OCEAN Challenge

The Challenger Society for Marine Science

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Vol. 24, No.1

OCEAN Challenge

The Challenger Society for Marine Science

Volume 24, No.1, 2018
(published 2020)

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.

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ISSN 0959-0161 Printed by Halstan Printing Group

OCEAN Challenge

The Magazine of the Challenger Society for Marine Science

SOME INFORMATION ABOUT THE CHALLENGER SOCIETY

The Society's objectives are:

To advance the study of marine science through research and education

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

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

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

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

Holding regular scientific meetings covering all aspects of marine science

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

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

Membership provides the following benefits:

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

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

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

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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**

CONTENTS

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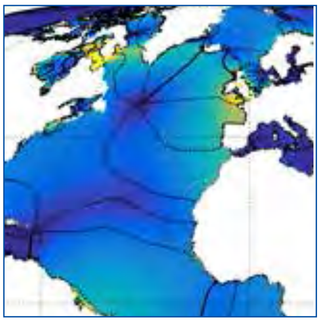
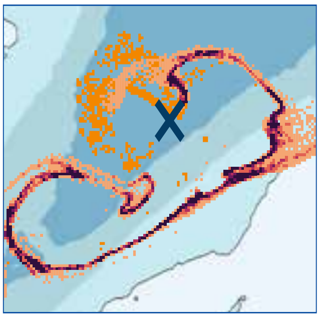




Most of the maps and diagrams were drawn by The ArtWorks.

The cover and heading graphics were designed by Ann Aldred.

Cover photo: Matt Gubbins, Marine Scotland Science.

CONTENTS *(cont.)*

Message from the Editor

I would like to begin by expressing my gratitude to Grant Bigg for chairing the Editorial Board since July 2013. Grant's role has now been taken by Stephen Dye from Cefas. Stephen's first job was to interview distinguished marine biogeochemist, Tim Jickells, himself a long-serving Editorial Board Chair (see pp.3–5).

As well as articles covering a wide range of oceanographic disciplines, this issue contains appreciations of three influential marine scientists who have died over the last few months: Sidney Holt, Robert (Bob) Dickson and Anthony (Tony) Laughton, who as Challenger Society President in the late 1980s oversaw the reconstitution and reinvigoration of the Society, and was instrumental in getting *Ocean Challenge* started. If you would like to learn more about Bob and Tony and their work, go to the British Library's 'Oral history of British science', https://sounds.bl.uk/Oral-history/Science, which contains photographs of, and interviews with, 1685 scientists including some marine scientists.

Don't forget to book your place at the Challenger Society Conference!

Angela Colling

Come to stunning Oban!

Challenger Society Conference 2020

7–11 September 2020

Hosted by the Scottish Association for Marine Science

See http://www.challenger2020.co.uk

AMBIO IX: Biogeochemistry Across Boundaries A celebration of the career of Prof. Tim Jickells

AMBIO – Advances in Marine Biogeochemistry – is one the Challenger Society's most thriving Special interest Groups. Its 9th biennial meeting, held in June 2019 at the University of East Anglia, was also a celebration of the career of Professor Tim Jickells, whose work has covered the full breadth of marine biogeochemistry. In recognition of his sustained contribution to marine science, including some pioneering and transformative research, Tim was awarded the Challenger Medal in 2006, and recognised more widely by an OBE for services to marine and environmental science in the 2010 New Year's honour's list.

The first session of the meeting – 'Air–Sea exchange' – began with Professor Robert (Bob) Duce, Texas A&M University, presenting a cleverly illustrated account of Tim's career, from his first paper (published in *Nature* in 1982, about the transport of acid rain over the western Atlantic Ocean) to his service on many scientific committees, and various advisory roles for the UK research community and government departments.

Audience members were awed at some of the statistics that Bob quoted: Tim has published about 220 papers (~53 relating to air–sea exchange) – that's about six papers a years for almost 40 years – and those papers have been cited more than 21 300 times. He has had 22 Ph.D students who, with others, have benefitted from his long-term support. As the meeting announcement noted: 'Tim championed many of us in diverse roles: marine biogeochemical research, teaching, and governance at local, national and international scales.'

An aspect of Tim's work that is perhaps less well known is his contribution to GESAMP Working Group 38: The Atmospheric Input of Chemicals to the Oceans. GESAMP is the body that advises the United Nations on scientific aspects of marine environmental protection; Tim has been a member of WG 38 since its inception, and replaced Peter Liss as Co-Chair in 2015.

