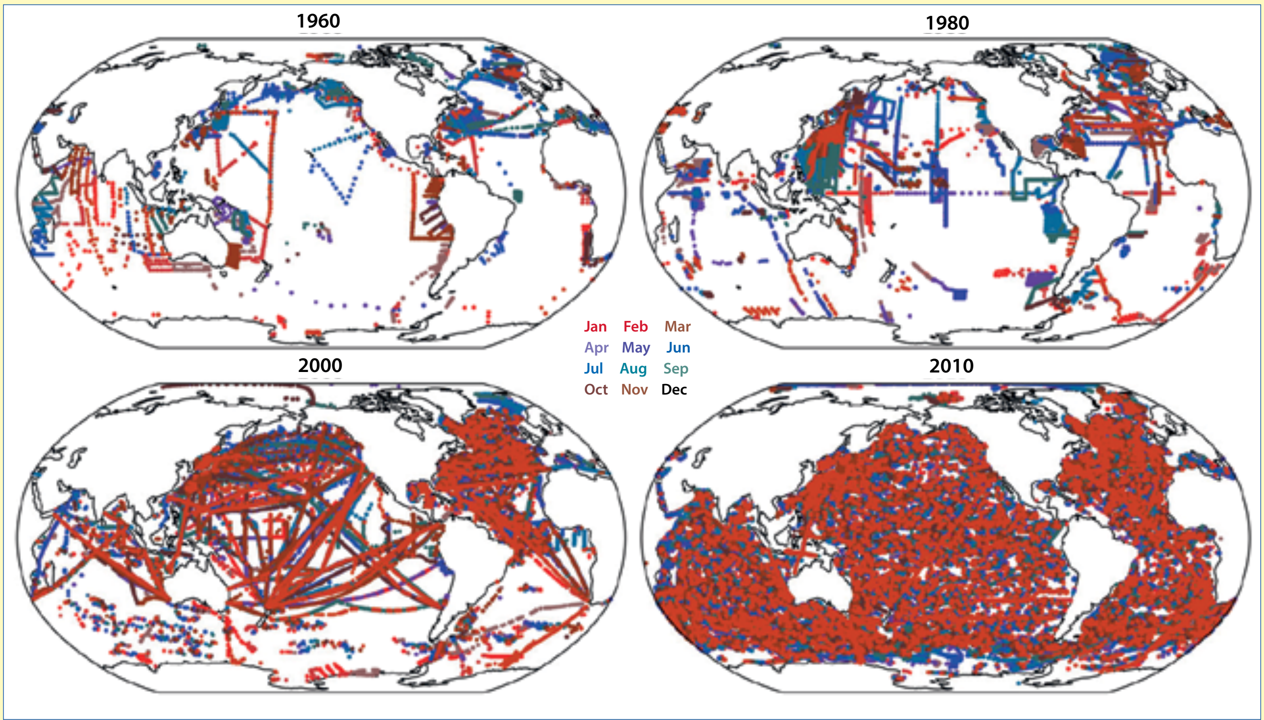
Figure 1 *Number of profiles per year by instrument type from the World Ocean Database. Note the marked increase in observations in the 21st century (see also Figure 2), mainly as a result of the* Argo *programme and the use of marine mammals. MBT = motorised bathythermograph, XBT = expendable bathythermograph (discussed overleaf), CTD = conductivity (for salinity)–temperature–depth probe, XCTD = expendable CTD. (Courtesy of Tim Boyer, NODC NOAA)*



The scarcity (Figure 2) of historical ocean observations, in addition to the investment of logistical effort, money and time spent in acquiring them, underline the need to maximise their utility for ocean and climate research and services of societal benefit. This is a challenge, in terms of finding optimal ways to extract maximum information from the sparse historical observations, eliminating erroneous data values, and correcting the inter-platform biases that can confound the analysis of ocean climate change.

In many cases, the metadata needed to help correct these biases are not available, so further work is required to provide a 'best guess' of specific instrument type and other aspects of the data records. The International Quality-controlled Ocean Database (IQuOD) initiative aims to address this challenge, through the timely development and distribution of the highest quality, most complete and consistent long-term database of ocean temperature profiles. This is being achieved over the next few years, through international coordination of resources from institutions in 17 nations, together with support from international programmes, such as SCOR, the International Oceanographic Data and Information Exchange (IODE) of the Intergovernmental Oceanographic Commission (IOC-UNESCO), and Climate and Ocean: Variability, Predictability and Change (CLIVAR), one of the four core projects of the World Climate Research Programme (WCRP). Under the auspices of SCOR, as a working group (WG 148) since December 2015, the IQuOD initiative is allowing coordinated progress in the objective development of data quality-control procedures, the documenting of instrumental uncertainties and providing 'best guess' estimates of missing metadata needed to develop corrections of inter-platform biases.

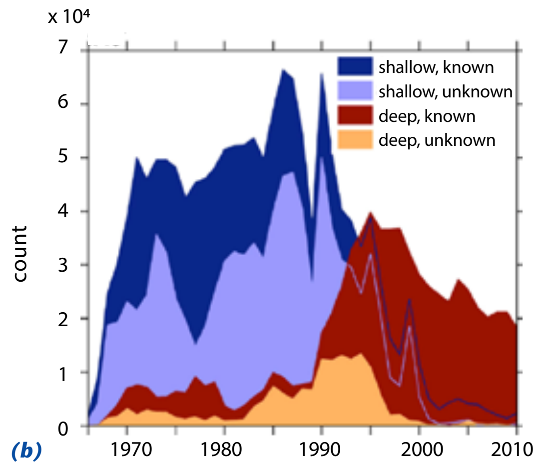
Figure 2 *Distribution of historical ocean temperature observations for all profiles that reach at least 700 m depth in four example years. Colours indicate the month in which the profile was recorded. (Courtesy of Simon Good and reproduced from Palmer, 2017)*



Getting the most out of historical data

Prior to the 2000s, the majority of ocean temperature profiles came from expendable bathythermographs, initially developed in the 1960s as a cheap means to measure upper ocean temperature from ships while underway (Figure 4(a)). However, it was discovered that XBTs record higher temperatures than research quality observational systems by an amount that has varied over time. This introduced artificial climate signals into observed global ocean temperature and sea-level change over the latter half of the 20th century, which were at odds with climate model simulations. Since 2007, a number of bias corrections for XBTs have been proposed but a key issue remains: the lack of metadata for a large fraction of XBT profiles (Figure 4(b) and (c)).

(a)



(b)

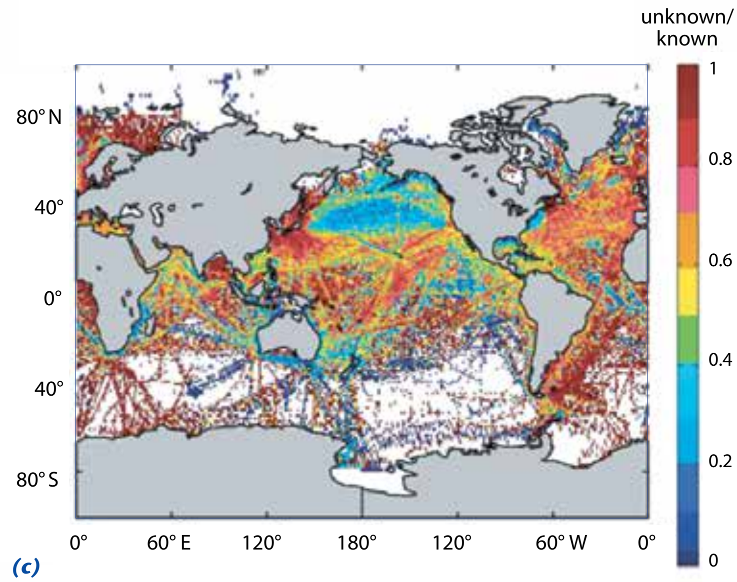
Figure 4 (a) *Deployment of an expendable bathythermograph (XBT). An XBT consists of a torpedo-shaped probe (here already discharged from its canister) inside which is a thermistor which is connected electronically to a recorder on the ship. The probe falls freely under its own weight, which enables a temperature profile to be recorded. Eventually, the wire runs out and breaks, and the XBT sinks to the sea bed. Since the deployment of an XBT can be done while a vessel is underway, XBTs are often deployed from vessels of opportunity, such as ferries. (Photo by courtesy of John Gould)*

(b) *The number of XBT profiles recorded each year and the proportion of profiles where either probe type and/or manufacturer is unknown (approximately 50% of the historical database). 'Shallow' and 'deep' XBT profiles correspond to nominal sampling depths of 460 m and 760 m, respectively.*

(c) *The ratio of shallow XBT profiles for which type and/or manufacturer are unknown, to shallow XBT profiles for which this information is known, as a function of geographic location. Where the number is close to 1, nearly all XBT profiles are of unknown type and/or manufacturer. Where the number is close to zero, nearly all XBT profiles are of known type and manufacturer. ((b) and (c) reproduced from Abraham* et al.*, 2013)*

Metadata include vital information needed to develop more accurate bias corrections, such as the specific XBT probe type used, the manufacturer, the cruise number, ship identification code and country of origin. IQuOD will help address this challenge by developing 'intelligent metadata' schemes to give a best guess answer when information on probe type and manufacturer are missing.

Another challenge is to address the mixed quality of the historical temperature profiles found, which is imperative for the development of more accurate bias corrections and ocean change estimates. IQuOD is working towards refining the quality of the ocean climate record through a systematic intercomparison of several automated quality-control (QC) procedures. The aim is to arrive at an optimal set of automated QC checks, drawing on the results of quantitative tests and coordinated input of expertise from around the world. This effort will improve the quality and consistency of the database and will allow us to quantify the impact of data QC on derived ocean data products and eventually even the accuracy of seasonal to decadal forecasts.



(c)

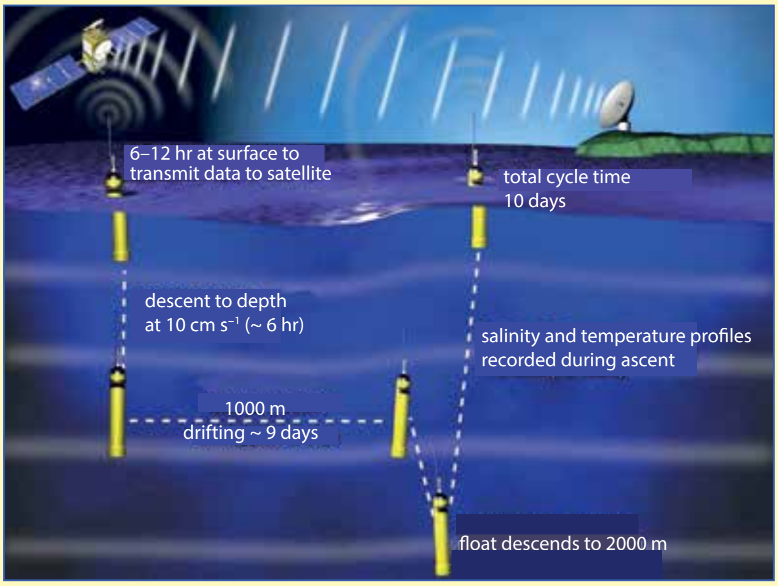


Figure 5 ***Left*** *An Argo profiling float observation cycle. The Argo array of autonomous profiling floats has provided unprecedented coverage of the open ocean since its inception in the early 2000s.* ***Below*** *Marine mammals, such as the elephant seals pictured, can provide valuable ocean observations in ice-covered regions of the ocean.*

For more information about Argo, see http://www.argo. Photo: Clive R. McMahon, IMOS Animal Tagging, Sydney Institute of Marine Science)

Linking historical and future observations

Since the mid 2000s, the *Argo* array of autonomous profiling floats has revolutionised our ability to observe the upper 2 km of the open ocean, and marine mammals are now frequently used to provide valuable observations in regions covered by sea-ice (Figure 5).

It is essential to sustain and build on these observations if we are to improve our understanding of ocean climate change, sea-level rise and the current rate of anthropogenic global warming. IQuOD data products are being developed so that they will operate with modern data streams, so promoting seamless analysis of both current and historical ocean change. Both modern and historical data will be treated with consistent quality-control procedures and provided with estimates of instrument uncertainties. This will help improve ocean data-assimilation products used to study historical climate change, and to initialise seasonal-to-decadal forecasts.

The historical observations, made by XBTs and other past observing technologies, provide essential context for the future changes that will be revealed by *Argo* and the evolving ocean observing system.

Further Reading

Abraham, J. and 27 others (2013) A review of global ocean temperature observations: Implications for ocean heat content estimates and climate change. *Reviews of Geophysics*, **51**(3), 450–83. doi: 10.1002/rog.20022

Cheng, L. and 14 others (2016) XBT Science: Assessment of Instrumental Biases and Errors, *Bull. Amer. Meteor. Soc.,* **97**(6), 924–33. doi:10.1175/BAMS-D-15-00031.1

Domingues, C.M., and M.D. Palmer, (2015) The IQuOD initiative: Towards an International Quality controlled Ocean Database. *CLIVAR Exchanges*, No. 67, International CLIVAR Project Office, Southampton, 38–40. http://www.clivar.org/documents/exchanges-67

Gouretski, V., and K.P. Koltermann (2007) How much is the ocean really warming? *Geophys. Res. Lett*. doi: 10.1029/2006GL027834

Palmer, M.D. (2017) Reconciling estimates of ocean Heating and Earth's radiation budget, *Curr. Clim. Change Rep*., **3**(1), 78–86. doi: 10.1007/s40641-016-0053-7

Palmer, M.D., T. Boyer, R. Cowley, S. Kizu, F. Reseghetti, T. Suzuki and A. Thresher (2018) An algorithm for classifying unknown expendable bathythermograph (XBT) instruments based on existing metadata. *Journal of Atmospheric and Oceanic Technology*, **35**(3), 429–40. doi: 0.1175/JTECH-D-17-0129.1

von Schuckmann, K. and 11 others (2016) An imperative to monitor Earth's energy imbalance. *Nature Clim. Change*, **6**(2), 138–44. doi: 10.1038/nclimate2876

You can find out more about IQuOD activities, workshops and publications at http://www.iquod.org.

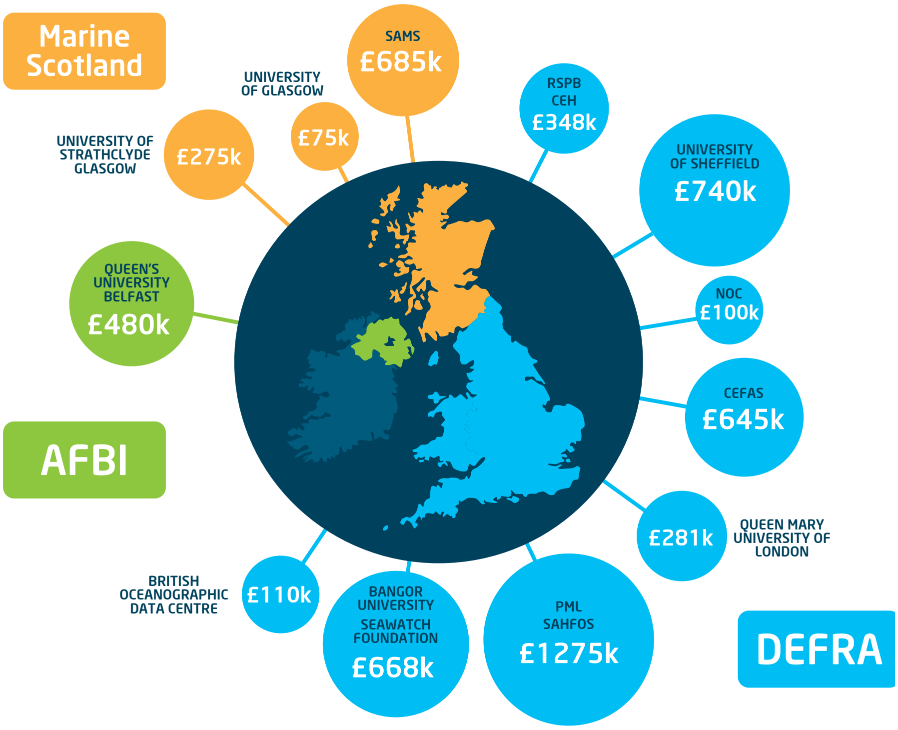
For more information about SCOR activities, see the Challenger website at http://www.challenger-society.org.uk/SCOR, or the SCOR webpage (www.scor), including in their 60th Anniversary Newsletter: http://www.scor-int.org/Publications/SCOR-NL-35.pdf

Filling the gaps for predicting the future

The Marine Ecosystems Research Programme (MERP)

Kelvin Boot

The NERC/Defra-funded Marine Ecosystems Research Programme (MERP) is now drawing to a close. MERP set out to integrate existing marine data and specially collected new data with current models and knowledge of marine ecosystem services in order to improve understanding of the whole UK marine ecosystem. Kelvin Boot worked alongside MERP scientists and stakeholders and here provides a summary of the aims, activities and outputs from MERP.



The NERC/Defra-funded Marine Ecosystems Research Programme partner institutes and their shares of the funding. The three main beneficiaries of programme outputs across UK administrations are Marine Scotland, Defra (England & Wales) and the Agri-Food & Biosciences Institute (Northern Ireland).

Services under stress

Marine ecosystems provide a wide range of 'services' to humanity, which are highly dependent on biodiversity and high ecological functioning. Perhaps the more recognised are the so-called provisioning services, of which wild-capture fisheries is the most obvious, but other ecosystem services also support human life and livelihoods, for example by contributing to climate regulation, leisure and tourism, and bioremediation of polluting substances. However marine ecosystems are facing ever-increasing stress and environmental change through human activities such as ecosystem restructuring generated by fisheries, eutrophication, pollution, and the CO_2-induced changes of global warming and ocean acidification. Other human uses of the ocean, like gravel extraction, generation of marine renewable energy and coastal development, also add to the stressors that we impose on the ocean.