Needless to say, all speakers took delight in including references to, and photographs of, Tim, in their talks. To take just one example: Parv Sunthalaralingam showed a group photo from the 2017 GESAMP workshop at UEA, where Tim had arranged both the meeting and the teas, but wasn't in the group photo as he had taken it!

Sadly, there isn't room here to describe all the presentations and posters. The session on 'Macronutrient Cycling' was introduced by Laura Bristow's keynote talk on the pivotal role of nitrate in the marine nitrogen cycle; Sian Henley, speaking about how biogeochemistry in the Arctic and around Antarctica is changing with the climate, introduced the session on 'Polar and Carbon Processes'. There were also sessions on 'Carbon in the Ocean', and 'Trace Metal Dynamics'. Following the session on 'Sediment and Estuarine Biogeochemisty', we were entertained by Richard Sanders' talk: 'Standing on the shoulders of a giant: a tribute to Tim Jickells and his role in shaping the field of Marine Biogeochemistry'. The last keynote talk of the meeting was by Tim himself: '40+ years looking at the nitrogen cycle'.

The finale of the meeting was the presentation of prizes, by Tim. The prize for the best oral presentation by a student went to Korinna Kunde for her talk on 'The pivotal role of colloidal iron in the dusty subtropical Atlantic'. The student poster prize was won by Ruth Payne for her 'Determination of carbonate parameters in estuarine waters: challenges and solutions'. The prize for the best presentation by an early-career researcher was won by Neil Wyatt for his talk on 'Hydrothermal venting as a globally relevant source of zinc to the oceans'; Robyn Tuerena and Lucie Cassarino were highly commended.

The final award of the meeting went to Tim himself. Since his early days at UEA, Tim has been a stalwart of the Challenger Society. As well as working hard for the Society behind the scenes Tim was President of the Society from 2014 to 2016 and has twice been Chair of the *Ocean Challenge* Editorial Board. In recognition, Tim was presented with a certificate for Honorary Lifetime Membership of the Society, by the (very grateful) Editor of *Ocean Challenge*.

Altough Tim formally retired in 2018, he is now an Emeritus Professor, and will not be saying goodbye to UEA or to academia. For more about Tim's career so far, see pp.4–5.

The convenors of the meeting – Alex Baker and Matt Humphries (UEA), Amber Annett (Southampton) and Will Homoky (Oxford) – are to be congratulated for this smoothly run and highly enjoyable event. *Ed.*

Tim presenting Korinna Kunde with her award for the best talk by a student

(Photo: Amber Annette)

An interview with Tim Jickells

At the AMBIO meeting last June, Professor Tim Jickells of the University of East Anglia was awarded an Honorary Lifetime Membership of the Challenger Society (see p.3). Stephen Dye (Cefas) met up with Tim to talk about the Society, and discuss some of the highlights of Tim's long and distinguished career in environmental and ocean science. *Ed.*

Tim wearing his Emeritus Professor robes (Photo: University of East Anglia)

What makes the Challenger Society special for you?

Challenger is great – it represents oceanographers in the UK, the scientific community, very well. The biennial conferences are terrific. People really enjoy them as well as turning up for the science. So I think it does a great job of bringing the community together and keeping us talking to one another.

I can remember when Peter Liss first suggested I get involved with Ocean Challenge *– this was around 1990, when the Society was being reinvigorated. I think* Ocean Challenge *alongside* Challenger Wave *is a really good combination. You can get the immediate news out in* Challenger Wave *and then you have the more thoughtful stuff in* Ocean Challenge*.*

Where did your interest in marine science begin?

Well, I grew up in Barry. I spent time on the sea shore, and I could see the Bristol Channel from my bedroom window so when I was bored with my homework, which was much of the time, I could look out at the sea. We're talking now about the late '60s when there was a kind of alternative culture, a sense that the environment was under a huge amount of pressure – I remember having a T-shirt saying 'Save the whale'. My father had been in the Navy during the war, and my grandfather had run away to sea for a while. There was something about the sea that was romantic and exciting, but growing up in Barry before the arrival of RVS [Research Vessels Services] I never knew you could make a living as a scientist at sea.

Then in the late 70s you worked for the Clyde River Purification Board. What was that like??

I was part of the marine team which was trying to understand the Clyde estuary system and monitor its recovery – we actually had the first passage of salmon! The Clyde had suffered from sewage pollution for years but it was transformed by the new sewage works. And Glasgow was fantastic. Despite all its troubles it was the most exciting city, and the highlands were on our doorstep. It was all great – except for the rain!

Then you went to Bermuda – what was it that made you take that step – apart from the weather?

We came back from a holiday and there was a postcard saying 'Are you interested in a job in Bermuda?' It was exciting – a chance to do something wildly different. My wife Sue and I both gave up civil service jobs with local government pensions. We were in our mid 20s, and at that age you don't quite think about your pension in the same way. We had no idea what Bermuda was even, so we just said 'Yes', burnt our boats and went. It was an 18-month contract and it turned into 7 years. It was a fantastic opportunity. There weren't many permanent staff, but lots of people came through. There was a kind of 'can do' attitude and you kept saying 'Yes' to all sorts of exciting things.

Did you find that those years in Bermuda were valuable to your later career?

Yes – things that happened in Bermuda served me for years. One person I met there was Tom Church and we worked together for the next 40 years. Plus it was really valuable for the teaching I did afterwards because I could talk to students about environments that were not just the southern North Sea or even the deep ocean, but also coral reef systems and other really different habitats.

Bermuda's a very expensive place to go to on holiday and somebody paid us to live there for seven years! But it was always soft money and you would be very hard pressed to get citizenship, so there was always going to be a time to say the party's over. Luckily, I got a job at UEA.

So in the mid '80s the UEA School of Environmental Sciences was a really exciting place?

Yes! And it also turned out to be a great time to come to the UK because the government were actually doing things. I was really lucky to arrive just as the North Sea Project kicked off and we got some money to start looking at atmospheric inputs to the North Sea. Then the BOFs programme and the international JGOFS programme came along. One of the things I'd been involved in in Bermuda was Werner Deuser's sediment-trapping programme. Although I'd never deployed a sediment trap, I had analysed material collected by traps, so when I came back I worked with Richard Lampitt, and with the impetuosity of youth we set up the UK BOFS sediment-trap programme. Luckily one of the things that had come out of Bermuda was a whole host of relevant papers, so I had a track record, and we got the funding.

It sounds as if, as a young scientist, it can sometimes be beneficial to be impetuous?

Exactly – it's about grasping opportunities! You've just got to say 'Yes' to all sorts of things and then some of them will turn into great ventures and some of them will crash and burn. That's just the way it is.

The cruises you went on looked like great fun!

Yes, absolutely. Oceanography is a fantastically collaborative activity – nobody gets a research ship for a one-person cruise. It means that you make *friends and form collaborations in a way that I don't think happens in terrestrial science. You get to really know people well when you are stuck on a ship together for four or five weeks. You come up with wholly new ideas about ways to do things, new experiments you didn't plan. Shipboard science is really exciting.*

What are your feelings about large-scale collaborations?

The UK does collaborative science well, including with Europe. We can get some really good science done in these big international programmes. There is currently a particularly strong focus on the Southern Ocean – programmes like ROSES and CUSTARD are really valuable. Without the institutes – Cefas, or the National Oceanography Centre or Plymouth or wherever – it's really hard to imagine getting to sea with that critical mass of scientists.

For me, AMT [the Atlantic Meridional Transect] was absolutely critical to the whole second phase of my career. Get on a boat in the Falklands and sail back to Britain and by the time you get home you've seen most of the ocean environments, and got a sense of the way they interact, and of that scale. It's like you turn the telescope round the other way and you look at the Earth as a really big system. Because the ship is undertaking an annual voyage to supply science bases in the South Atlantic anyway, you can get a lot done for relatively modest costs – and it connects up with the satellite work too.

NERC is now part of a new body – UK Research and Innovation. Do you think that will be good for marine science?

I think that UKRI will help marine science in a general way, as it's going to allow cross-disciplinary working much more effectively than ever before. I've worked with environmental economists for the last few years and trying to get funding in that area has always been really challenging because it's half physical science and half social science. But it's important because we don't only need the scientific evidence about climatic and environmental problems, we also need acceptance by society of what has to be done.

Do you think that the public and policymakers have begun to appreciate the value of marine science over the last few years?