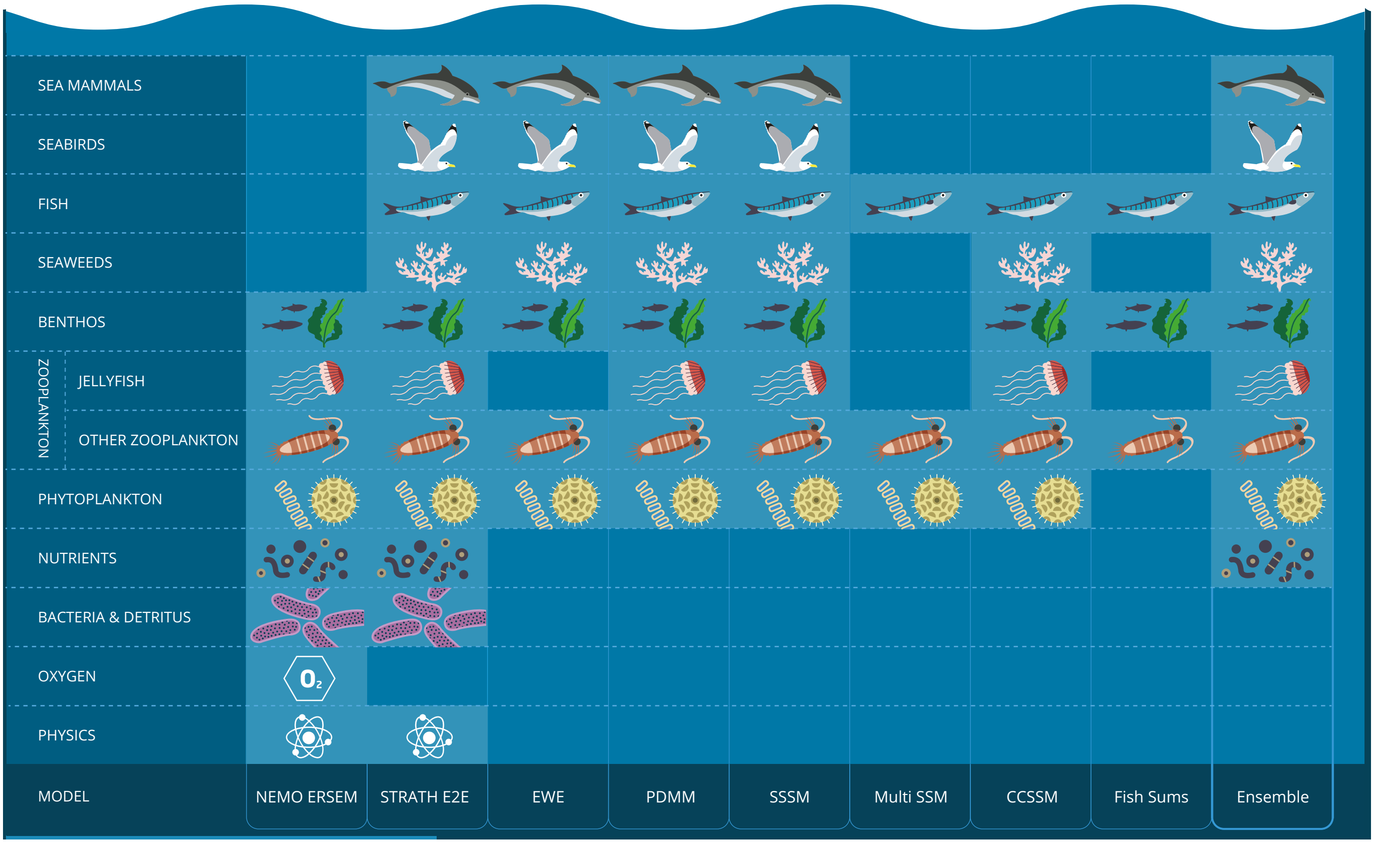
Our coastal seas are busy places with many competing demands and users; now, more than ever before, it is crucial for us to understand any consequences of changes and how they impact biodiversity and the delivery of ecosystem services. We now recognise that these impacts can have much wider consequences than had been previously suspected, due to interactions through food webs. Marine ecosystems are complex and it is essential to develop a much better understanding of how they function, how their constituent parts interact, and how they may change into the future. Policy-makers, regulators and the wide range of users are all concerned about maintaining the long-term delivery of services from marine ecosystems, so understanding the consequences of any changes is necessary when designing, testing and refining management approaches.

Bringing data together

Although there is considerable scientific activity and associated data-collection in the north-east Atlantic, from a whole-ecosystem perspective it tends to be fragmented, focussed on limited descriptors of food webs (e.g. a single tracer of trophic level) or components of the system (e.g. a specific habitat or component of the biota) or issues (e.g. fishery management or renewables), each largely reflecting the interests and responsibilities of individuals and organisations doing the work. There is widespread recognition among the research and policy communities that a whole-ecosystem perspective is now required. The step-change envisaged by MERP is to integrate existing data, specially collected new data, and state-of-the-art ecosystem models, all within a common framework built around the latest and most appropriate ecological theories, and to use these to improve our understanding of the whole marine ecosystem rather than just parts of it, how it responds to changes in pressures, and the consequences of those changes in terms of ecosystem services.

Working together

MERP brought together more than 50 scientists from 12 research institutes and a large number of supporting organisations. The quality of its outputs are a testament to the approach, which brought together scientists with different expertise and experience. They used the best available modelling approaches and developed them further, merged existing data from a range of sources and added new data where necessary; they also linked what they learnt about natural processes and ecosystem state to services, and tailored the programme's outputs to provide better understanding relevant to policies. It was an underlying aim that, in addition to laboratory studies, literature reviews, fieldwork and sampling cruises, MERP would bring together and further develop a suite of eight different marine ecosystem models, provide vital evidence, tools and advice to support compliance with the *Marine Strategy Framework Directive*, the *Marine and Coastal Access Act*, the *Marine (Scotland) Act* and the Common Fisheries Policy), and inform the OSPAR Joint Assessment and Monitoring Programme. MERP science has already fed into these and other guidelines, directives and legislation. Applying MERP outputs to forecasting



Dynamic Ecosystem Models, an interactive document on the MERP website, invites stakeholders to find the most appropriate model or suite of models to answer their queries. It provides information on a model's geographical and ecological coverage and scale, details of how it has been used, and links to the key contacts for each model. NB The place of 'jellies' as both prey and predator has been revealed by genetic studies during MERP and this knowledge has enabled a gap to be filled in ecosystem models.

any changes in the provision of ecosystem services as a result of natural and human pressures is an equally important outcome of MERP. The approach has been to follow the *National Ecosystem Assessment* (2011) guidance, focussing on food provision, biological checks and balances, leisure and recreation, and bioremediation of waste (see uknea.unep-wcmc.org/LinkClick.aspx?fileticket=ryEodO1KG3k%3D&tabid=82).

Science to support policy

Engagement with various stakeholder groups was identified as a priority for MERP, and a stakeholder advisory group (SAG) was brought together at the very beginning to ensure the programme would produce relevant and useful outputs. The SAG members, who came from backgrounds in policy advice, regulation, NGOs and industry, set the researchers a series of 14 policy questions, distilled from a much longer initial list, under the three headings:

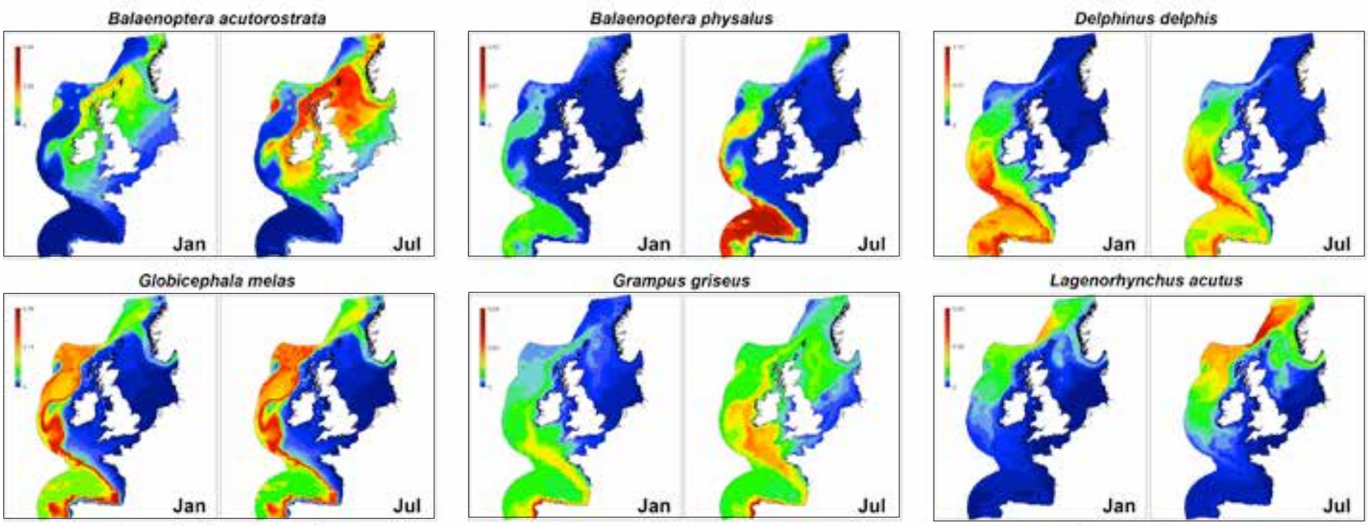
- The state of food webs (or their components) in relation to specified targets.
- Effects of natural and anthropogenic change on the state of marine food webs and the services they provide.
- The future state of marine food webs and ecosystem service provision under scenarios reflecting various management situations in UK waters.

Each of the 14 questions informed the route MERP research would follow, and how the eight models were brought to bear on bringing the resulting data together for making predictions. Groupings of scientists and modellers, regular dialogue and strategic meetings ensured good communication and sharing of challenges, approaches and solutions. A summary of how these questions were addressed, and how the models performed and produced specific outputs, has already been shared with stakeholders, in an online interactive document. A second web resource (*shown above*) demonstrates how each model has been used and how it contributes to a larger ensemble, looking across the marine ecosystem at different trophic levels and scales. This easy-to-use resource enables interested parties to select which model or modelling approach is likely to be the most relevant for a particular stakeholder question and further links to the model's website and the person who is best placed to help. The idea is that that stakeholders outside of the immediate stakeholder advisory group can see which model or combination of models is going to be most helpful. Hopefully, this will go some way to overcoming the barriers of stakeholders not knowing what is available or who to talk to, while satisfying scientists' desire for their work to be recognised and used.

Top predators

MERP's work on top predators and the part they play in ecosystems has brought together a huge amount of data revealing where cetaceans and seabirds are to be found, how their distributions vary with seasons, what they are eating and how they interact within ecosystems in top down/bottom up ways. A series of maps has been produced which will have imme-

The role of seabirds in marine ecosystems, their distributions and numbers and how they may be affected by human activities were key drivers in MERP. (Photo: Francis Daunt)



MERP brought together the most comprehensive dataset, to date, of top predator distributions and movements in UK waters, resulting in a series of unique maps. The maps, being published as an Atlas*, will provide an invaluable tool for decision makers. Here are distributions of just six cetaceans.* ***Top:*** *minke whale, fin whale and short-beaked common dolphin;* ***bottom:*** *long-finned pilot whale, Risso's dolphin and Atlantic white-sided dolphin. In all, 35 species will be covered, 12 of them in greater detail. Publication of the* Atlas *is planned for early 2019.*

diate utility for stakeholders concerned with Marine Protected Areas and *Marine Strategy Framework Directive* indicators, and marine management including that relating to effects of offshore renewable energy installations, and risks posed by bycatch, shipping and offshore developments. This unique series of maps is now, thanks to additional funding, being brought together as an *Atlas*, which will soon be available online (*see above*).

Fish, fisheries and fishing

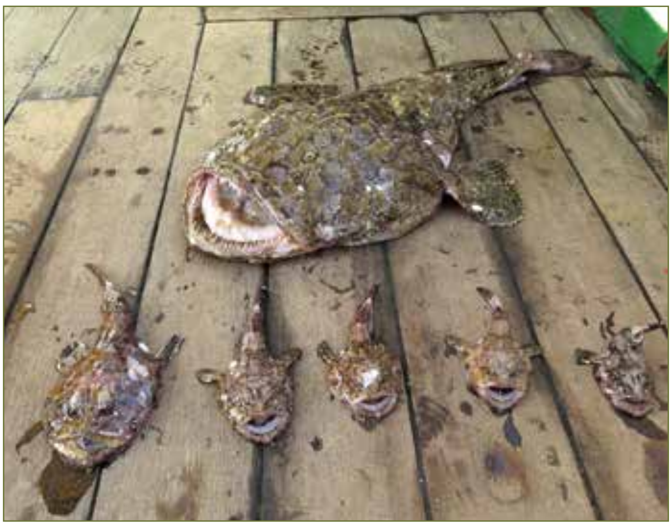
Fishing remains an important UK industry that exploits natural marine ecosystems to provide food and employment, as well as supporting strong cultural identities within the coastal communities concerned. The Marine Ecosystems Research Programme investigated fish, fisheries and fishing across many of its research threads, from better understanding of how fish fit into and control trophic cascades, to modelling the impacts of commercial fishing on target species and the ecosystems of which they form a part. Investigations into fish-related topics provide excellent examples of how groups of scientists have been assembled within MERP to share expertise and techniques in order to reach new conclusions and approaches, which not only increase our knowledge base but are also of great utility for a wide range of marine stakeholders. Dedicated MERP research cruises and modelling showed how the effects of fishing on marine ecosystems vary with regional productivity.

MERP provided an opportunity to 'tune' models to embrace more parameters, such as the inclusion in the *Strath E2E* model of migrating fish species to refine the annual cycles which many models do not cater for, but which have dramatic impacts on model outputs. MERP also used the *Ecopath with Ecosim* model to question whether marine renewable energy devices are a positive benefit to fisheries, by providing 'reefs' and sanctuary, or deleterious by displacing existing fisheries or disturbing important sea-bed habitats and their benthic communities. At another level, genetic sequencing was applied to open the possibility of identifying overlooked species, as well as unravelling the relationships between prey and predator: the technique has already been used to disentangle the relationship between fish and jellyfish – a previously neglected but important link in ecosystem models.

Natural capital

As human populations grow in size, coastal communities increase and the pressures on the seas that surround our coast spread: the shallow seas that encircle the UK are busy places with often competing demands on them. Improving our understanding of how the marine environment functions to maintain natural capital – so continuing to provide goods and services – and of how we balance our varied demands upon marine natural capital, is essential for a sustainable future for the seas and ourselves. MERP brought to bear a vast range of skills and experience from experts ranging from empirical scientists to modellers to socio-economists, with the aim of understanding how we can maximise the benefits we get from our seas through trade-offs between economic, ecological and cultural activities and services while maintaining clean, safe and healthy seas, and the living natural capital they contain.

Kelp communities and mussel beds are both examples of valuable marine capital. MERP investigated the overlooked but



Monkfish collected on a cruise aboard the Prince Madog*. Species size-spectra were included in the models.*
(Photo: Leigh Howarth)

important connectivity between kelp communities, coastal carbon stores and the food web. Research 'mini-cruises' sampled at various points around the coast and found that the levels of seaweed-derived carbon in diets of sediment fauna, many kilometres from land, are greatest during autumn and winter when seaweed detritus production is also high. This link highlights the need to think more widely to manage and protect subtidal carbon stores and has already attracted international attention. Another MERP project looked at the part played by mussels in bioremediation. Mussels are able to bioremediate many types of waste, including excess phytoplankton resulting from eutrophication of coastal waters, toxic products of plankton, highly carcinogenic and mutagenic particles from burnt fossil fuels, heavy metals, microplastics, nanoparticles and pharmaceuticals. Thus while it has not been possible to place a financial value on mussels' bioremediation of waste, there is no doubt that it is an important contributor to a healthy ecosystem, and anything that reduces mussels' ability to provide this service is likely to have impacts on water quality and knock-on effects for other ecosystem processes, food supply, recreation and tourism.

'Mini research cruises' carried out at various locations around the UK showed that the influence of kelp as a carbon source for benthic organisms stretched many kilometres offshore

Sea-bed sediment maps

Access to reliable maps of the sea bed is essential for addressing marine policy, planning, spatial management and scientific issues; existing maps are patchy, leaving large gaps in our knowledge, but filling these gaps would be expensive and time-consuming. Benthic species have differing sediment requirements, so mapping sediments can be helpful in providing information on mud content and median grain size, enabling identification of ecologically distinct habitats. Statistical models have been shown to have the ability to predict sediment composition in British waters and the North Sea with a high degree of accuracy. By taking existing data on sea-bed sediments and combining it with statistically modelled values, the missing parts of the sea-bed jigsaw puzzle can be added and help to provide a series of 'synthetic' maps of the north-western sedimentary environment covering the area from the Bay of Biscay to the Faroes. This approach, developed by MERP scientists, has produced the most extensive dataset of sediment composition and disturbance regimes, over a large spatial scale, available to date.

It all comes back to stakeholders

The mosaic of activities and interests around our coasts can be complex, including industries such as fishing, aquaculture, gravel extraction, shipping and trade, offshore energy and tourism. Individuals may pursue angling, bird- or whale-watching, or simply enjoy a walk along the seashore; others just like to know we have 'clean and healthy marine environments'.

Ideas coming together at one of the stakeholder workshops. Stakeholder engagement and feedback were guiding principles of MERP.

A wide range of bodies are involved in managing the coast for economic, environmental and cultural sustainability. These stakeholders have an interest in using the coast, but increasingly they may come into conflict as competing users demand their share of coastal seas. MERP has completed an analysis of its stakeholder landscape, which involved mapping 278 representative stakeholders in terms of their interest in MERP, their power and influence over policy, and their potential as funders for future works. Three stakeholder 'defining workshops' were held during April–May 2017 for North Devon, Cornwall and the west of Scotland, each attended by a range of fishing industry, NGO and policy-related representatives. The workshops aimed to document stakeholders' expectations and ambitions for the direction of change of a range of attributes of the state and exploitation of their marine regions. Interviews were filmed and edited and will be used to re-interview individuals to see how their needs and attitudes may have been modified in the face of changes that are taking place, and information gained from models that predict consequences of various activities in the marine environment.

MERP works

MERP outputs, backed up by 75 (to date) peer-reviewed scientific papers, are making their mark. More than 140 external presentations have taken MERP results to Defra, the Scottish Government, Natural Resources Wales, ICES, ASCOBANS, the UN Sustainable Development Group, JNCC, Natural England, PICES, the European Parliament, UNEP MMO, CSIRO, the UN and other bodies concerned with managing our seas. As with any significant research programme, MERP results will take time to be analysed and further outputs and publications will be forthcoming, and there is no doubt that MERP will continue to be relevant into the future.

This article can highlight only some of the diversity of approaches and results of MERP to give a flavour of the vast amount of research and development that it carried out. Stakeholders and other readers are encouraged to visit marine-ecosystems.org.uk for more details of the various MERP projects, the people who led them and their outputs, along with links to the interactive documents and the models. The Marine Ecosystems Research Programme is now drawing to a close, having made major inroads into answering the questions it was first set. Some data-gathering continues and other data are still being analysed, but the outputs so far have provided some novel insights into how our coastal marine ecosystem functions, how its constituent organisms interact and how they may be affected by change. MERP has identified further gaps in our knowledge, but demonstrates that by bringing to bear upon the challenge a diverse group, with widely differing expertise and experience, the complex jigsaw puzzle that is the coastal environment can be pieced together.