The policymakers absolutely – thank you, David Attenborough! At Defra, where I was yesterday, the marine team were emphasising how they are suddenly being listened to. People have recognised that two-thirds of the planet is watery and that the ocean provides us with a host of key environmental services: taking up carbon dioxide, biodiversity, fisheries, all sorts of resources. Much of our power is going to come from wind and perhaps tidal as well. The success of wind farms off the coast is really striking, whether you like them or not. What's strange is that the general public don't have much idea of the water much beyond swimming depth so we rely on things like TV programmes to give them a sense of the wonder that's out there.

How about those unglamourous muddy sediments?

You see a curlew or a red-shank pottering around in the mud on a cold day and you think: How much do they have to eat to keep warm, when what they are eating is worms which are feeding on bacteria? In his Ocean Challenge *interview Nick Owens said that he used to tell students that if you could see it, it wasn't important, that we should be looking at processes operating at a really micro level, and he's right. But to be honest we probably just have to accept that photosynthetic bacteria are an aquired taste and recognise that some people will want to think about bigger organisms. Wild animals such as birds really do grab peoples' imagination.*

Tim relaxing and contemplating the North Atlantic in the Outer Hebrides

In your career, what's the work you feel has had the most impact so far

The work we've done on dust inputs to the ocean had the highest profile, but one of the areas I'm most intrigued by is coastal management. For the first paper, which was on the Humber, I worked with my friend Julian Andrews and it was a collaboration the like of which I'd never experienced before. Literally the night before we finished the final report I pulled all the numbers together and we were astonished by the conclusion we reached about how estuaries had functioned previously. I learnt how much we'd managed and changed estuaries over the last 300 years – the coastal ocean as well.

I think the work contributed to the idea of finding different ways to protect the coast. There's now an understanding that while saving money on flood defences you also store carbon and remove nutrients – additional environmental services.

Back to sea for one last question: If you were to go to sea again which research vessel would you choose, and where would you go?

I would probably like to go back to Antarctica, but I've never been to Greenland and that would be exciting. I sailed on the Discovery *before it was lengthened and it was a lovely old ship, but the ship I've sailed on the most is the* James Clark Ross *– that's a lovely ship too. So I would probably go back on another cruise to Rothera Reseatrch Station, off the Antarctic Peninsula, on the* James Clark Ross.

Sir Anthony Laughton DSc., FRS (1927–2019)

A tribute to a leading light of UK oceanography

Anthony Laughton, known to his many colleagues as Tony, died on 27 September at the age of 92 after a short illness. He was a geophysicist whose career in oceanography spanned the immediate post-war period to well into the 21st century. He rose to become Director of the Institute of Oceanographic Sciences, from which he retired in 1988. He was a warm and approachable man who could charm, but could also be tenacious in the pursuit of what he thought was right.

After national service in the Royal Navy, Tony graduated from Cambridge University in 1951 with an honours degree in Natural Sciences, specialising in physics in the final year. After a false start doing research in atomic physics Tony became a research student of Maurice Hill in Cambridge's fledgling marine geophysics group. Here he obtained his first experience of doing science at sea on board *RRS Discovery II*. After completing his Ph.D in 1954, Tony worked for 12 months at the Lamont Geological Observatory just outside New York, and spent some time at sea operating a deep-sea camera.

On his return to the UK, Tony was recruited by Dr (later Sir) George Deacon, founder Director of the National Institute of Oceanography (NIO) in Wormley, Surrey. In those days, NIO scientists had free rein and Tony decided to build a deep-sea camera that improved on earlier designs (see Box). Within a year he was able to take photos of the sea-floor, some in colour, at depths down to 4800 m. On the same cruise he became interested in using the echo-sounder to map the sea floor and this was to have a lasting impact on him. A new, NIO-designed precision echo-sounder, which could measure depths to within one fathom, was trialled in 1958. It enabled him to demonstrate that the Tagus Abyssal Plain and adjacent abyssal plains had very low gradients over hundreds of miles. Tony's interest in sea-floor bathymetry continued for the rest of his life.

The International Indian Ocean Expedition (IIOE) took place in 1962–63 with UK scientists on board the brand new *RRS Discovery*. A major three-month geological/geophysical cruise in 1963, led by Maurice Hill and in which Tony participated, offered new directions for his research. In particular, he began to consider how the geological development of the Gulf of Aden – which had been traversed twice by *Discovery* as well as by other research ships collecting geophysical profiles – related to the history of the mid-ocean spreading Carlsberg Ridge. The eventual result, following a second *Discovery* cruise in 1967, was the publication, with other members of his growing group at NIO, of seminal bathymetric and magnetic anomaly charts of the Gulf of Aden, which helped to tie the history of the Red Sea in with that of the north-west Indian Ocean. In parallel, Tony was also working on a bathymetric chart of the north-west Indian Ocean which contributed to one of three IIOE Atlases published in 1975.