Kelvin Boot is a science communicator working with Plymouth Marine Laboratory and the Marine Ecosystems Research Programme. kelota@pml.ac.uk

Making progress with the plastic problem

As might be expected, the problem of plastics in the ocean was addressed by quite a few presenters at the Challenger Conference in Newcastle. We learnt about microplastic pollution of the ecosystem in the Rockall Trough, and about modelling the three-dimensional distribution of plastics in the ocean. There were talks and posters about different ways of assessing the amount of plastic in the marine environment using direct sampling along the coast, using the Continuous Plankton Recorder at sea, and using a hyperspectral infrared camera on an unmnanned automated vehicle, and from satellite. (For more information, see the Conference abstracts at challenger-society.org.uk.)

Valuable though all this research is, if we want to reduce the rate at which plastic is entering the ocean (significantly reducing what is already there must be a lost cause?), there can be no doubt that the most pressing need must be to prevent the plastic entering the sea in the first place – a point strongly made by keynote speaker, Erik van Sebille. It is therefore heartening to learn that a pilot project with this aim, described in *Oean Challenge*, **22**, No.1, is now up and running.

The project, which is the brainchild of architect Ramon Knoester, involves trapping plastic that has been carried down the rivers Rhine and Meuse into Rotterdam harbour, and putting it to good use.

Once recycled, the plastic has been used to construct modules that fit together to form a 'Recycled Park', 140 m^2 in area. Not only does the park illustrate that plastic litter collected from natural watercourses is a valuable material, but the building blocks create a new riverside green area for Rotterdam and have an ecological function as habitat for micro- and macrofauna, such as larvae, snails, flatworms, beetles and fish. The floating park provides birds and aquatic fauna with food, breeding grounds and shelter, so stimulating the ecology in Rotterdam harbour as a whole.

Ramon hopes that Rotterdam can set an example for port cities elsewhere in the world. He sees such local projects as contributing to a larger aim, which he is pursuing through the Recycled Island Foundation (RIF) which he and others founded to develop an active approach to tackling plastic pollution in open waters worldwide. Along with retrieval of debris from rivers and river mouths and the sustainable use of plastics, RIF organises clean-ups, and works to create awareness and improve education about sustainability.

Related links

https://youtu.be/ZpwtWPnta68 = Opening Recycled Park

https://www.youtube.com/watch?time_continue=1&v=lna6cOELLT8

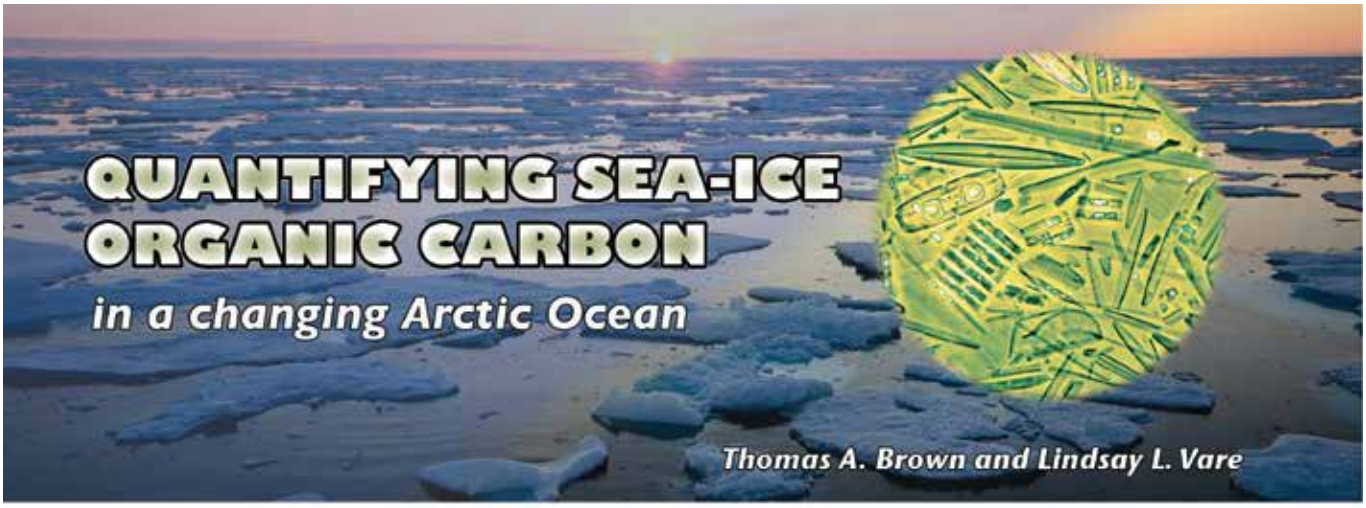
https://www.youtube.comwatch?v=vwE7A-9SRcYk

www.recycledpark.com

A short video about the making of the 'Recycled Park' is available on request from Ramon Knoester ramon@recycledpark.com

Ed.

Right *One of the plastic traps being used in Rotterdam harbour. The traps were tested, monitored and improved over the course of a year and a half, resulting in a system that works effectively even with heavy ship traffic, tidal current reversals and variable wind direction.*
Below left *The first artifical islands, some recently planted.*
Below right *A nesting coot making use of the new habitat.*



Sea ice is a key feature of the Arctic Ocean, but since satellite-borne sensors started observing and measuring Arctic sea ice, its extent has been continually declining; today, sea-ice cover in the Arctic is about 60% of that in the late 1970s (Figure 1). There is an urgent need to gain a better understanding of the significance of sea ice as a habitat for specially adapted sea-ice algae which form the basis of the Arctic food web. Although in a practical sense we are unlikely to be able to slow the loss of Arctic sea ice, knowledge gained through the study of sea-ice algae will be important for helping society adapt to the change by, for example, developing novel management approaches to reduce stress on sub-Arctic commercial fisheries that may be impacted by the effect on the ecosystem of a loss of sea ice.

Sea ice: a dynamic environment for life

Sea ice covers, on average, 25 million km^2 of the Earth, about 6% of the ocean surface. In the Arctic, in summer, sea-ice covers about 6–7 million km^2, which increases to an average maximum areal extent of approximately 15–16 million km^2 in the winter months. As seawater freezes to form sea ice (see Box), a complex interior network of pores and channels forms, which can provide a unique and dynamic habitat for micro-organisms, including sea-ice diatoms.

In the Arctic, much ice survives year-round, so multiyear ice up to 4–5 m thick is formed, but it is within the thinner seasonal ice cover, which freezes and melts each year, that most ice algae are found (see Box). In some regions of the Arctic over half of the total annual primary

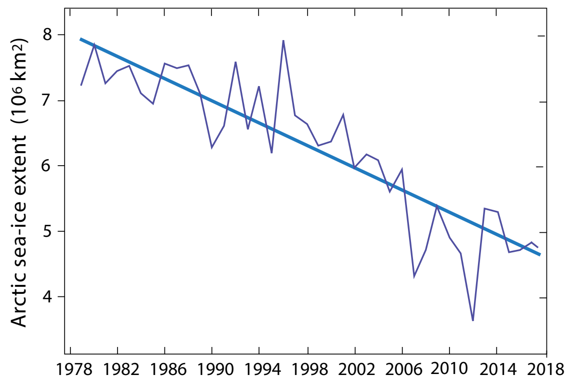


Figure 1 *The observed September Arctic sea-ice extent for 1979 to 2018, showing a decline of 13.3% per decade. (Courtesy of the National Snow and Ice Data Center, University of Colorado, Boulder)*

Sea-ice cover in the Arctic has declined by about 40% since the late 1970s

Seasonal and multiyear ice in the Arctic

In contrast to the waters around Antarctica, where sea-ice forms seasonally, in the Arctic a significant proportion of sea ice survives from year to year, with the result that much of the Arctic Ocean is permanently covered in ice, and most Arctic pack ice is several years old. Pack ice is continually moving under the influence of winds, and as it cracks and shifts, layers of ice raft over one another; where ice floes are forced together, pressure ridges form, increasing the ice thickness locally from 3–5 m to 40–50 m. These processes, combined with the snowfall that is added each winter, means that its albedo is higher; incoming solar radiation which is not reflected is greatly attenuated as it passes through multiyear ice. By contrast, the sea ice that forms anew each winter is much thinner and carries less snow, and in the spring sufficient sunlight can penetrate through the ice to allow photosynthetic organisms to flourish in the lowest parts.

When seawater begins to freeze, relatively pure ice is formed, so that the salinity of the adjacent seawater is increased. Most of the salt in sea-ice is therefore in the form of concentrated brine droplets trapped within the ice as it forms. The presence of salt lowers the freezing point (which is why salt is used on icy roads), and so the droplets gradually melt their way through the ice, forming cavities and channels, and providing a habitat for micro-organisms.

production can originate from the sea-ice habitat, providing a valuable food source for many consumers both in the water column (pelagic) and at the sea floor (benthic).

Optimal conditions for primary production associated with sea ice usually occur in spring, when sufficient solar radiation provides the stimulus for the spring sea-ice algal bloom. In springtime, diatoms are one of the most important groups of primary producers within Arctic sea ice. As summer approaches, seasonal sea ice melts, removing the physical ice habitat, and ice-adapted microorganisms are released to the underlying ocean. (The implications of this are discussed on p.28.)

Particulate organic carbon associated with Arctic sea-ice

As the climate warms and sea-ice extent continues to decline, there will be an associated loss of the physical habitat that currently supports the diatoms and other micro-organisms that live in it, leading to a net loss in particulate organic carbon of sea-ice origin, i.e. the micro-organisms themselves, organic remains, faecal pellets etc. The reproductive life-cycle of certain Arctic macro-fauna, such as calanoid copepods and amphipods (Figure 2) that graze upon sea-ice algae, are inextricably linked to the timing of the sea-ice algal bloom. Many larger animals, from fish, up to seals, whales and polar bears, time at least some activities – especially hunting and reproduction – to coincide with the spring sea-ice bloom period in order to take advantage of the abundant energy-rich supply of organic carbon. Sea-ice loss is therefore likely to have a broad and complex range of ecological impacts. Yet, beyond our direct observation of interactions between animals and sea ice, quantifying the amount of sea-ice particulate organic carbon taken up by the ecosystem is challenging. This is one of a number of problems that we need to solve if we are to be better placed to predict the future ecological impact of declining sea-ice cover. To improve our understanding of the role in the ecosystem of particulate organic carbon from sea ice before it disappears, we first need to be able to accurately and unambiguously distinguish, as well as quantify, this particular type of organic carbon so that we can track it through the ecosystem.

Figure 2 *A 'swarm' of amphipods feeding on sea-ice algae. These amphipods are often the dominant fauna at the underside of Arctic sea ice, and are consumed by Arctic cod and seals.*
(Courtesy of Shawn Harper, North Carolina Department of Natural and Cultural Resources)

Amphipods are just one of the groups of crustaceans that feed on sea-ice algae

Developing a chemical signature for sea-ice particulate organic carbon

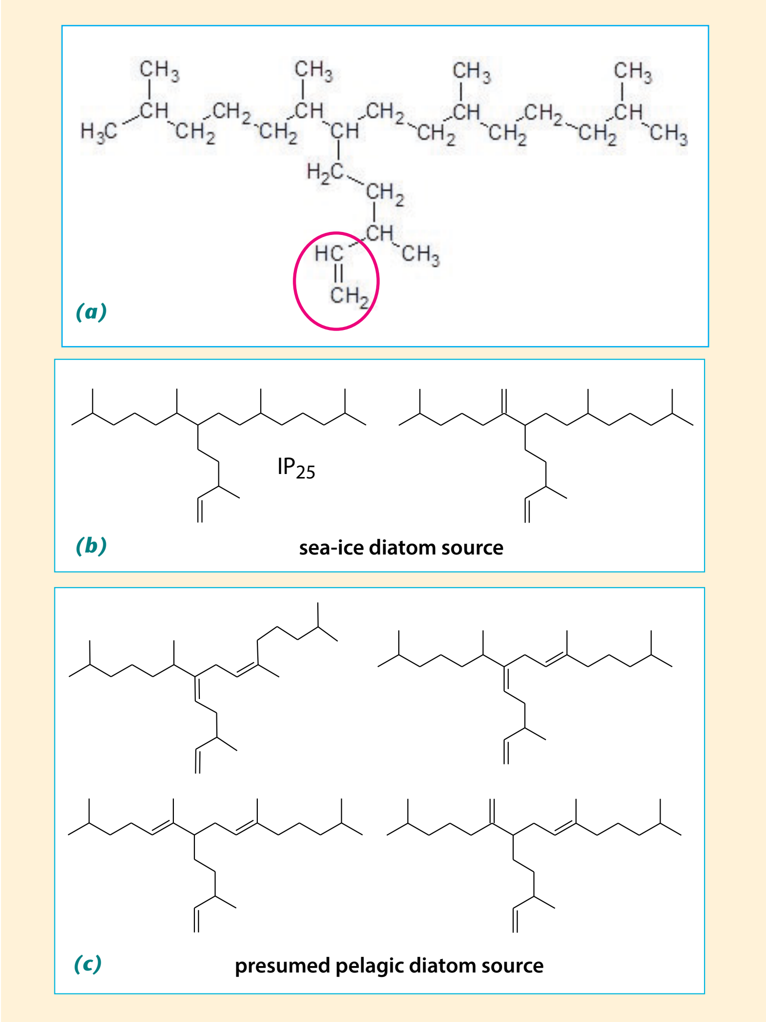
One approach that is beginning to offer new insight into the cycling of sea-ice carbon in the Arctic uses the analysis of hydrocarbons known as highly branched isoprenoids, or 'HBIs'. This is the name given to a group of lipids usually containing 20, 25 or 30 carbon atoms and with one or more double bonds between carbon atoms (Figure 3). A growing number of HBIs have been identified in aquatic environments, being characterised as either alkanes or alkenes, with variations of the latter being distinguished by both the number and position of double bonds. The most commonly reported HBIs are the alkenes with 25 carbon atoms, and between one and six double bonds.

The biological source of these HBIs, considered to be secondary metabolites,* was determined by John Volkman and his team (CSIRO, Tasmania), when they identified C_{25} and C_{30} HBIs in cultures of the marine diatoms *Haslea ostrearia* and *Rhizosolenia setigera*. Following this initial biological identification, subsequent studies went on to discover further diatom species that appeared to share the ability to biosynthesise HBI lipids, although HBIs are not present in all diatoms. The global ubiquity of HBI-producing species of diatom has meant the use of HBIs in environmental research can span freshwater and marine systems as well as temperate and polar settings.

Observing how the number of double bonds in the HBIs synthesised by *Haslea ostrearia* decreased as the culturing temperature in the laboratory was decreased, Simon Belt, Guillaume Massé and Steven Rowland from Plymouth University hypothesised that species of *Haslea* diatoms living in very cold conditions, such as those found at high latitudes, might synthesise an HBI possessing a single double bond. It was further postulated that the specificity of the biosynthetic pathway of HBI production in cold-water species of *Haslea* would make such an HBI structurally unique and, therefore, distinguishable from any other. With the support of Canadian researchers, the team confirmed this hypothesis by identifying

*Secondary metabolites are organic substances produced by an organism, which are not directly involved in the normal growth, development or reproduction of the organism. Their purpose is often unknown.

Figure 3 ***(a)*** *The structure of the highly branched isoprenoid (HBI) known as IP_{25}, showing the positions of the hydrogen atoms and the 25 carbon atoms, and the position of the single double bond.* ***(b)*** *Structures of HBI lipids from sea-ice diatoms and* ***(c)*** *structures of HBI lipids presumed to originate from pelagic diatoms.*

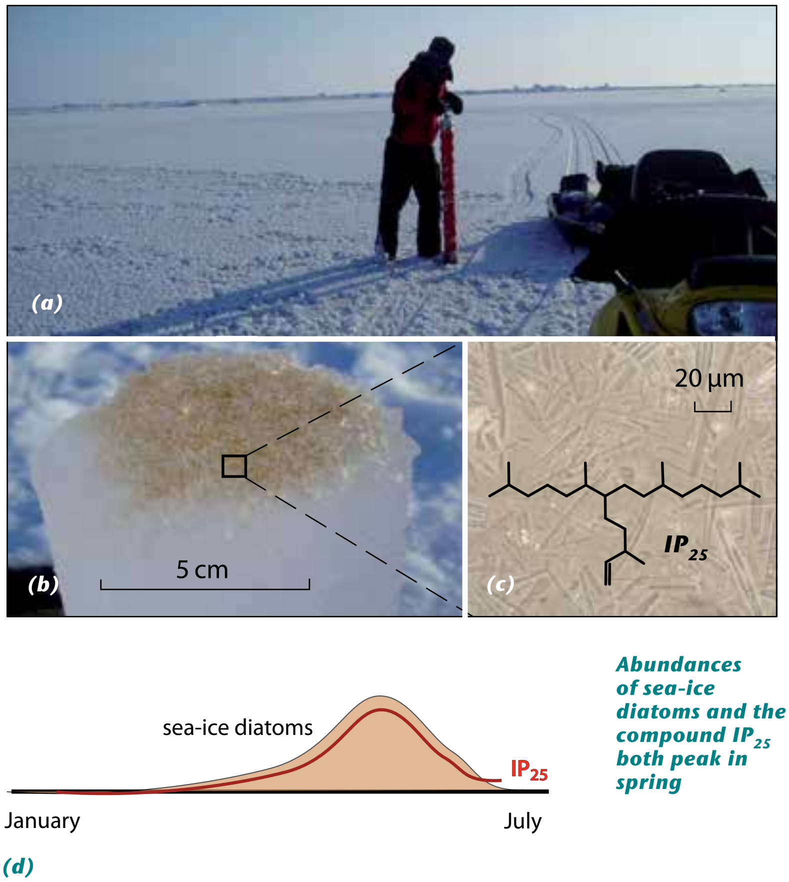


a C_{25} HBI with a single double bond that was located at a distinctive location in the chemical (ringed in red in Figure 3(a)). This HBI was termed the 'Ice Proxy with 25 carbons' or IP_{25} (see Belt *et al.*, 2007, in Further Reading).

A subsequent study of lipids in a series of samples of sea ice collected between January and June in the Canadian Arctic constrained the temporal and spatial variability of IP_{25} in sea ice, and demonstrated peak concentrations of both IP_{25} and sea-ice diatoms at the ice–water interface during the spring (March–June) sea-ice bloom (Figure 4). Following the manual isolation of over 1500 individual sea-ice diatoms from natural sea-ice samples, it was established that at least *Haslea kjellmanii* and *H. crucigeroides* biosynthesise IP_{25} within sea ice. In addition, it was also found that *Pleurosigma stuxburgii* var. *rhomboides* also contributed to IP_{25} production in this habitat (Figure 5).

Subsequent meta-analysis of taxonomic studies describing the sea-ice flora of various Arctic

Figure 4 ***(a)*** *The author sampling seasonal sea ice in the Amundsen Gulf (Canadian Arctic) during the Circumpolar Flaw Lead Project in 2008.* ***(b)*** *The brown discolouration caused by ice algae inhabiting the underside of an extracted sea-ice core.* ***(c)*** *Light microscope image of acid-cleaned sea-ice diatoms.* ***(d)*** *Schematic time-series of diatom abundance (brown) and IP_{25} concentration (red) in a series of sea-ice cores, showing peaks in both that represent the spring sea-ice bloom.*



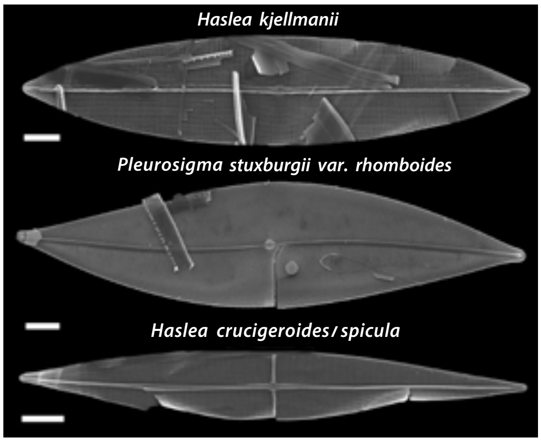


Figure 5 *Scanning electron micrograph of sea-ice diatoms known to biosynthesise the IP_{25} biomarker. Scale bar = 10 µm.*

regions revealed that these IP_{25}-producing diatom species were not only ubiquitous in sea ice within the sea-ice diatom assemblage throughout the Arctic, but were also present at relatively consistent abundances (~1–5% of all sea-ice diatoms in spring). On the basis of this work, the presence of sea-ice diatoms and, therefore, the presence of overlying Arctic sea ice, could be inferred from the presence of IP_{25} in the Arctic sea-bed sediment. Since this point, interest in the use of IP_{25} has expanded (Figure 6).

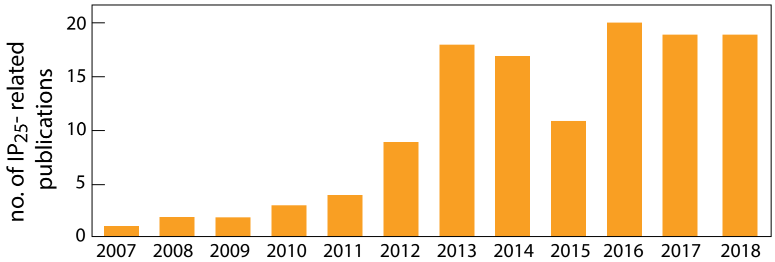
Investigating sea-ice particulate organic carbon in the ecosystem

Direct evidence for the uptake of particulate organic carbon from sea ice into the food web obtained using IP_{25} was first reported in benthic animals. Significantly, in this first study, IP_{25} was detected in 19 of the 21 specimens analysed across 15 species, representing a confirmation of well established ideas on sea ice-benthic coupling within Arctic ecosystems. The initial report represented a qualitative, yet important, development regarding the application of IP_{25}, since it demonstrated a direct connection between sea-ice primary production and a range of benthic Arctic animals.

Subsequent studies went on to show that IP_{25} was present in animals on a pan Arctic scale, in both pelagic and benthic habitats and at all trophic levels of the marine, terrestrial and avian food chains (see www.IP25.co.uk). However, in order to quantify the uptake of particulate organic carbon from sea ice within the food web it was necessary to explore how IP_{25} analysis could provide more quantitative data.

Research on IP_{25} has been burgeoning since 2007

Figure 6 *Frequency of peer-reviewed publications reporting and interpreting the presence of the sea-ice diatom biomarker IP_{25}, as of June 2018. For full bibliographic details and links to these studies please visit www.IP25.co.uk.*

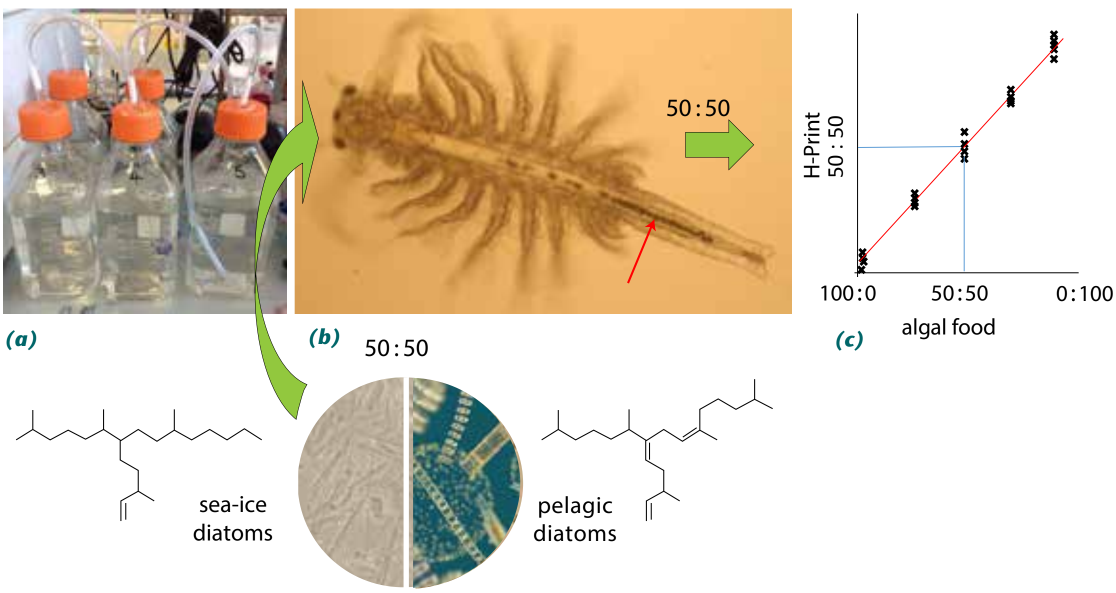


Measuring uptake into the ecosystem of sea-ice particulate organic carbon

Recently, quantitative estimates of the proportion of particulate organic carbon at all levels of the food web, from zooplankton to polar bears, have been achieved by using the so-called 'highly branched isoprenoid lipid fingerprint', often referred to as the H-Print. The H-print is obtained by combining measurement of amounts of IP_{25} with measurements of amounts of additional HBIs that are derived from certain pelagic diatoms (e.g. *Pleurosigma* spp. and *Rhizosolenia* spp.). A laboratory-based calibration of the H-Print was achieved by preparing a series of samples consisting of increasing proportions of sea-ice diatoms and decreasing proportion of

Figure 7 *Experimental setup used to establish the first calibration of the H-Print.* ***(a)*** *Five replicate experimental bottles each containing 20 adult* Artemia *sp. being fed a combination of sea-ice and phytoplanktonic diatoms and kept in suspension by aeration.* ***(b)*** *Light microscope image of an individual* Artemia *with algae visible in the gut (highlighted by red arrow).* ***(c)*** *Illustration of the linear regression of the H-Print ratio of* Artemia *and their faecal pellets versus the ratio of sea-ice and pelagic diatoms fed to the* Artemia*. (See Brown and Belt 2017 for a discussion of these results)*

The H-print ratio of organisms (and their faecal pellets) reflects the balance between sea-ice diatoms and pelagic diatoms in their diet



pelagic diatoms, and the H-print is defined so that a ratio of 100 : 0 corresponds to all food being of sea-ice origin. The resulting linear trend in a plot of H-Print ratio versus the sea-ice algae to pelagic algae ratio in the food demonstrated how accurate numerical estimates of the proportion of organic carbon from sea-ice diatoms versus that from pelagic diatoms could be achieved.

With the calibration established, the ability of the H-Print to provide representative data on the composition of sea-ice particulate organic carbon assimilated by herbivorous grazers was also tested by feeding the same range of algal samples to brine shrimp (*Artemia* sp.) in the laboratory (Figure 7(a) and (b)). After 24 hours feeding on algae, the *Artemia* sp. and their faecal pellets were isolated and their H-Print ratios were determined across the calibration gradient (1000 individuals in total) (Figure 7(c)). Since there was no statistically significant difference between either the H-print of the algae and that of the *Artemia*, or beween that of the *Artemia* and that of their faecal pellets, it was concluded that the H-Print was not altered during grazing and digestion.

In ecology it is useful to be able to estimate the trophic positions of animals. One established approach to doing this makes use of the stable nitrogen isotope composition of animal tissue, expressed as δ^{15}N,* which increases by a predictable amount across trophic levels. Recent complementary analysis of the H-Print and nitrogen stable isotopes (e.g. Figure 8) provided an added dimension to food-web analysis. This powerful combination illustrated how sea-ice and pelagic carbon within a food-web model were incorporated within multiple species across a range of trophic levels.

H-Print ratios have also been successfully combined with physical environmental variables, including sea-ice extent. For example, H-Prints were calculated for over 300 ringed seals sampled during 1990–2011 as part of the Inuit subsistence harvests from Cumberland Sound, Baffin Bay, and the results showed that interannual variability in sea-ice extent had a significant impact on the amount of particulate organic carbon from sea ice that was being used by the ecosystem (Figure 9).

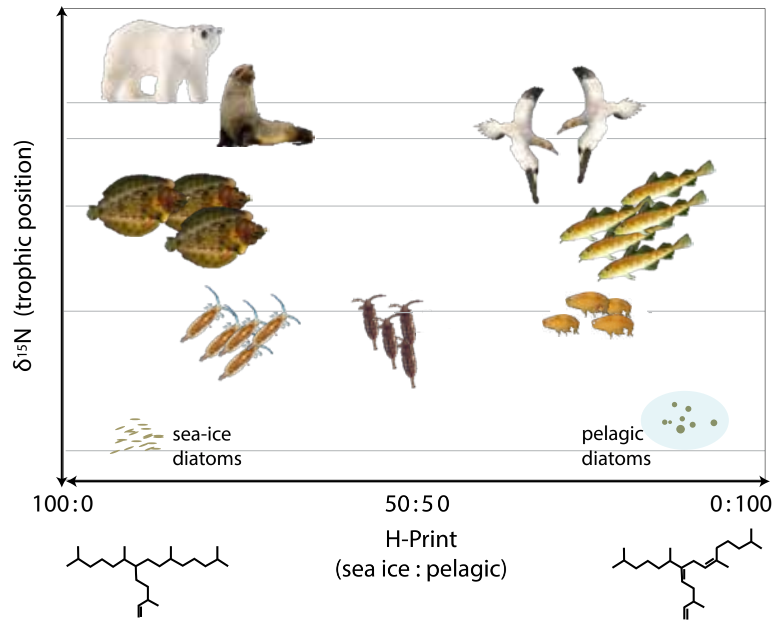


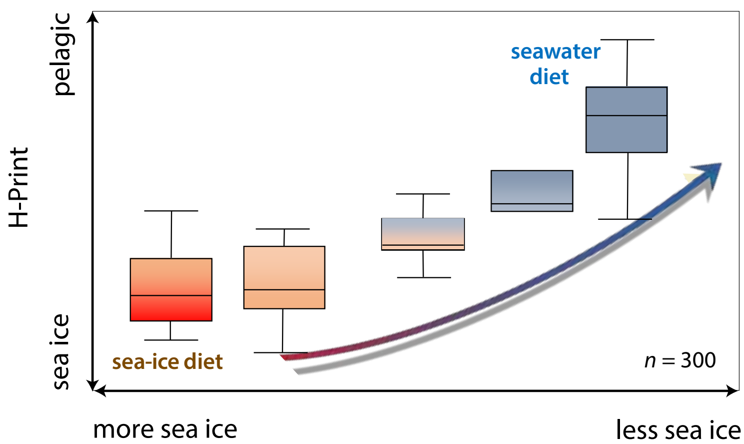
Figure 8 *Schematic plot to show how the H-Print ratio can be combined with δ^{15}N (a proxy for trophic position) to assist in assessment of the transfer of particulate organic carbon from sea ice up through the food web. (See Brown* et al.*, 2017, for a more detailed illustration)*

Particulate organic carbon can be tracked through the food web using the H-print and stable nitrogen isotopes

Collectively, these studies provide persuasive evidence that the H-Print approach can result in new quantitative insights into the utilisation of sea-ice and pelagic organic carbon within Arctic ecosystems during this current period of noticeable change in climate. In the future, less ice will result in increased light penetration from early spring to late autumn, which is likely to result in increased phytoplanktic productivity. However, in this scenario the benthic community is expected

Figure 9 *Plot of sea-ice extent versus the relative proportions of sea-ice and pelagic particulate organic carbon (i.e. the H-Print) in livers of ringed seals (*Pusa hispida*) sampled from the Cumberland Sound region of Baffin Bay. Years with smaller sea-ice extent resulted in lower contributions of sea-ice particulate organic carbon reaching ringed seals. (Data from Brown* et al.*, 2014)*

The H-print of the livers of ringed seals reflects the degree of sea-ice cover



*Natural nitrogen has two stable isotopes, ^{14}N and ^{15}N; ^{14}N makes up about 99.636% of the total. δ^{15}N is a measure of the ratio of the heavy isotope to the lighter one. It is defined by:

$$\delta^{15}\mathrm{N} = \frac{(^{15}\mathrm{N}/^{14}\mathrm{N})_{\mathrm{sample}} - (^{15}\mathrm{N}/^{14}\mathrm{N})_{\mathrm{standard}}}{(^{15}\mathrm{N}/^{14}\mathrm{N})_{\mathrm{standard}}} \text{‰}$$

to suffer from the absence of a pulse of particulate organic carbon from ice during the spring bloom. Calculating the deficit in particulate organic carbon supply in the likely future scenario of a total loss of sea ice therefore requires data on the absolute quantities of sea-ice particulate organic carbon entering the food web at present. This will be an important step in predicting how ecosystems will behave in the future.

Absolute quantities of sea-ice particulate organic carbon entering the food web

The historical challenges associated with unambiguously distinguishing between particulate organic carbon from sea ice and that from phytoplankton has been overcome, to some extent, by obtaining data from captive organisms fed controlled diets. Indeed, such an approach enables us to obtain fully quantitative estimates of grazing rate and organism turnover which might later be up-scaled to the natural environment. However, the transferability of such laboratory-derived data to the environment needs to be critically assessed since there is no guarantee that captive organisms will behave naturally, or that individuals are even representative of the population. There is, therefore, a great advantage in being able to quantify an animal's carbon assimilation *in situ*. Arguably, the first step towards achieving this is being able to distinguish sea-ice-derived particulate organic carbon from carbon assimilated from other, non-sea ice, sources – something which IP_{25} and the H-Print have demonstrably made possible. In addition, the particulate organic carbon component needs to be quantifiable in absolute rather than relative (i.e. the H-Print) terms.

In fact, particulate organic carbon can be, and is, readily quantifiable within sea ice, but as soon as the sea ice melts and this carbon becomes mixed with other (i.e. pelagic) sources of carbon, quantification becomes much more difficult: something that is further complicated by grazing by animals. To overcome these challenges, a recently proposed methodology exploits the sea-ice specificity of IP_{25} to generate realistic estimates of absolute sea-ice particulate organic carbon concentration, outwith sea ice. This is achieved by first quantifying both IP_{25} and total sea-ice particulate organic carbon concentrations within sea ice, i.e. prior to it becoming mixed with non-sea-ice carbon. From these values, a representative sea-ice particulate organic carbon : IP_{25} ratio can be determined for sea ice. The absolute amount of sea-ice particulate organic carbon in a given sample can then be estimated based on IP_{25} concentration alone, even within samples containing carbon from many other non-sea-ice sources. The ability of this approach to generate reasonable estimates of sea-ice particulate organic carbon concentration was recently established by applying the method to seawater samples collected during the springtime sea-ice melt in the Canadian Arctic. The sea-ice particulate organic carbon : IP_{25} ratio in sea-ice samples was determined and this ratio was then used to estimate sea-ice particulate organic carbon by measuring IP_{25} in the underlying water column which was shown to contain both sea-ice and pelagic carbon. It was therefore possible, over a period of about four weeks, to observe and quantify the sinking and dispersion of sea-ice particulate organic carbon throughout the entire water column.

Whilst successful in this first instance, the method is highly novel and further detailed application and assessment will be necessary to determine the full capability of the technique. Reassuringly, application of this method to almost 100 amphipods sampled from the Nansen Basin, in the Norwegian Arctic, is also providing data that are in line with existing captive experiments and best knowledge. This study showed that, during the spring period, amphipods were feeding exclusively on sea-ice particulate organic carbon, consuming more than 70% of the available sea-ice algae, which equated to 0.48 mg of sea-ice particulate organic carbon per square metre entering the food web each day. Therefore, by combining quantitative IP_{25} and H-Print analyses, it will be possible to provide a wealth of novel data that can complement and advance our ability to predict the impacts of, and so prepare for, a decreasing sea-ice extent.

An opportunity for young scientists

Rapid change is occurring in the Arctic and it is important to be able to quantify, among other things, the ecological impact of a loss of sea ice. Unusually, perhaps, the predicted time-frame of this major change in the sea-ice environment is relatively short (decades), meaning that many of the current generation of scientists are likely to experience it first-hand, making them best placed to observe and quantify the likely impacts. Thus far, the analysis of IP_{25} and related HBI lipids has been demonstrated to represent a useful emerging complementary technique which can provide novel information on Arctic ecosystem structure and functioning, an ability that is underpinned by identifying the link between HBI biosynthesis and specific diatom species. It is anticipated that the continued development and application of HBI-based techniques to polar science will ensure that further important and valuable data can be generated, which will further improve our understanding of the polar ecosystem's response to a rapidly changing climate.