The Deep-Sea Drilling Project (DSDP) had begun its long life in 1968 and by 1969 there were plans to drill in the northern Atlantic. After approaches from the UK, backed by suggestions of drill sites from Tony, these plans came to fruition. Tony was appointed as one of the two Co-Chief Scientists for DSDP Leg 12, along with Bill Berggren, a micropalaeontologist from Woods Hole Oceanographic Institution. Bill was a species of Earth scientist that Tony had probably not encountered hitherto but the two got on very well. The expedition drilled nine sites, in the Labrador Sea, on the Reykjanes Ridge and Rockall Bank, and in the Bay of Biscay. Tony's involvement and interest in DSDP, and its subsequent incarnations, continued for many years afterwards.

Tony Laughton when Director of the Institute of Oceanographic Sciences
(Archives, National Oceanographic Library, National Oceanography Centre Southampton)

Tony Laughton examining a core on board DV* Glomar Challenger *with Bill Berggren (left) and Bill Allinder, Cruise Operations Manager, during DSDP Leg 12 in 1970
(Courtesy of the International Ocean Discovery Program (IODP), JOIDES Resolution Science Operator (JRSO), and photographer Larry Lauve)

DSDP Leg 12 caused Tony to re-focus on areas nearer to home and led to publication between 1975 and 1983 of an important and widely used series of five bathymetric charts of the north-east Atlantic at the scale of 1 : 2.4 million. At about this time Tony's contribution to the *General Bathymetric Chart of the Oceans* (*GEBCO*), in which he had been involved since 1966, increased. Through his membership of an Intergovernmental Oceanographic Commission (IOC) scientific working group he was invited to join GEBCO's Guiding Committee at a crucial time when the specifications for GEBCO's new 5th Edition charts were being formulated. These 5th Edition charts were eventually used in labs the world over. In 1986 Tony became Chairman of the Guiding Committee and he stayed in that role, overseeing the eventual digitisation and release on CD of all the 5th Edition charts, until GEBCO's Centenary in 2003. This was not to be Tony's last GEBCO hurrah however. In the search to raise badly needed funds the Japanese member of the Guiding Committee suggested that an approach be made to the Nippon Foundation. After prolonged negotiations, led by Tony, GEBCO succeeded in setting up a training programme in undersea mapping funded by the Nippon Foundation at the University of New Hampshire. This programme is now in its 16th year and trains around six international students each year.

An alternative way to map the sea bed, intermediate in scale between photography and contouring on the basis of soundings, was by using beams of sound projected sideways. Indeed, NIO had used its own side-scan sonar equipment to study the sea bed of the continental shelf since 1958. But by the mid-1960s there was a push to use this technique to map the deep ocean too. In 1969 the resulting in-house designed, towed instrument (*GLORIA* or *Geological LOng-Range Inclined Asdic*) was used for the first time in open Atlantic conditions. Although useful data were collected, the launching and recovery operations proved to be hazardous at times and required good weather. One early serendipitous success was the discovery that, towards its western end, the transform plate boundary between Gibraltar and the Azores was expressed on the sea floor as a single linear fault over 400 km long. Tony (now working with Roger Searle) subsequently conducted other surveys of the Mid-Atlantic Ridge, some using the vastly improved *GLORIA Mark II* which could survey 1100 km^2 per hour.

Tony became Director of the Institute of Oceanographic Sciences (IOS), formerly NIO, in 1978. Subsequently he oversaw eight years of *GLORIA* surveys of the whole Exclusive Economic Zone of the USA. This project was managed by Tony Rees, and for its work with *GLORIA*, IOS was awarded the Queen's Award for Industry. Around 1980, Tony coordinated a major influx of new staff to IOS – which included the thriving geophysics group now led by Tim Francis – to set up a multidisciplinary research programme funded by the Department of the Environment to study the feasibility of disposing of high-level radioactive waste at sea.

Tony received many awards over the course of his long career. In 1980 he became a Fellow of the Royal Society and he was awarded a knighthood in the Queen's birthday honours of June 1987 for 'Services to oceanography'. To his great delight he was awarded an honorary DSc. degree by the University of Southampton in July 2019.