Further reading

Belt, S.T., G. Massé, S.J. Rowland, M. Poulin, C. Michel and B. Leblanc (2007) A novel chemical fossil of palaeo sea ice: IP_{25}. *Organic Geochemistry* **38**, 16–27. doi: *10.1016/j.orggeochem.2006.09.013*

Brown, T.A. and S.T. Belt (2012) Identification of the sea ice diatom biomarker IP25 in Arctic benthic macrofauna: Direct evidence for a sea ice diatom diet in Arctic heterotrophs. *Polar Biology,* **35** (1),131–7. doi: *10.1007/s00300-011-1045-7*

Brown, T.A., S.T. Belt, M. Gosselin, M. Levasseur, M. Poulin and C.J. Mundy (2016) Quantitative estimates of sinking sea ice particulate organic carbon based on the biomarker IP_{25}. *Marine Ecology Progress Series*, **546**, 17–29. doi: *10.3354/meps11668*

Brown, T.A., E. Chrystal, S.H. Ferguson, D.J. Yurkowski, C. Watt, N. Hussey and S.T. Belt (2017) Coupled changes between the H-Print biomarker and $\delta^{15}N$ indicates a variable sea ice carbon contribution to the diet of Cumberland Sound beluga whales. *Limnology and Oceanography*, **62** (4), 1606–19. doi: *10.1002/lno.10520*

Brown, T.A., C. Alexander, D.J. Yurkowski, S.H. Ferguson and S.T. Belt (2014) Identifying variable sea ice carbon contributions to the Arctic ecosystem: A case study using highly branched isoprenoid lipid biomarkers in Cumberland Sound ringed seals. *Limnology and Oceanography*, **59,** 1581–9. doi: 10.4319/lo.2014.59.5.1581

Brown, T.A. and S.T. Belt (2017) Biomarker-based H-Print quantifies the composition of mixed sympagic and pelagic algae consumed by *Artemia* sp. *Journal of Experimental Marine Biology and Ecology* **488**, 32–7. doi: 10.1016/j.jembe.2016.12.007

Post, E., U.S. Bhatt, C.M. Bitz, J.F. Brodie, T.L. Fulton, Hebblewhite, J. Kerby, S.J. Kutz, I. Stirling and D.A. Walker (2013) Ecological consequences of sea-ice decline. *Science* **341**, 519–24. doi: 10.1126/science.1235225

See also www.ip25.co.uk

Tom Brown is an environmental scientist interested in the discovery and measurement of chemical biomarkers derived from diatoms. Although his work focusses on the Arctic, his interests also span temperate marine and freshwater settings. In 2016, Tom was appointed as a lecturer at the Scottish Association for Marine Science (SAMS). thomas.brown@sams.ac.uk

Lindsay Vare is a marine geochemist and Project Manager for SAMS Research Services Ltd. Her research interests include palaeo-reconstruction of past environments through a range of techniques using both inorganic and organic geochemistry. Her experience also includes investigating and assessing anthropogenic impact on the marine environment by monitoring pollutants, and studying the biogeochemical processes involved in their redistribution. lindsay.vare@sams.ac.uk

The challenge of meeting the Paris Climate Accord

Phil Goodwin

The *United Nations Paris Climate Accord,* agreed in 2015, set out targets for restricting the rise in global mean surface temperature. Under the *Paris Climate Accord*, the rise in global mean surface temperature is to be kept less than 2 °C above pre-industrial, and efforts are to be made to keep the rise to less than 1.5 °C above pre-industrial. However, at the current observed rate of warming both the 1.5 and 2 °C warming limits will be exceeded during the middle of this century. The more ambitious 1.5 °C target is the subject of a new *Intergovernmental Panel on Climate Change (IPCC) Special Report*, published in October.

Complex climate models agree that meeting the *Paris Climate Accord* will be a significant challenge: to restrict the rise in global surface temperature we must restrict the amount of CO_2, and other greenhouse gases, being released into the atmosphere. The trouble is that the various complex climate models predict a range of values for the amount of extra carbon dioxide that can be emitted before warming exceeds the limits set by the *Paris Climate Accord*. According to these models, for the 2 °C limit to be broken, the total amount of future carbon emissions could be as little as 80 gigatonnes of carbon or as much as 580 gigatonnes of carbon. If carbon emissions continue at their current rate, this means between 8 and 50 years from now. This large uncertainty makes it difficult to plan strategies to achieve the desired outcome for future warming.

In two recent papers, co-authors and I applied a different approach to constrain how much CO_2 emissions have to be curbed to satisfy the *Paris Climate Accord*. Using a very fast climate model, we first ran many millions of simulations, each with a different set of model parameter values (e.g. the model's climate sensitivity*). Then we tested each simulation against observational records of surface warming, ocean heat uptake, and carbon uptake in the ocean and on land. We kept only the simulations that agreed with all observational records, and used these observation-consistent simulations to project into the future. We identified that the 1.5 °C warming limit would be breached in around 17 years at current carbon emission rates, and that the 2 °C warming limit would be breached in around 35 to 40 years. This means that if we are to stabilise climate we cannot continue to emit carbon at the current rate but must continually reduce the carbon emission rate until we reach zero-carbon world. This zero carbon world must be achieved by 2050 to stabilise at 1.5 °C warming.

The fast climate model can be run on smartphones and tablets through the CO2 Modeller app (*illustrated below*). This app allows anyone to explore different emissions pathways, and see if they comply with the *Paris Climate Accord*. Users set an emission pathway via a simple touchscreen and the app then runs 1000 simulations of the fast climate model to project future warming, sea-level rise and ocean acidification up to the year 2100.

Both the app and published papers emphasise the enormity of the challenge ahead if we are to avoid the most dangerous consequences of climate change.

The CO2 Modeller climate app is available on App Store and Google Play via www.CO2modeller.info

*A model's climate sensitivity is the equilibrium global mean surface temperature change that results from a doubling of atmospheric CO_2 concentration.

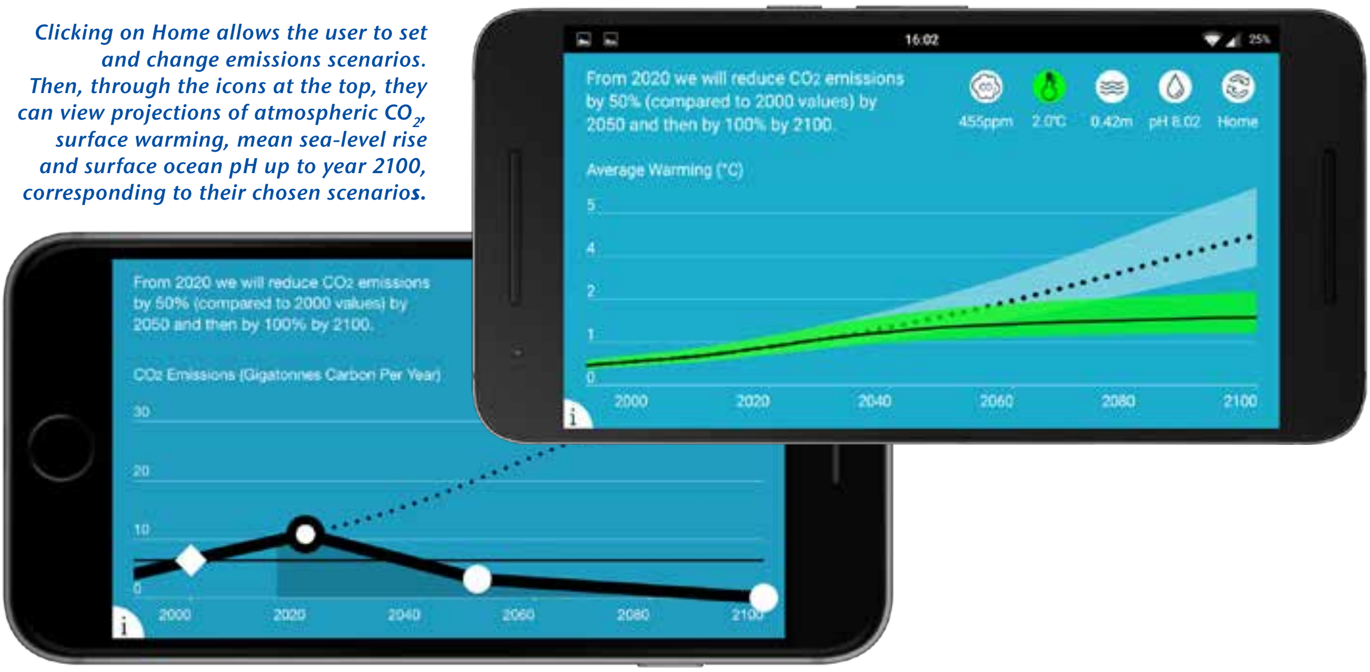
Further Reading

Goodwin. P., A. Katavouta, V.M. Roussenov, G.L. Foster, E.J. Rohling and R. Williams, (2018*a*) Pathways to 1.5 and 2 °C warming based on observational and geological constraints, *Nature Geoscience,* **11**, 102–7. doi: 10.1038/s41561-017-0054-8.

Goodwin, P., S. Brown, I.D. Haigh, R.J. Nicholls and J.M. Matter (2018*b*) Adjusting mitigation pathways to stabilize climate at 1.5 °C and 2.0 °C rise in global temperatures to year 2300, *Earth's Future* **6**, 601–15. doi: 10.1002/2017EF000732

IPCC Special Report (2018) http://www.ipcc.ch/report/sr15/

Phil Goodwin is a lecturer in Ocean and Earth Science at the University of Southampton. p.a.goodwin@soton.ac.uk



Clicking on Home allows the user to set and change emissions scenarios. Then, through the icons at the top, they can view projections of atmospheric CO_2, surface warming, mean sea-level rise and surface ocean pH up to year 2100, corresponding to their chosen scenarios.

‘An idiosyncratic partiality for the sea’

Alexander von Humboldt’s legacy to oceanography

Gerhard Kortum

This article is an abridged translation from the German of a paper by the late Gerhard Kortum, first published in the **Northeastern Naturalist** *(for more details, see end of article)*

During his ‘journey to the equinoctial regions of the new continent’ about 200 years ago, Alexander von Humboldt (1769–1859) made many oceanographic observations in the North Atlantic and eastern Pacific Ocean. His main interest was the relationshisp between climate and the global ocean circulation, still a major topic in marine research. Ever since 1790, when he first saw open waters at the North Sea coast, and embarked on his trip to England in the company of his friend and mentor Georg Forster, Humboldt had a longing for the ocean, especially the Pacific, and a strong interest in matters relating to oceanography. Unfortunately, his writings on the sea are scattered through his major publications, and many of his notes have never been published. Humboldt never finished his decade-long work *Oceanica*, a summation of his ideas about marine natural history. Nevertheless, while he was not an oceanographer in the modern meaning of the word, it is generally accepted that Humboldt belongs in the list of pioneers of marine science.

Humboldt’s Latin American Journey 1799–1804

On 5 June 1799 Humboldt started his remarkable voyage of research to South America, which almost became a circumnavigation of the world. After lengthy preparations he embarked on the Spanish frigate *Pizarro* in the Spanish harbour of La Coruña. Accompanied by the French doctor and botanist Aimé Bonpland, he arrived at Tenerife where he stayed from 19 to 25 June 1799. Then, following in the wake of Christopher Columbus, whose travel reports he studied keenly, Humboldt arrived in the New World after a fast and pleasant crossing. He wrote:

At dawn on 16th July 1799 a picturesque green coast lay before us. The mountains of New Andalusia, half veiled in cloud, formed the horizon to the South. The town of Cumana with its castle appeared between groups of coconut palms. At nine o’clock in the morning, twenty-one days after our departure from Corunna, we dropped anchor in the harbour … .
(*Journey*, p.217)*

The Atlantic was crossed, the first target attained – but Humboldt’s American journey would not end until he sailed into Bordeaux on 1 August 1804. The historical scientific significance of the journey can perhaps be compared only with Charles Darwin’s 1831–36 round-the-world voyage on the *Beagle* (where he was an avid reader of Humboldt’s books). *On the Origin of Species* was published in the year of Humboldt’s death (1859), and a new era was born. Humboldt and Darwin (roughly 40 years younger) knew each other through their personal correspondence and cited each other favourably in their main publications. In both of their famous travel narratives, questions of marine science played a significant (though relatively minor) role.

*In this article, *Journey* refers to Vol. I of *Reise in die Aequinoctial-Gegenden des neuen Continents* (*Journey to the Equinoctial Regions of the New Continent)* edited and translated from Humboldt’s French original by Hermann Hauff and published in 1861.

The legs of the journey were as follows: ***I*** *On the Spanish corvette* Pizarro *from La Coruña to Curmaná, via Tenerife in the Canary islands, and then to Caracas;* ***II*** *75 days' journey inland, on the Orinoco and the Rio Negro;* ***III*** *From Nueva Barcelona (between Cumaná and Caracas) to Havana, three months in Cuba, across the island to Trinidad, and thence by sea to Cartagena;* ***IV*** *Through today's Colombia, Ecuador and Peru to Lima;* ***V*** *From Callao (the port of Lima) to Acapulco via Guayaquil, followed by a year in Mexico;* ***VI*** *Back to Havana from Veracruz, then on the Spanish vessel* Concepción *to Philadelphia and by road to Washington, and finally to Bordeaux on the French frigate* Favorite.

Figure 1 *The route of Humboldt's journey to the Americas, 1799–1804. By courtesy of WikiMedia*

Humboldt confessed '*an idiosyncratic partiality for the sea*' in a personal remark at the end of his classic summary of his oceanographic knowledge and opinions in his major work *Cosmos: model of a physical description of the world* (Vol.1). In his prefaced remarks to *Journey*, p.3, Humboldt added that he '*always felt, from early youth onwards, the drive towards the sea and to long journeys*,' although – or perhaps because – he had grown up in Berlin, far from the coast. Furthermore, he reported that '*I was blessed by my constitution never to be seasick, and as soon as I was on board a ship, I always felt a great drive to work.*' (*Journey,* p.28)

Table 1 *The individual voyages made during Humboldt's American journey. The roman numerals correspond to legs of the journey shown in Figure 1 (legs II and IV were over land).*

	Passage	Dates	Days at sea	n.m.
I	La Coruña–Tenerife	5 June to 19 June 1799	15	1078
	Tenerife–Cumaná	25 June to 16 July 1799	22	3072
	Cumaná–Caracas	18 to 21 Nov. 1799	4	162
III	Nueva Barcelona–Cumaná	26 to 27 August 1800	2	54
	Cumaná–Nueva Barcelona	17 Nov 1800	1	54
	Nueva Barcelona–Havana	24 Nov. to 19 Dec. 1800	25	1563
	Trinidad, Cuba–Cartagena	9 to 30 March 1801	21	647
V	Callao/Lima–Guayaquil	24 Dec.1802 to 4 Jan 1803	12	863
	Guayaquil–Acapulco	17 Feb to 22 March 1803	35	2264
VI	Veracruz–Havana	7 to 19 March 1804	13	915
	Havana–Philadelphia	29 April to 20 May 1804	22	1240
	Philadelphia–Bordeaux	30 June–1 August 1804	33	3611

It is to this deep personal interest in the sea that we owe not only the numerous observations and measurements that Humboldt made during his voyages but also, in his later years, his constant examination of advances in the then poorly developed field of oceanographic research.

Humboldt knew personally James Rennell (1742–1830) and Matthew Fontaine Maury (1806–1873), the leading English and American hydrographers of the first half of the 19th century, and corresponded with them. Their ideas about oceanography are dispersed as notes and longer passages within Humboldt's most important writings, collected at different times.

Humboldt manifestly continued to develop his oceanographic views over time. Of special significance in this connection are the references to Rennell in Humboldt's *Views of Nature* (of which English translations were published in 1849 and 1850), as well as pages of citations from Rennell's *An Investigation of the Currents of the Atlantic Ocean* (1832) in his unpublished writings. (Similar brief references to Humboldt appear in Rennell's book, and it was Humboldt who suggested the phrase that became the title of Maury's long-lived textbook *The Physical Geography of the Sea* (1855).)

When Humboldt visited London at the end of April 1827 he met Rennell and obtained documents from him. Basically Humboldt, and thereby also the German geographer Heinrich Berghaus, aligned themselves with essential aspects of Rennell's concept of the circulation of the oceans. Berghaus took this idea cartographically from Rennell in the form of a detailed map of the oceans with corresponding notes and explanations, in his two-volume *Physical Atlas** (1845 and 1848). His *Physical School Atlas*, published in Gotha in 1850, contains a simplified representation of the world map of 'Ocean Currents', which is most probably a map attributed to Humboldt that was said to be lost.

Of course, Humboldt's (now classic) description of the crossing from La Coruña to Cumaná in *Journey*, reflects his earlier state of knowledge. Shortly before his death on 26 March 1859, Humboldt directed Hauff to undertake a German translation of his travel writings (originally published in French). In its Foreword, Humboldt refers to his 'antiquity' and explains why he refused to rework the text written a good 50 years before, in the interest of a more realistic representation *'of my journey, which was undertaken with the joys and aspirations of youth. Material used to explain general cosmic results'* were shortened or omitted.

Sadly, Humboldt did not manage to publish a work that he planned to call *Oceanica,* which would have included all his oceanographic observations and knowledge, and would have been Volume 2 of his *Shorter Writings*. His life's work *Cosmos* also remained unfinished. Likewise, his *Journal* ended with his arrival in Cartagena on 30 March 1801, so fails to reflect the extensive observations recorded in his diaries. Thus we know only sketchily from other notes about Humboldt's famous journey in the 'South Sea' (i.e. the South Pacific) from Peru to Mexico, and in particular, so far we really know very little about his return journey from Veracruz via Havana, Philadelphia and the Azores to France, following the Gulf Stream system. These facts have both contributed to a limited recognition of Humboldt's contributions to oceanography, in what became a very extensive body of writing, and to a general lack of critical appreciation of his work.

The naming of the Humboldt Current

Although Humboldt's Pacific studies are well known as an episode of the total journey, their value to the history of oceanography had been scantily assessed until relatively recently. At the end of 1802 / beginning of 1803, 47 days were spent at sea crossing from Callao, via Guayaquil, to Acapulco (V on Figure 1). Humboldt was first able to see the South Sea in 1802, on the way from the Inca city of Cajamarca to the coast. A dream he had nurtured since his youth was thus fulfilled, as we can learn from a very personal passage in *Views of Nature*:

'The sight of the South Sea seemed like a celebration for one who owed part of his education and the directions of many of his desires to his interaction with a travel companion of Captain Cook. Georg Forster had already known my travel plans early, in broad outlines,*

*Berghaus (1797–1884) was most famous for his cartographic work; his *Physical Atlas,* which provided the illustrations for Humboldt's *Cosmos,* was his greatest achievement.

*When young, Forster had accompanied his father on several scientific expeditions, including James Cook's second voyage to the Pacific.

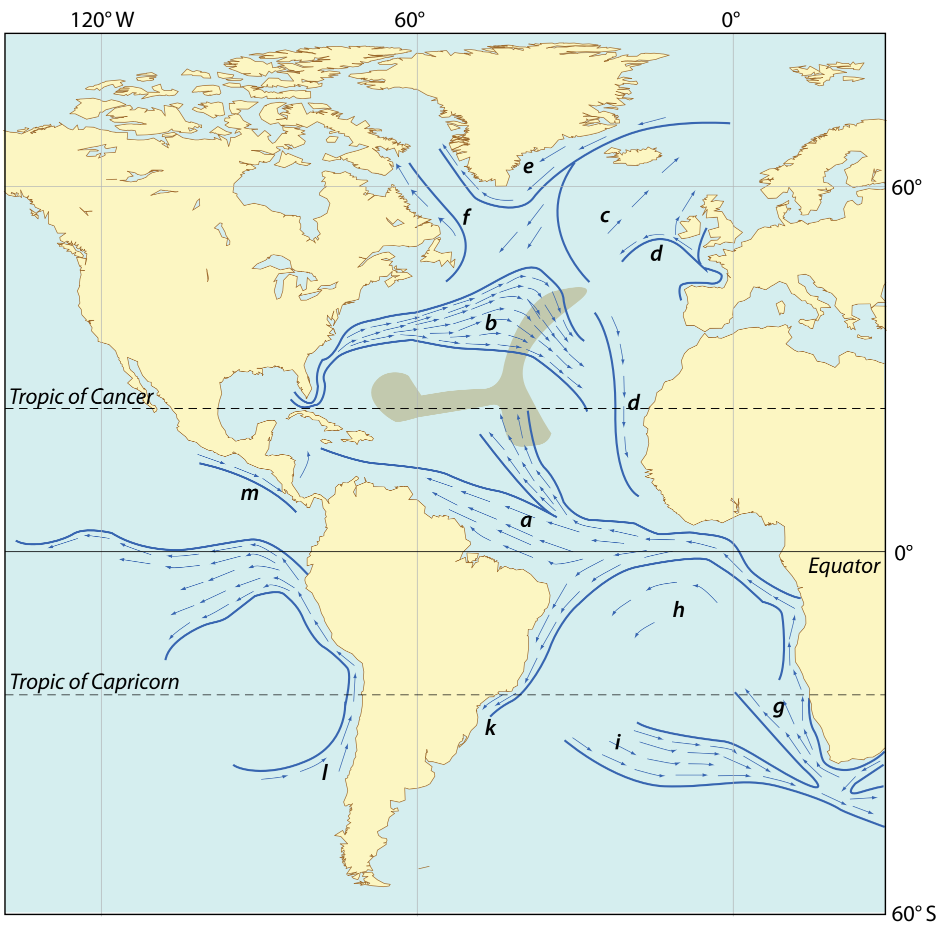


Figure 2 *Important ocean currents in the Atlantic and eastern Pacific Ocean, according to Humboldt:*
a *Equinoctial Current;* ***b*** *Gulf Stream;* ***c*** *North Atlantic Drift;* ***d*** *Rennell Current and North African Current;* ***e*** *Arctic Current;* ***f*** *Hudson Bay Current;* ***g*** *South Atlantic Current;* ***h*** *Southeast Trade Wind Drift;* ***i*** *Southern Connecting Current ;* ***k*** *Brazil Current;* ***l*** *Peru Current;* ***m*** *Mexican Current.*
Also shown is the position of the accumulation of Sargassum *weed in the North Atlantic, as estimated by Humboldt.*
(From Kortum (1999a) in Further Reading)

Humboldt and the Royal Navy

John Phillips

Humboldt and Bonpland sailed to South America under the Spanish flag. Britain was already in a state of war with Spain and remained so during most of the expedition. Their departure from La Coruña on 5 June 1799 in a Spanish warship, the *Pizarro*, was a risky undertaking. Humboldt wrote:

'We directed our course to the north west, in order to avoid the English frigates, which we supposed were cruizing off those coasts.' Four days later he continues: *'at sunset, we descried from the masthead an English convoy, which sailed along the coast, steering towards the south east. In order to avoid it, we altered course during the night. From this moment no light was permitted in the great cabin, to prevent our being seen at a distance. This precaution ... was extremely irksome to us ... We were constantly obliged to make use of dark-lanterns to examine the temperature of the water, or read the divisions on the limb of the astronomical instruments.'*

The first port of call was Santa Cruz de Tenerife, and here they had an even closer shave. The *Pizarro* anchored in thick mist, but as this lifted *'we saw four English ships of the royal navy lying to very near the poop. We had passed without being perceived; and the same mist .... had saved us from the danger of being carried back to Europe ... We immediately got up our anchor, and the Pizarro stood in as close as possible to the fort, to be under its protection.'*

Five years later they sailed homeward from the United States on board a French frigate, the *Favorite*. By then Britain was at war with France as well as Spain, and French ports, particularly the principal naval bases of Brest and Toulon, were under heavy blockade from the Royal Navy. Apparently the *Favorite* was able to slip into Bordeaux without any trouble.

Ironically, the most direct seaborne threat to the expedition occurred during their shortest voyage – eastward along the coast of Venezuela from Nueva Barcelona to Cumaná in August 1800, a distance of about 40 nautical miles. Impatient to reach Cumaná and take passage for Cuba, Humboldt hired an open boat loaded with contraband for the island of Trinidad, which the British had recently occupied. They had covered scarcely a quarter of the distance when their boat was captured by a privateer from Halifax, Nova Scotia. Humboldt's attempt to negotiate their release was interrupted by a stroke of luck:

'Happily for us, an English sloop of war, the Hawk, was cruising in those parts, and had made signals to the captain to bring to; which he not being prompt to obey, a gun was fired from the sloop, and a midshipman sent on board our vessel ... [who] invited me to accompany him on board the sloop, assuring me that his commander, captain John Garnier, of the royal navy, would furnish me with better accommodation for the night ... I accepted these obliging offers, and was received with the utmost kindness by captain Garnier ... [who] gave me up his own stateroom.'

Humboldt had been doubly fortunate in the identity of his rescuer: John Miller Garnier, born the fourth son of a prominent Hampshire family in 1774, had sailed as a midshipman with Vancouver's exploring expedition to the west coast of North America in 1791–95. He was naturally very interested in Humboldt's recent travels, which he had followed in the British newspapers. Humboldt was presented with astronomical tables for the years he had not been able to procure in France or Spain and concluded *'I owe to captain Garnier the observations I made on the satellites beyond the equator, and feel it a duty to record here the gratitude I feel for his kind offices.'*

Humboldt and Bonpland resumed their passage to Cumaná the next day. In striking contrast with previous sightings of British naval vessels, this encounter had been essential to their success; without the intervention of HMS *Hawk*, a five-year expedition to Spanish America might have ended after less than eighteen months, and in a distant port under British control!

Garnier's later career was tragically brief. The following year he was promoted Captain at the early age of 26 and assumed command of the frigate HMS *Southampton*, but only three months later he died of yellow fever on St Martin in the Leeward Islands. After a further six years his estate received the payment due for both commands, much delayed by missing official paperwork. The family's naval connections certainly didn't end there: the next generation of Garniers included, by marriage, Admiral of the Fleet Sir Henry Keppel, GCB, OM (1809–1904) and, almost two centuries after the Humboldt incident, Rear Admiral Sir John Garnier, KCVO, CBE was commanding officer of the Royal Yacht, HMY *Britannia*, from 1985 to 1990.

Quotations on this page are from Humboldt's Personal Narrative of Travels to the Equinoctial Regions of the New Continent, during the Years 1799–1804, *translated from the French by Helen Maria Williams (7 volumes, published in London, 1814–29).*

when I enjoyed the privilege of visiting England under his guidance for the first time (now more than a half century ago).'

Through this voyage, Humboldt became one of the pioneers of oceanography. At least in the German-speaking world, the name 'Humboldt Current' has prevailed over the conventional oceanographic nomenclature for the cold water current along the coast of Chile to Ecuador. This has to be regarded as a special honour. In the 1930s this dedication led to a rather unproductive academic argument between the marine geographer Gerhard Schott and the oceanographer Georg Wüst, who was still active in Berlin at that time (later at the Institute of Oceanography, Kiel). There is no sympathy with this quibbling in South America. To this day they see no reason to depart from naming the current after Humboldt: after all, there are still Humboldt penguins along the Pacific coast of South America! But how did this nomenclature actually come about, given that Humboldt and Berghaus always used 'Peru Current' or 'Peruvian Current' in their writings and maps (Figure 2)?

From the beginning, the naming of this current was not without controversy. Humboldt had selflessly made his hand-written records pertaining to ocean currents available to Berghaus for his cartographic work. Berghaus reproduced these records verbatim in the first volume of his *General Geography and Ethnology* in 1837. Amongst these was a (now classic) report on the Peru Current. In 1904, the geographer and marine scientist Otto Krümmel included this short treatise in a collection of classics for university students, published as *Selected Classics of Geography for Use in Universities*. This was how Humboldt's account of the Peru Current survived – his intended monograph 'About ocean currents in general; and the cold Peruvian current of the South Seas, as opposed to the warm Gulf or Florida streams' was never finished and dealt mainly with the Gulf Stream.

So the name does not come from Humboldt himself. Berghaus, however, wrote an addendum on his 'pirate copy': '*Twenty years after his return to Europe, Herr von Humboldt at last had the pleasure and satisfaction of seeing his work completely confirmed. The observation first made by him and with that the discovery of a cold ocean current in the eastern part of the Pacific Ocean, and the influence of this current on the climate of the coastal plain of Peru, was witnessed by three travellers in the most different of seasons*.'

To this text he added the following footnote: '*Which is why it can be justly named 'Humboldt's Current*'. Here, Berghaus was following a proposal made by Franz Meyen (a naturalist and doctor), in his *Journey around the Earth,* published in 1833–35.

At this time, Berghaus was working on a map of the waters along the Peruvian coast for his Royal *Prussian Maritime Atlas*. He wanted to dedicate this to Humboldt with an extensive tribute in the spirit of the time. Part of this reads: 'Showing Bn [Baron] Humboldt's thermometrical navigation and various passages from Callao to Guayaquil during the last days of the month of December 1802'. However Humboldt objected strongly to this, in a letter written on 21 February 1840:

'Similarly I also protest at least publicly against any 'Humboldt's Current' … The current was known to all fishing youths from Chile to Payta 300 years before me: I have simply the credit for being the first to measure the speed of the water stream.'

But when Berghaus eventually sent the maps to him on 6 December 1840, Humboldt was flattered and relented. His reply written the following day read: *'On my return from Charlottenburg I find your beautiful maps, amongst them the one on which you have honoured my name too much for such small achievements.'* The name was therefore bestowed in Berlin, far from the territory which Humboldt explored.

In his report on the Peru Current, Humboldt considered the significance of its temperature:

'The first task of a travelling physicist, when he arrives at the sea coast after a long absence in mountainous regions, is to measure the barometric pressure and the water temperature. I was busy with this in the region between Truxillo and Guaman, at Callao de Lima and, on the ship crossing from Callao to Guayaquil and Acapulco, along a stretch of the Pacific Ocean of more than a hundred German miles. In those latitudes where the surface water temperature is 26° to 28.5° outside the current, I recorded, to my greatest astonishment, 16 degrees in the vicinity of Truxillo, at the end of September, and 15° at Callao, at the beginning of November.'

Humboldt presented a great number of observations, and arrived at the *'opinion, confirmed by many seafarers, that the Peruvian current is a polar current which follows the main curves of the coast and the NNW direction, from high to low latitudes.'*

Some ten years later, in *Cosmos*, Vol. 1, Humboldt wrote:

'The counterpart to this current in the Atlantic basin between Africa, America and Europe [i.e. the Canary Current]*, belonging almost entirely to the Northern Hemisphere, is found in a current in the South Sea. I first discovered its low temperature and obvious effect on the littoral climate in Autumn 1802. It brings the cold waters of the high southern latitudes to the coasts of Chile, follows the coasts of this land and those of Peru firstly from the south towards the north, then (from the Bay of Arica onwards) from south–south-east towards north–north-west. At certain times of the year, in the middle of the tropical region, this cold oceanic current is only 15.6°, while the still water outside the current shows a temperature of 27.5° and 28.7°…'*

The idea that the Humboldt Current is cold merely because it flows from high latitudes has since been abandoned. The waters off the coast of Chile and Peru belong to the areas of upwelling in the world's oceans, similar to those found on the west coasts of North America and Africa under the influence of the Trade Winds. The water is 5–8 °C colder because it wells up from a depth of about 200 m. This results in a very fortunate situation, because the upwelling provides nutrients for the phytoplankton at the surface – the water of the Humboldt Current is often bottle green from its rich content of plankton. In turn this promotes the abundance of fish and the large population of sea birds in the coastal ecosystem. However, when the tropical Pacific is subjected to an El Niño event, the upwelling fails, with catastrophic consequences for the ecosystem and the fishing industry.

When we analyse the diagrams and measurements Humboldt made on the voyage from Lima via Guayaquil to Acapulco, it becomes evident that Humboldt travelled the coast when the upwelling was strong. It was clearly not an 'El Niño year', as shown by Humboldt's 'Table of Sea and Air Temperatures from Callao de Lima to Guayaquil'. Humboldt and his companions left Callao on 24 December 1802, reached Guayaquil on 4 January 1803, left on 17 February, and arrived at Acapulco on 22 March 1803. Modern archive studies into El Niño show that this phenomenon appeared in 1791 and 1804.

The Humboldt Current flows as a 3000 km long and 80–100 km wide stream from 32° S to Cabo Blanco at 4° S with a speed of 0.4–0.7 $m\,s^{-1}$ (15 n.m. day^{-1}). The volume of water transported, however, is 10–15 x $10^6\,m^3\,s^{-1}$, so the Humboldt Current does not attain the significance of the Gulf Stream. But, like the Gulf Stream, the Humboldt Current is characterised by variability in time and space. Using numerous records, Humboldt discussed extensively the changeability of the maritime meteorological conditions in this ecologially sensitive coastal region. He reported on the effects of abnormal years with high rainfall and the formation of the typical coastal fog (*garua*). *'Only the presence of a physicist for many years at this boundary, a true weather divide, would be able to satisfy us …'* to explain the variability of the sea and atmosphere that Humboldt clearly recognised. Was this an early glimmer of the idea of El Niño? That would not be surprising given the universality of Humboldt's perspective of Nature, and his intuitive understanding. He may never have completed *Oceanica*, but Humboldt's spirit lives on in many projects within today's climate and ocean research.

*The period of circumnavigations started with Cook's voyages. Around that time there were about two dozen government-funded expeditions, including that of the *Challenger* (1872–76). They each had a scientific team on board, which initially comprised 'all-round' natural historians. Darwin's voyage was one such.

Humboldt and the Gulf Stream

During his Latin American journey, Humboldt became the first to propose the use of government ships equipped with instruments to capture synoptically the variability of ocean currents. An innovative idea for the time, it was unfortunately acted on only very much later. The idea first appears in an entry in Humboldt's diary for 16 December 1800, written during the journey through the Caribbean from Nueva Barcelona to Cuba. As set out in *Journey* (pp.41–2) this reads:

'Since knowledge of the currents can make an essential contribution to shortening sea voyages, it would be of such great importance for the practice of sea-faring, as well as of scientific interest, if ships with high quality chronometers could determine the distance between the Gulf Stream and the foothills of Hatteras and Codd in different seasons and under different wind conditions. This could be achieved by these ships crossing in the gulfs of Mexico and in the northern Ocean between 30° and 54° of latitude, purely for this purpose … Such an expedition could, in addition to direction and speed of current, engage in taking measurements of sea temperature, and observe lines of equal magnetic deviation, the inclination of the magnetic needle and the intensity of the magnetic field … .'

This proposal is typical of Humboldt's intuitive feel for scientific problems, which still have relevance in today's marine research. The manuscript about ocean currents, written shortly before the end of his life, contained numerous ideas for investigating the circulation in the North Atlantic. The then elderly Humboldt expressed his regret that the proposals he made decades earlier had not been put into practice.

If things had turned out differently, Humboldt might never have had the opportunity to study the Gulf Stream. As he explained in his introductory remarks to the *Journey*, he had originally intended to sail with a French voyage of circumnavigation* led by Nicolas Baudin in 1798 (and thus met his friend Bonpland). When its departure was postponed he sought an alternative route to tropical climes, eventually crossing Spain to Madrid where, after much effort, he obtained a passport giving him freedom to visit any of Spain's overseas possessions. He had always wanted to return to Europe via the Pacific and India, but access to the East was denied him; so instead of sailing west toward the Spanish Philippines, Humboldt took passage northward, to Spanish Mexico (New Spain).

In the history of research as well as with respect to marine science, Humboldt stood between particular periods, however these are delineated. He almost became a 'round the world sailor', like his teacher and travelling companion, Georg Foster, whom he had much admired since his student days.

So what would have happened if Humboldt had followed Forster's example by crossing the Pacific? Most likely the history of science would have taken a different course and Humboldt's research of the Gulf Stream during his return voyage could never have taken place. Through this voyage, the founder and master of the comparative method in geoscience, could carry out an oceanographic comparison between the North Atlantic and East Pacific current systems with respect to their spatiotemporal variability. His still unpublished memoir 'About Ocean Currents in general and the cold Peruvian Current of the South Sea in contrast to the warm Gulf or Florida Stream', which would have formed a major part of *Oceanica* was intended to address this topic. (A current chart centred on the Americas from Berghaus' *Physical Atlas* can be found in a paper by the author (Kortum 1999*b* in Further Reading).

The breadth of Humboldt's marine research

Humboldt's contributions to marine science relate mainly to the fields of physical oceanography, marine biology and maritime meteorology, and to a lesser extent, marine geology. Overall, they seem no less significant than those he made to general climatology, geology, botanical geography, geophysics, astronomy, comparative geography and other sciences.

Humboldt should not be viewed as the founder of marine research, but his comprehensive and holistic approach to searching for interactions in Nature clearly included an engagement with marine science, particularly the circulation of the ocean and its effects on climate, and on life in the sea – all based on his own observations and measurements.

His multifaceted contributions to marine science are scattered amongst his major works and in some less accessible writings. in *Cosmos* (Vol. 1), Humboldt reiterated with justification a fundamental principle of marine and climate research: *'In all climate zones, the ocean tends to retain the warmth of its surface in the layers of water closest to the air, since the cooled parts are heavier and move downwards.'*

It is well known that Humboldt took with him on his expeditions a large number of scientific instruments from the best European manufacturers, and made full use of them. He was better equipped, however, for taking measurements in the 'ocean of air' ('Luftmeer') than for oceanographic observations in the 'fluid wrapping of our planet' (*Cosmos*, Vol. 1). The thermometer could be put to use in both fluid media but in the ocean, only in surface waters. In the 1999 exhibition in Berlin and Bonn, 'Alexander von Humboldt: Networks of Knowledge', an old densimeter was displayed. The salt content could be recorded with this by determining the density at a given temperature, but no recorded measurements of salt content are to be found in Humboldt's writings. Thermal factors are key for Humboldt in the development of circulation, and salinity remains very much in the background.