Tony sat on many national and international committees during his career. He was adept at pressing home his point, and invariably succeeded. He served on committees of the Royal Society, NERC and British national committees, as well as of GEBCO and DSDP, already mentioned. These networking opportunities often led to scientific collaborations. There was also committee work connected with the Institute's numerous contracts with HM government which sometimes required careful handling. Because of his background in geophysics and bathymetry he also advised the UK government, and later the IOC, on aspects of the *United Nations Convention on the Law of the Sea* (*UNCLOS*).

After retirement in 1988, Tony continued his committee work, notably playing an important role in the reconstitution of the Challenger Society, while he was its President. He was also involved in the Society for Underwater Technology and was a trustee of the Natural History Museum. As a fitting reflection of a career spent in oceanographic research, which often made use of the latest technology, Tony chaired the committee overseeing the development of *Autosub* (see Box). With former NIO colleagues he documented the development of oceanography at NIO in a book entitled *Of Sea and Ships and Scientists* published in 2010.

Tony had interests beyond science which included music (he played the French horn in two orchestras for many years), dinghy sailing, gardening and woodwork. In latter years he was a regular tennis player. He leaves his wife Clare and their daughters Rebecca and Susanna, Andrew his son from his first marriage, and three grandchildren.

Bob Whitmarsh (National Oceanography Centre Southampton) with assistance from **John Gould**, **Gwyn Griffiths**, and **Clare Laughton**.

Tony Laughton: a man who made things happen

From his earliest days at NIO, Tony Laughton had an affinity for technology. In the mid 1950s he devised a deep-sea camera, which was deployed on the end of a wire lowered from a ship. When a weight below the camera touched the sea floor the flash would trigger, a photograph would be taken, and the 35 mm film wound on. Later versions, designed with Dickie Dobson, added a shutter for use in shallower water where there could be ambient light, and a photocell to detect whether there was sufficient reflected light for a decent photograph.

Tony's bathymetric work needed greater repeatability in depth soundings than provided by the mechanical governors in the echo-sounders of the time. Along with John Swallow he introduced crystal-controlled timing, leading to the Precision Echo Sounder so familiar to Wormley sea-goers. Less well known was his invention of a Continuous Profile Recorder, a small display of the full depth range to complement the 400 fathom window on the main display. This must have been a boon to heavy-eyed watchkeepers who might lose track of what depth needed to be added to the main display.

His instruments were used beyond science. For example, in the early 1960s, he took a Precision Echo Sounder, deep-sea camera and corer to the Luzon Strait to survey a new telephone cable route for Cable and Wireless, finding hazards including fast currents at the sea bed and outcrops of sandstone.

When, in 1997, the Natural Environment Research Council sought a steering committee Chair for the *Autosub* Science Missions programme, Tony was an inspired choice. At a time when autonomous scientific submersibles might have turned out to be a mere technical curiosity, Tony's appointment sent a clear and confident message that excellent science was to be the principal outcome. And, as then President of the Society for Underwater Technology, he epitomised the productive bridging of marine technology and science.

I will never forget his meticulous preparation before meetings, his mastery of the detail, the steer he gave other members not to flinch from supporting daring proposals, and his ability to get the members to reach a consensus. Under his leadership the *Autosub* steering committee proposed a portfolio of projects that took the AUV from the North Sea to the Antarctic. Successful scientific results from a community of researchers with ideas about how best to exploit *Autosub* made possible today's NERC fleet of some 40 autonomous vehicles. Tony closed his final steering committee meeting by praising the efforts of Nick Millard and his team of engineers on delivering such a scientifically productive programme. In turn, Southampton technologists owe a great debt to Tony.

Gwyn Griffiths

Remembering Robert (Bob) Dickson (1941–2019)

Bob joined the Lowestoft Laboratory, the MAFF Directorate of Fisheries Research (now Cefas), in 1964. He was first appointed there as a NERC-funded Ph.D student associated with the newly formed University of East Anglia. The title of his 1967 Ph.D thesis, one of the very first in the new School of Biology, encapsulates the themes of Bob's career in science over the next 45 years: 'Long-term changes in the hydrography of the European shelf seas since 1905, and the effects of these upon the distribution and abundance of various marine organisms'. In 1966, he was employed as a Scientific Officer in the Hydrography Section at the Laboratory where his work quickly extended well beyond the shelf and fisheries hydrography. His first publication in *Nature*, in 1973, was on global perspectives on climate and advised that *'early interest ... by planners in agriculture, industry and government has developed into an outright demand that climatic forecasts be made a few years or even decades ahead'.* By the time he retired in 2008 his career-long contribution to science had earned him a CBE in the Queen's New Year Honours List.

From the early days of the self-recording current meter Bob contributed to the available stock of direct current measurements by which the pattern and variability of the deep ocean circulation became better understood. In the 1980s he and colleagues found and explained seasonal variations caused by wind stress and stratification at a depth of 4 km where they had no right to be!

Work in the eastern North Atlantic to assess potential nuclear waste disposal sites ended by 1986, so instead Bob used the instruments to make the first year-long direct measurements of the cold, dense Denmark Strait overflow. This effort at the Angmagssallik Array finally drew to a close in 2015, providing almost 29 years of observations which have changed the way we understand this key component of the Atlantic overturning circulation. This effort earned him, in 1998, the oceanographic honour of which he was probably most proud – the Albatross Award of the American Miscellaneous Society, who mischievously accused him of attempting to stem the flow through the Denmark Strait with a weir of current meters.

Robert Royds Dickson was the son of teachers, with an artist mother and a chemist father. The Dickson side of the family was a line of fishers out of St Abbs in Berwickshire, and the maternal side was distantly related to Lieutenant Charles Royds who sailed with Scott and Shackleton on the first mission of RRS *Discovery* for the British National Antarctic Expedition 1901–1904 and for whom Cape Royds, site of Shackleton's hut, is named.

Outside of science he wrote children's books, plays and histories of Lowestoft fishing, enjoyed dramatics, and had a passion for antiquarian books and fiction. His favourite novels brought together his liking for a good tale with his passion for marine science, whether in Steinbeck's *Cannery Row* or O'Brian's Aubrey–Maturin series. Anyone who travelled with Bob will have been astonished by his extraordinary ability to reach science meetings using routes that just happened to pass close to a bookshop.

It was this joy of words and story that really set Bob apart from most scientists and led to his incredible publication record and global influence. When an internationally leading researcher or Ph.D student presented new scientific details he would put them into the big picture and see how they connected to other bits of the puzzle to provide a complete story of ocean–atmosphere climate variability and its ecosystem effects.

Bob (with brown jacket) with the team from the Lowestoft Laboratory on RV Cirolana *in the Irminger Sea after the successful recovery of first Angmagssallik Array of current meters in the mid 1980s. (Back row: John Wooltorton, Stuart Jones, Ed Gmitrowicz, Peter King; front row: John Read, Bob, Don Kirkwood, Malcolm Fulcher. (Photo: Cefas © Crown Copyright)*

Bob with a spotted wolf fish on the RV Ernest Holt *in the Barents Sea in the 1960s. (Photo: Cefas © Crown Copyright)*

There is not room here for me to discuss Bob's assessment of the Great Salinity Anomaly, where he was the first to join the dots as reports rolled into ICES of unusually fresh seawater progressing around the margins of the northern North Atlantic, or his advice to government regarding shelf-sea oceanography; or his world-leading work on the North Atlantic Oscillation, its multidecadal evolution from historically negative to positive conditions forming a backdrop to his own career. I have not described the pain of the stonefish he stood on (in Mauritius at the end of the ADOX cruise), or his searching the Californian desert for mineral crystals with Josephine Scripps; or the various Cold War tales of roubles, bugged showers and H-bomb tests. Bob could tell these stories much better – and he has.

In 2011 Bob was interviewed by the British Library as part of the 'Oral History of British Science' project. So you can to hear his joy of science, and of life with family, friends and colleagues, in his own distinctive Scottish accent.

He refused to let heart disease stop him doing exactly what he wanted for more than three decades but on 5 December – within days of sending his final book (a history of the east coast herring fishing community) to the printers – it finally brought an end to an extraordinary life.

Stephen Dye
Cefas and University of East Anglia

Sidney J. Holt: saviour of the great whales

Sidney J. Holt died in Paciano, Italy, on 22 December 2019, aged 93. In fisheries science, he is probably best known for the book which he and Ray Beverton wrote, based on their ground-breaking work at the MAFF Lowestoft Laboratory during the post-war years. *The Dynamics of Exploited Fish Populations,* published in 1957, laid the foundations of fisheries science and includes many insights into broad areas of fish biology and population ecology. It has now been cited more than 7000 times, and more than 60 years later, continues to shape the evolution of quantitative fisheries science

Ray Beverton (left) and Sidney Holt (right) busy at work on their 1957 book in Lowestoft. Ray writes while Sidney deals with the mathematics on the hand-operated Brunsviga calculating machine.