At the time it was difficult to measure temperature at depth, though individual results from other seafarers interested in the natural sciences were available. Humboldt reported only one of his own attempts, undertaken on the Galician coast in the first week of June, 1799, shortly before his departure to America in the *Pizarro*. In his travel narrative he writes:

'During the crossing from Corunna to Ferrol over a shallow near the 'White Signal' in the bay, which according to d'Anville is the 'Portus Magnus' of antiquity ... we used a thermometer probe with valves to make several measurements of the sea temperature and of the fall in temperature in the layers of water lying one below another. At the surface above the bank, the thermometer read 12.5°–13.3° on the hundred part scale [i.e. Centigrade]*, while around this, where the sea was very deep, the thermometer stood at 15–15.3° at an air temperature of 12.8°.'* (*Journey*, p.21)

A portrait of Humboldt, painted by Joseph Stieler in 1843, when HUmboldt was in his early seventies

(By courtesy of WikiMedia)

Humboldt took this result as proof for his thesis of 'the cooling of sea water over shallows', which he also elaborated on in other texts. With his tendency for seeking practical applications of scientific results, he proposed that this concept could be used for 'thermometric navigation' in the sense used by Benjamin Franklin. The idea is now viewed as obsolete, and 'the cooling of sea water over shallows' can in many cases be explained by the local upwelling of cooler, deeper water.

Although Humboldt himself could not directly observe deep polar currents, he could introduce this idea theoretically – and correctly. This realisation anticipated the idea of the ocean conveyor, driven by convection in polar oceans. Indeed, many theoretical ideas first formulated by Humboldt have been splendidly confirmed.

Humboldt's contributions to marine biology also require further elucidation. Not only do they complement Humboldt's phytogeographical work on land, but they lead into the early phase of planktology. Humboldt was a diligent user of his microscope on board ship. Later in his career, together with Christian Gottfried Ehrenberg (who accompanied him on his 1828 Siberian journey), he carried out studies on plankton specimens from Kiel harbour, which Professor Michaelis from the University of Kiel had sent to him in Berlin (Humboldt discusses marine phosphorescence in *Views of Nature*.) Humboldt was never in Kiel, but a scientific connection to this centre of German marine research, with all its richness of tradition, was established.

Some final questions must remain open. In particular, the sources which Humboldt used when writing his texts need to be clarified. At the moment, the reason why Humboldt broke off the preparations for printing his treatment of ocean currents, even though large parts were already typeset and in proof, is unknown. The question must also be asked: why did Humboldt not make greater use of the good hydrographic results from the voyages of the ships of the Prussian maritime Trading Company, and instead leave these almost entirely to Berghaus? It would not have been difficult for him to arrange that he also took part in a voyage, something he had already done for Franz Meyen, who in the end was responsible for the naming of the Humboldt Current. But for some reason he didn't do this.

Humboldt was well known to have a great interest in the history of science. This is particularly evident in the second volume of *Cosmos*, as well as in his *Critical investigations into the historical development of the geographic knowledge about the New World, and advances in nautical astronomy, in the 15th and 16th centuries* (1836–39) which covers in meticulous detail a range of topics in the history of discovery and of navigation. As a result, Humboldt and his comprehensive body of work has time and again been studied by historians of the geosciences. Engagement with his writings is timeless and rewarding, particularly in view of the ease of establishing their relevance to research questions of today.

So Humboldt was not simply a great polymath but also a chronicler of natural sciences in the 19th century. By the time of his death, he had already become a monumental figure. Since then, there have been several periods of intensive renewed interest in Humboldt's thinking – Humboldt remains timeless.

Historical examinations of a scientific discipline with relevance to the present day require no justification. Humboldt, who will himself remain the object of reflection in the geosciences, already knew this: '*Nature is an inexhaustible source of research and, as science advances, always offers to one who knows how to ask her the right questions, a fresh page, something he has not considered before …'* (*Journey,* p.188)

Acknowledgements

Grateful thanks are due to the following people: the Editor of *Northeastern Naturalist*, where the article first appeared, in Vol. 8**,** Special Issue 1, *Proceedings: Alexander von Humboldt's Natural History Legacy and Its Relevance for Today*, 91–108 published in 2001; Lina Talbot for translating the article from German; Ingo Schwarz (Berlin-Brandenburg Academy of Sciences) for up-to-date information about access to Humboldt's writings; and John Phillips for bibliographic assistance. John would like to thank Admiral Sir John Garnier for help with 'Humboldt and the Royal Navy'.

Humboldt's name sails on

It is not unusual for a ship to be named after Humboldt. Research vessels in both Germany (Leibniz Institute for Baltic Sea Research) and Peru (Institute of the Sea of Peru, IMARPE) bear his name, as do several other vessels. One such is a three-masted barque designed in Bremen as a lightship and launched in 1906. In 1988 she was converted to a sail training vessel (*left*) and renamed *Alexander von Humboldt*. Ten years later she sailed on a goodwill tour to South America and the Caribbean, flying the flag where Humboldt had sailed many years before.

She was retired in 2011 and her replacement, *Alexander von Humboldt II*, was launched in the same year. This purpose-built successor continues to offer sail-training cruises for the charity Deutsche Stiftung Sail Training. The original vessel is now a floating hotel and restaurant back in Bremen.

Further reading

Humboldt's Publications

Alexander von Humboldt published prolifically throughout his life. Many works were originally published in French or German, then translated into other languages, sometimes with competing translations. English editions of the works mentioned in the article are given below.

Personal Narrative of Travels to the Equinoctial Regions of the New Continent, 7 vols, translated by Helen Maria Williams, London (1814–29).

This is the first, and only complete, edition in English. A modern abridged version, translated by Jason Wilson, is available in Penguin Classics (1995).

Views of Nature translated by Elise C. Otté and Henry G. Bohn, London (1850).

Cosmos: Sketch of a Physical Description of the Universe, 4 vols, translated by Elizabeth Sabine, London (1846–58).

There is a useful index at www.avhumboldt.de with links to the works of Humboldt that are available online. The books by Humboldt that were part of the library on board HMS *Beagle* are available at www.darwin-online.org.uk.

Humboldt's unpublished work

Unfortunately, Humboldt's 'About ocean currents in general; and the cold Peruvian current of the South Seas, as opposed to the warm Gulf or Florida streams' (which he prepared for *Oceanica*, Vol.2 of his 'Shorter Writings', mentioned in the article) was never completed. However, proof sheets can be found on http://www.deutschestextarchiv.de/humboldt_meer_1833.

Many of Humboldt's original works and letters have been digitally scanned by the Biodiversity Heritage Library. biodiversitylibrary.org

Humboldt's diaries Editing and publishing Humbolt's diaries is currently being undertaken at the Alexander von Humboldt Research Centre in the Berlin-Brandenburg Academy of Sciences. The diaries describing travels on the River Magdalena, through the Andes and Mexico, and in Venezuela, have been published as Volumes 8, 9 and 12 of the series *Beiträge zur Alexander-von-Humboldt-Forschung*.

The diary that Humboldt wrote on the return journey from Philadelphia to Bordeaux no longer exists as Humboldt re-arranged the pages before they were re-bound; some parts may be in other diaries, others might be in the 'Nachlass' (Humboldt papers) in Berlin or Krakow, some may be lost.

Scans of the American travel journals can be found at: http://kalliope.staatsbibliothek-berlin.de/de/search.html?q=Humboldt+Reisetageb%C3%BCcher

Biographies of Humboldt

Botting, Douglas (1973) *Humboldt and the Cosmos.* Michael Joseph, London, 295pp.

Kellner, Lotte (1963) *Alexander von Humboldt*. Oxford University Press, 247pp.

Wulf, Andrea (2015) *The Invention of Nature: the adventures of Alexander von Humboldt, the lost hero of science*. John Murray, London, 473 pp.

For more about James Rennell, see the Special James Rennell issue of *Ocean Challenge* (1993) **4**, No.1 & 2.

Humboldt studies

Kortum, Gerhard (1990) An unpublished manuscript of Alexander von Humboldt on the Gulf Stream. In *Ocean Sciences: their History and Relation to Man, Proceedings of the Fourth International Congress on the History of Oceanography*, ed. W. Lenz and M. Deacon, *Deutsche Hydrographische Zeitschrift* Suppl. Ser. B, No. 22, pp.122–9.

Kortum, Gerhard (1999*a*) Über A. v. Humboldts Atlantikquerung vor 200 Jahren. In *Deutsche Gesellschaft für Meeresforschung*, No.1, pp.3–9.

Kortum, Gerhard (1999*b*) 'Die Strömung war schon 300 Jahre vor mir allen Fischerjungen von Chili bis Payta bekannt': der Humboldtstrom. In *Alexander von Humboldt: Netzwerke des Wissens*, Berlin and Bonn, pp.89–99.

Théodoridès, Jean (1965) Alexander von Humboldt et la biologie marine. In *Colloque international sur l'histoire de la biologie marine: les grands expéditions scientifiques et la création des laboratoires maritimes Vie et Milieu,* Suppl. 19, pp.13-62.

Humboldt: contemporaries and Influences

Berghaus, Heinrich (1837-44) *Allgemeine Länder- und Völkerkunde,* 6 vols, Stuttgart

Krümmel, Otto (1904) *Ausgewählte Stücke aus den Klassikern der Geographie für Gebrauch an Hochschulen.* 2nd series, Kiel & Leipzig.

Maury, Matthew Fontaine (1855) *The Physical Geography of the Sea*. Harper & Brothers, New York, 274pp.

Rennell, James (1832) *An Investigation of the Currents of the Atlantic Ocean*. J.G. & F. Rivington, London, 359pp.

General

Deacon, Margaret (1997) *Scientists and the Sea 1650–1900: a study of marine science,* 2nd edn, Ashgate Publishing Ltd, Aldershot & Brookfield VT, 459pp.

Mills, Eric L. (2009) *The Fluid Environment of our Planet: how the study of ocean currents became a science*. University of Toronto Press, 434pp.

Peterson, R.G., L. Stramma and G. Kortum (1996) Early concepts and charts of ocean circulation *Progress in Oceanography* **37**(1), 1–115.

Gerhard Kortum was appointed Scientific Director and Curator of the Institute of Oceanography at the University of Kiel, Germany, in 1987. He was appointed to Extraordinary Professor in 1989, and later became Provost. Athough he retired in 2003, he remained with the institute for another ten years, on the board that managed the mergers which led to the formation the GEOMAR Helmholtz Centre for Ocean Research. His great passion was the history of marine research, especially Alexander von Humboldt and the Kiel oeanographer Otto Krümmel. He died in 2013.

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

Part 4: Friends in high places

Tony Rice

In the last episode of the *Lightning* saga* we left the four-year-old paddle steamer in the summer of 1827 accompanying the Royal Yacht *Royal Sovereign* carrying William, Duke of Clarence (soon to become William IV) on a tour of naval establishments. In April that year William had been appointed to the resurrected post of Lord High Admiral in a clever ruse by the Prime Minister, George Canning, with the aim of keeping control of the Navy in the hands of the Cabinet and not in those of a single, powerful, politician. The arrangement was short-lived. Canning died suddenly on 8 August, to be replaced as PM by the equally unfortunate Viscount Goderich. Unable to hold Canning's loose Tory/Whig coalition together, Goderich was forced to resign in January 1828, to be replaced in turn by a Tory government under the Duke of Wellington.

William's days as Lord High Admiral were now numbered and Wellington simply needed an excuse to get rid of him. William provided one in July 1828 when, totally contrary to his job description, he pinched a squadron of ships from under its admiral's nose and took it to sea for several days of fun, including gunnery practice, without the admiral's permission or even knowledge. But in the meantime William was titular head of the Navy and despite restrictions on his powers he was able to make a number of important decisions, including some crucially affecting the status of steam-driven naval vessels in general and the *Lightning* in particular. So now let's return to South Wales in late July 1827.

* *Ocean Challenge*, **22**, No.2, pp.33–6.

Having completed his official visits to the dockyards at Devonport and Pembroke Dock, William returned to Portsmouth for the final part of his tour in the *Royal Sovereign*, initially, at least, apparently towed by the *Lightning* because of contrary winds, or even too little wind. But according to Sir John Barrow, the Second Secretary to the Admiralty, who was travelling with William, once the little flotilla had crossed the Bristol Channel and reached the Cornish coast *'... it began to blow so strong that the steamer was cast off. The Wolf rock roared tremendously, between which and the coast of Cornwall the yacht went beautifully, and rounded the Land's End without our seeing any more of the steamer. On the 30th of July, at six in the evening, we reached Portsmouth.'*

A significant threat to shipping, then and now, the Wolf Rock sits between the coast of Cornwall and the Isles of Scilly, about eight miles south-west of Land's End. Since 1870 it has been marked by a 35-m high lighthouse, but in 1827 it was unmarked other than by the remains of previous fairly minimal attempts to make it more visible. Instead, passing seafarers relied on its most distinguishing feature, the howling noise caused by high winds blowing through fissures in its structure, giving the rock its name.

The engraver Henry Moses now took up the story, describing how the *Royal Sovereign* arrived at the Solent under her own sail and eventually came to anchor at 9 p.m. at Spithead near the entrance to Portsmouth harbour, where the Lord High Admiral spent the night in preparation for the pomp and ceremony of his official visit the following day.

The Wolf Rock lighthouse. It was built between 1862 and 1869, and the light was automated in 1988. Since 1972 it has had a helipad on its top, making it the first lighthouse in the world to be supplied with one. (Photo: Alvaro)

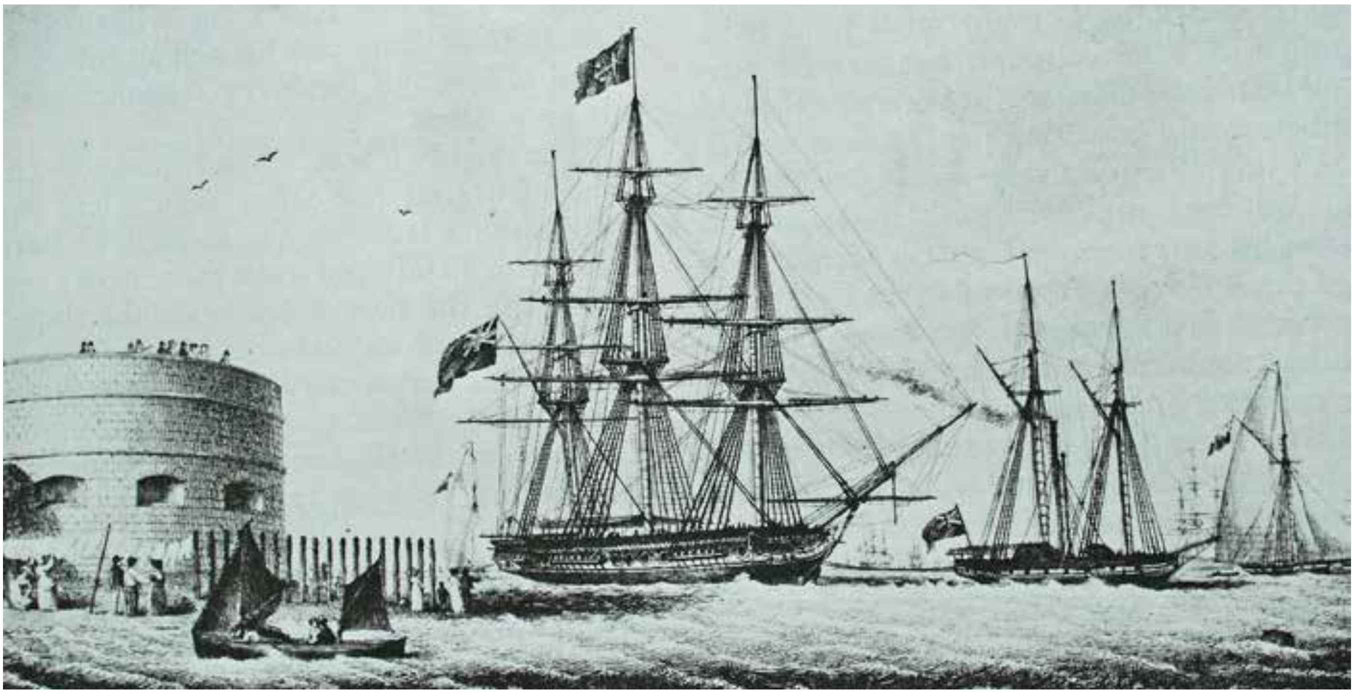
But where was the *Lightning*? We've heard nothing of her since her tow line was cast off somewhere between Milford Haven and Lands End. Well, it seems that the poor old *Procris*, the rather inefficient brig-sloop that we met in the last episode also accompanying the *Royal Sovereign*, had been unable to keep up with the Royal Yacht yet again and possibly needed a tow from the *Lightning* (or the *Comet*, which was also in attendance) because Moses reports that '*On Tuesday* [31 July] *morning early, the Procris brig, and the steam-vessels, which attended his Royal Highness, arrived and went into the Harbour.*' But now *Lightning*'s moment of glory is nigh.

Lightning to the rescue, 'in a most beautiful manner'

'*At 10* [wrote Moses] *the Commander-in-Chief* [Admiral Sir Robert Stopford] *and the Captains of the Fleet, in their respective barges, with the Lieutenant-Governor* [Major General Sir James Lyon, KCB] *and Staff, went to Spithead, and were received by the Lord High Admiral on board the Royal Sovereign. At 11, his Royal Highness, attended by the Admiral, and the flag retinue, went on board his Majesty's brig Musquite,* to muster her crew and examine the ship. From this vessel he went to his majesty's cutter Starling,† then to his Majesty's ship Warspite, and from her returned to the Royal Sovereign Yacht, which was immediately taken in tow and brought into the Harbour by the Lightning steamer, with the Lord High Admiral on board, in the most beautiful manner, amidst cheers from thousands of the most respectable people we have ever yet seen assembled on the lines* [sea walls] *and beaches.*'

*Presumably actually the *Musquito*, a Cherokee class brig-sloop, like the *Procris*, in this case built in Portsmouth Dockyard in 1825.

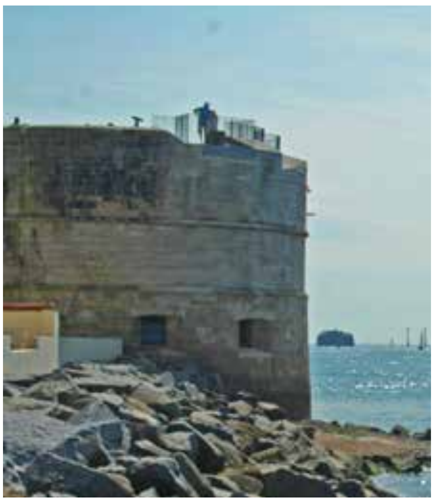
†The *Starling* was a 10-gun cutter built at Chatham Dockyard in 1817 and broken up in 1828, only months after the visit to Portsmouth.



Henry Moses' engraving showing the Royal Sovereign *being towed into Portsmouth harbour by the* Lightning *on 31 July 1827. (From Moses, 1830)*

Moses' engraving of the scene (*above*) shows the *Royal Sovereign* sailing past the 15th century Round Tower at the entrance to Portsmouth harbour, with all her sails furled, being towed by a two-masted steamer belching smoke from her extremely tall funnel. Beyond the steamer is a cutter with her sails filled, while the 'thousands of the most respectable people' are represented by about a dozen figures standing on the top of the tower, then, as now, one of the best places from which to watch vessels entering the harbour. At the base of the tower stand another group of people apparently totally indifferent to what's going on only a few hundreds of metres away while, even more incongruously, a lady appears to be hanging out washing on a line rigged on the foreshore. But Moses was clearly aware of the politics involved in the proceedings. The star of the piece is the *Royal Sovereign*, so that although the *Lightning*, at a length of about 126 feet, was considerably larger than the 95-feet-long yacht, in the engraving she appears to be considerably smaller.

The Round Tower today. The structure on the horizon is one of the Solent Forts, completed in the 1870s.



So apart from the lady hanging out her washing, what would the onlookers have made of it all? Well for some, at least, it would have been a totally novel experience, seeing a vessel moving under steam rather than the conventional sail. For many of the others it would not have been quite such a surprise since steam vessels of various sorts had been chugging in and out of Portsmouth for the previous 15 or 20 years. But even for those familiar with steam propulsion, seeing a major naval vessel entering the harbour so smartly and with relatively little fuss would have been impressive.

And William himself would have been particularly pleased. After all, during the whole of his naval career, bringing a large sailing vessel safely into or out of a harbour, particularly one with a rather narrow entrance like that at Portsmouth, was one of the most difficult of all manoeuvres required of a naval officer, sometimes involving laborious towing by rowed whaleboats or warping the vessel using capstans and kedge anchors. Warping was an extremely tedious procedure in which the ship hauled itself up to a series of small anchors, or kedges, deployed ahead of it from its boats. Having had his yacht brought into harbour by the steamer 'in the most beautiful manner', William seems to have been so impressed that he decided, possibly there and then, that the *Lightning* would become his yacht as Lord High Admiral. But before this could happen, *Lightning* would have to become the command of a properly commissioned officer. Accordingly, on 4 December 1827 the Navy Board wrote to the Admiralty in the following terms: '*In obedience to the command of the Lord High Admiral signified by your letter of this date, we beg to propose the following as the proper establishment for steam vessels. One Lieutenant, one mate, two engineers, twelve men (including stokers).'*

The same day, the Duke of Clarence completed the process by signing the commissions of lieutenants Evans, Bullock and Hay to the command, respectively, of the steam vessels *Lightning*, *Echo* and *Meteor*. In turn, these vessels appeared in the next issue of the *Navy List,* published in January 1828, thus raising their status from the fairly lowly one of auxiliary transport vessel or tug under the command of a non-commissioned officer or even a civilian to that of a full naval vessel carrying the proud title of 'HMS' and commanded by an officer bearing the monarch's commission. Naval steam had finally come of age, and the *Lightning* had played a crucial role. Next time we will look at her early days under the command of Lieutenant George Evans, but before that let's have a brief look at another contemporary naval officer who would have loved George Evans' job.

Post Script: Black Charlie

Many contemporaries of Evans, Bullock and Hay would have considered their appointments to these strange new vessels as retrograde steps rather than improvements in their careers. After all, naval vessels were mainly driven by wind and sail and would remain so for several decades to come. Indeed, George Nares (*right*), HMS *Challenger*'s captain for the first two years of her famous scientific circumnavigation in the 1870s, wasn't born until 1831, three years after *Lightning* entered the *Navy List*; yet his training was as a sail-and-rope man and he wrote the definitive manual of seamanship first published in 1860. And to emphasise the continuing importance of sails, in the preface to the second edition he wrote that *'Engines and machinery, liable to many accidents, may fail at any moment, and there is no greater fallacy than to suppose that ships can be navigated on long voyages without masts and sails, or safely commanded by officers who have not a sound knowledge of seamanship.'*

But even in the 1820s by no means all naval officers felt this way. Then, as now, the main proponents of new technology were youngsters, but in Part 2 of the *Lightning* story (*Ocean Challenge,* **22**(1)) we've already seen that James Clark Ross's uncle John, a RN captain in his late forties, was so keen on steam that he wrote a sort of instruction manual on its use in warships which was published the very year *Lightning* entered the *Navy List*. And John Ross was not alone; another mature naval man, who had been an RN Captain for almost twenty years, actually applied for command of *Lightning* but was turned down despite his seniority, or perhaps partly because of it.

In 1828 Charles Napier (*right*), known as Black Charlie, initially because of his black hair and swarthy complexion, but subsequently also because of his sartorial shortcomings and indifference to personal hygiene, was a fairly impoverished captain on half pay and therefore desperate for further naval employment. He had been born in 1787 at Merchiston Hall, Stirlingshire, into an old and famous military and naval family, and was pretty well destined for a naval career. He entered the Navy in 1799 at the tender age of only 12, serving in a series of vessels in British and Mediterranean waters until he was eventually appointed Lieutenant in the 74-gun *Courageux* in November 1805. He then served with considerable distinction against the French in the West Indies and was promoted Captain in May 1809 at the age of 22, pretty early by the general standards of the day.

Captain (later Admiral Sir) George Strong Nares (1831–1915). Eric Linklater used this portrait in his book, The Voyage of the Challenger, *published in 1972 to mark the centenary of the* Challenger *Expedition.*

Portrait by Stephen Pearle, painted in 1877 after Nares had been withdrawn from the Challenger *Expedition to take command of the Arctic Expedition in HMSS* Alert *and* Discovery *in 1875/6.*
(© National Portrait Gallery, London)

But despite his rank, like so many young officers at the time, Napier then spent two years on half pay, some of it attempting to improve his education at the University of Edinburgh. This was followed by a further two years of naval employment, against the French in the Mediterranean, and against the young United States in the Atlantic, before returning to the UK in 1815 to another period on half pay and marriage to a naval widow with four children. Now in his late twenties, he had already established himself as something of a thorn in the Admiralty's side, bombarding them with a series of letters addressing his three major interests, reform of the Navy, particularly in the way it treated its seamen and its junior officers, promoting the use of ironclad ships to replace the conventional wooden hulls, and encouraging the use of steam propulsion. This interest in steam grew out of the period between 1815 and 1819 when the Napier family wandered around Europe, eventually finishing up in Paris. Having inherited a considerable fortune, Napier at this time became involved in funding a company to promote the use of steam vessels on the Seine, a venture which ultimately cost him a great deal of money and brought in no profit.

In 1820 the Napiers bought a house near Alverstoke in Hampshire and for several years lived a fairly peripatetic existence, sometimes at Alverstoke and sometimes in Paris or Havre. Finally, in 1827 the steamboat bubble burst, leaving Napier comparatively poor. As a result, he sold the Alverstoke house and moved to Rowlands Castle, only about 10 miles from Portsmouth, from where he made several

Charles Napier, in the uniform of an admiral in the Portuguese navy. This Charles Napier was, incidentally, first cousin of Sir Charles James Napier (1782–1853), famous as the conqueror of Sind and attributed with authorship of the famous (but sadly fictional) one-word Latin message to the Foreign Office in London in 1843, 'Peccavi', meaning 'I have sinned'.

Portrait by John Simpson (1782–1847) painted c. 1834 and now in the Museo Nacional Soares dos Reis, Oporto, Portugal

unsuccessful attempts to obtain further naval employment, including applying for the command of the *Lightning* which, as we have seen, he lost to George Evans. Eventually, in 1829, he was given command of the frigate *Galathea* on which he conducted a number of moderately successful trials in which the ship was fitted with paddles driven by winches on the main deck. During this commission Napier served in the West Indies and in Portuguese waters, becoming interested in Portuguese politics which were, at the time, fairly chaotic and, as we will see later, even touched on the *Lightning*. Although he continued his interest in steam, Napier disappeared from the *Lightning* story for the next 25 years before re-entering it with a vengeance when, as a 67 year-old Vice Admiral, he was given command of the British naval forces in the Baltic theatre of the Crimean War in 1854. In this, his very last naval job, his activities impinged on the *Lightning* again – and he fell out with his political leaders big time. But in the meantime, let's leave Black Charlie to his own eventful career and, in the next episode, return to the *Lightning*'s rather less tumultuous one.

Further Reading

Barrow, Sir John, 1847) *An autobiographical memoir of Sir John Barrow*, London.

Greenhill, B. and A. Gifford (1994) *Steam, Politics and Patronage*, Conway Maritime Press, 256pp.

Linklater, Eric (1972) The voyage of the *Challenger*. John Murray, 288pp.

Moses, Henry (1830) *The visit of William IV when Duke of Clarence, as Lord High Admiral to Portsmouth, in the year 1827, with views of the Russian squadron at Spithead*. London, Ackermann and Co.

Napier, P. (1995) *Black Charlie: A life of Admiral Sir Charles Napier* KCB *1787–1860*. Michael Russell, 238pp.

Nares, G.S. (1862) *Seamanship.* Gresham Books, 224pp. (Facsimile reprint published by Unwin Brothers Limited in 1979).

Pockock, T. (1991) *Sailor King. The life of King William IV*. Sinclair-Stevenson, 254pp.

Ross, J. (1828) *A Treatise on Navigation by Steam.* London, Longman, Rees, Orme, Brown and Green, 182 + 68pp.

Tony Rice is still 'a geriatric biological oceanographer with a passion for maritime history'. ricetony01@gmail.com

Book reviews

Politics, power and the NIO

Ocean science and the British Cold War state by Samuel A. Robinson (2018) Palgrave Studies in the History of Science and Technology, 278pp. £80+ (hardback, ISBN 978-3-319-73095-0), £71.50 (ebook, ISBN 978-3-319-73096-7).

The book *Of seas and ships and scientists** gives a readily accessible picture of the development of UK marine science during and immediately after World War II, leading to the formation of the National Institute of Oceanography. The picture it paints is from the perspective of scientists who worked at NIO. How would an outsider and an historian see those same events?

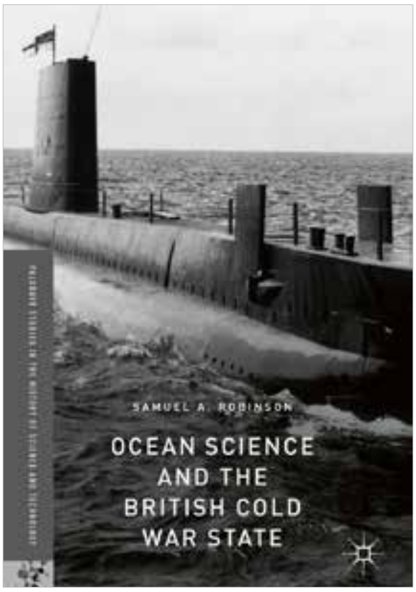
Well, now we know. Sam Robinson has burrowed deep into the archives at the National Oceanography Centre in Southampton, and into the National Records Office, to produce this impressively researched book. It is cleverly structured around the career of George Deacon (1906–84), the NIO's founding Director, as he progressed from his role as the chemist for the *Discovery* Investigations, to being the leader of a talented and diverse collection of scientists addressing urgent issues during the war, and then to the person who above all shaped the structure of the NIO.

This book is not a dry narrative; rather, it brings to the fore the conflicting visions of the *dramatis personae*, including Edward Bullard in Cambridge, Neil Macintosh (*Discovery* Investigations), Joseph Proudman and Arthur Doodson in Liverpool, and J.N. Carruthers who played a leading role for the Admiralty at the end of WWII. These were people of whom I already knew but the book introduced me to Sir Henry Tizard, a Whitehall 'insider' who was Chief Scientific Advisor to the Government (1948–52). The interplay of the strengths, weaknesses and prejudices of these men (in that era men were the sole players), and the interfaces between the networks within which each of them operated, make for a fascinating read. As Robinson states, '*It is a scientist that possesses a variety of skills, enabling them to shape the historical trajectory of networks in order to "get their own way" who succeeds (as Deacon did)*.'

It was during WWII that ocean science came to the help of the nation and the Royal Navy. Thus the NIO came into the world with close links to the Admiralty; indeed its scientists were, until the late 1960s, employees of the Royal Naval Scientific Service. Deacon's vision for a national institute was multidisciplinary: it included physical oceanography (which he had led in WWII), marine biology, as the legacy of the *Discovery* Investigations, and chemistry, marine geology and geophysics, the power base for which lay in university departments. Forming the new Institute, convincing the Admiralty of the value of marine biology and creating an Institute that did not tread on the toes of established laboratories was difficult.

The book then explores how the Admiralty's demands and priorities for NIO changed in response to the emerging threat of the Cold War, as well as in response to funding crises in which oceanography had to fight hard for scarce funds against the need for frigates and submarines.

And what of the 'British Cold War State'? NIO's science did indeed feed into the Royal Navy's requirements for ocean science but most of these were delivered by the Navy's own laboratories. What I had not realised was that as international collaboration developed, as exemplified by the International Geophysical Year in 1957–58, civilian scientists on planning



*Of Seas and Ships and Scientists (Lutterworth Press, 2011) was reviewed in *Ocean Challenge*, **18** (Winter, 2011), pp.49–50.

committees could provide intelligence on foreign scientific capabilities and priorities.

As Deacon approached retirement he was faced with negotiating the transfer of NIO's oversight from the Admiralty and the National Oceanographic Council to the much broader Natural Environment Research Council, which had a different vision of the Institute's role. There was also the not insignificant matter of who should be Deacon's successor as Director.

And so the narrative ends. Should you buy this book? It is not cheap and most individuals will baulk at the £80+ price for one so modestly illustrated. Should you read it? Yes, most certainly. It gives an insight into the roots of British marine science and into the workings of the government as they affected marine science. My suspicion is that, even today, the interplay of priorities, budgets, egos, networks and interdisciplinary rivalries is little changed. So just as C.P. Snow wrote of goings on in the 'Corridors of Power', this book gives an insight into how these played out in our own science discipline.

I can't wait to read the sequel, which will describe the following decades.

John Gould
National Oceanography Centre
Southampton

A tough read, but worth it

Orca: how we came to know and love the ocean's greatest predator by Jason M. Colby (2018) Oxford University Press, 408pp. £15.99 (hardcover, ISBN: 978-0-190-67309-3). Also available as an ebook and Audio CD.

I saw my first orcas decades ago, from a helicopter flying from the mainland to the offshore island of Lundy in the Bristol Channel: my most recent sighting was at dawn off the Galapagos when a pod of 15, complete with youngsters, gave we early risers the best possible start to the day. The sighting of an orca always makes the news, attracts onlookers and gives those of us lucky enough to witness the event a tantalising glimpse of the majesty of 'the ocean's greatest predator', a heartening symbol of wild nature. But this was not always the case; even as recently as the 1950s, orcas were regarded with fear, mistrust and revulsion as mindless killers, no doubt a hangover from days when we humans massacred the orca's cousins, the great whales, for profit and the orcas came to share in the spoils as whale carcasses were harpooned and dragged aboard the floating whale factories.

It was only when the first orcas were captured and taken into captivity that visitors to the tourist attractions, scientists and even the fishermen who had regarded them as pests, saw the killer whale for what it really is: a magnificent, powerful, beautiful and sentient animal worthy of our respect. *Orca* chronicles the changes in attitude which, in just a few short decades, took the animal from a creature to be killed on sight, to one that, once incarcerated, represented human dominance over dangerous and unpredictable nature, to an intelligent cohabitant of our world. The animal went from reviled killer whale to revered orca.

Jason M. Colby is an historian, ideally suited to write a book which will not be to everyone's taste. With the benefit of hindsight we know it was wrong to capture and 'cage' such amazing mammals; Colby has the ability to stand to one side and give us the often unpalatable truth about our relationship with orcas. In 19 chapters he takes us from early perceptions of orcas: '*Gaius Plinius Secundus had witnessed a lot of violence in his life – war in Germania, Sicilian raids, Nero's reign of terror – but killer whales really seemed to scare him*,' through the years of capture, and commercial gain, to the dawn of appreciation. Pliny described the killer whale as '*an enormous mass of flesh armed with teeth*'. This idea of the killer whale as a ferocious killing machine clung to the animal for centuries. Fishermen took every opportunity to spear, harpoon and shoot these 'demons from hell', massacring thousands in the name of fisheries and whaling; even the US military trained their guns on them.

Colby's meticulous research and attention to detail provides a compelling narrative from the days of mass destruction to the endeavours of one man who brought them into captivity. The dogged nature of Ted Griffin is a constant thread through the book, following his first success at trapping, transporting and exhibiting orcas in 1965. This was an orca watershed, as it gave ordinary people the opportunity to see orcas close-up and to marvel at their performances and intelligence. The following chapters are a hard read for anyone who admires orcas, as they catalogue the stages of the burgeoning industry of killer whale capture and captivity. There were successes, of course, but there were also failures, which we now see as tragic and unnecessary sufferings and deaths. Colby on more than one occasion refers to the 'cries' of orcas as pods are divided, mothers and calves separated; for him, the cries imbued the orcas with an almost human emotion. Griffin, the hardened entrepreneur, was himself 'painfully aware of the social ties he was breaking' and 'they were impossible to ignore' as the whales that were not retained followed 'in sad vigil for their lost pod mates'. As Colby progresses through from the early days of capture to an entire industry dedicated to procuring, trading and transporting orcas across the globe to perform tricks for our entertainment, he relates tales of double-dealing, treachery, rivalry and sabotage. Orcas were worth big money and attracted huge crowds. Despite protestations that 'live capture was essential to research' and 'whales in captivity are pampered and much better fed than other whales', the main driver of capture and incarceration was profit.

But attitudes were changing, pressure groups were forming, politicians were taking notice and even those involved in the orca industry were (reluctantly) recognising that the animals that provided them with a living should not be in captivity but living wild and free. Colby takes us through the transition, legislative regulation and public abhorrence at the fencing in of killer whales, and their ultimate rebranding as orcas to be marvelled at – as they disport themselves wild and free in the ocean.

I didn't want to enjoy this book, but I was compelled to read it from cover to cover, all 300-odd pages, and I am glad I did. If like me you are left hungry for even more, the book is backed up by a really useful set of chapter notes, bibliography and comprehensive index. I am not sure I always share Colby's generous spirit when he talks about those pioneering orca hunters and trainers, but he is writing with the objectivity of a historian and that made me see the other point of view. I appreciate orcas even more than I did, and can't wait for my next sighting.

Kelvin Boot
Science Communicator
working with Plymouth Marine Laboratory