(© Crown Copyright)

Sidney is more widely known for his role in the ending of widespread commercial whaling. Working at the UN's Food and Agriculture Organization (FAO) from 1953, he became one of the small panel (the 'Committee of Three') tasked by the International Whaling Commission (IWC) to find new methods to calculate whaling quotas. In 1961 the panel demonstrated that levels of whaling had been unsustainable for decades and needed to be cut back dramatically if whale populations were to recover. Then for more than thirty years (1959 to 2002), Sidney worked in various capacities in the Scientific Committee of the IWC, as well as in the Commission itself. Over that time he used his scientific knowledge, and his communication and diplomatic skills, to turn the IWC's focus from hunting whales to conserving them.

Through his work with the UN over the course of more than 25 years, he also made a sustained contribution to international fisheries management. At various times he was appointed Director of the Fisheries Resources and Operations Division of the Food and Agriculture Organisation of the UN (FAO, in Rome), Secretary of the Intergovernmental Oceanographic Commission (IOC) and Director of UNESCO's Marine Sciences Division in Paris.

Sidney was also a widely respected member of the academic community and held professorial chairs at the universities of California Santa Cruz, of Rhode Island and of Malta, as well as holding a Senior Overseas Fellowship at St John's College, Cambridge.

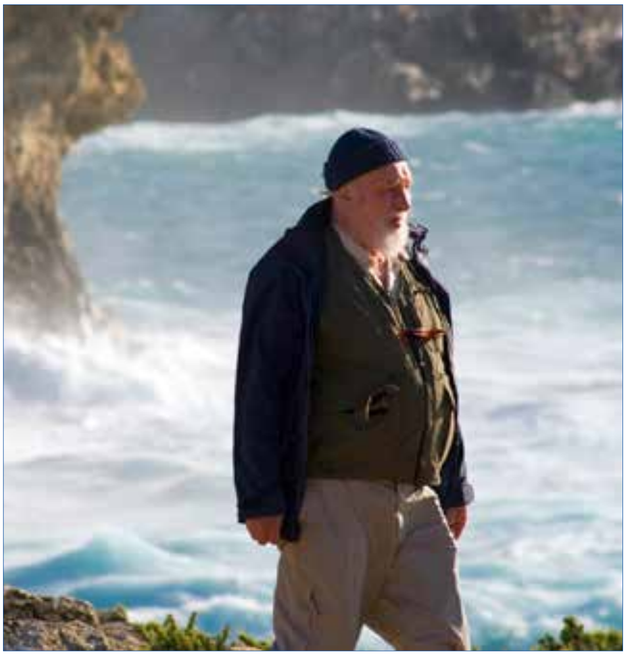
After Sidney retired from the UN in 1979 he became the first Director of the International Ocean Institute in Malta and helped draft the *Convention on the Law of the Sea* (1982). However, the great whales remained his passion. Through his role as scientific advisor to the Delegation to the IWC of the conservationist Republic of Seychelles, he was instrumental in the designation, in 1979, of the Indian Ocean Whale Sanctuary. In 1994, while adviser to the French, Italian and Chilean Delegations to the IWC, he worked behind the scenes to help secure the 50 million km^2 whale sanctuary in the Southern Ocean. The 1985/86 moratorium on commercial whaling also owed much to Sidney.

As Sidney got older he grew more radical. He became a Greenpeace representative, and helped to found Greenpeace Italy; he became a science adviser to the International Fund for Animal Welfare (IFAW) in 1980, and joined the Advisory Board of the conservation body Sea Shepherd in 2008 – the year they confronted the Japanese whaling fleet as it hunted in the Southern Ocean Sanctuary. Sidney continued to publish papers criticising whaling policy into his nineties.

Sidney has been honoured with the Gold Medal of the World Wildlife Fund, the Royal Netherlands Golden Ark, the Global 500 Award of the United Nations Environment Programme (UNEP) and the IFAW's Blue Planet Award.

Some of the phrases used to describe Sidney by his friends and colleagues include 'profoundly kind and gentle', 'an intrepid crusader for all sentient things' and 'a genius'.

Sidney Holt remains an inspiration to today's fisheries and conservation scientists but, as Beverton himself pointed out, Sidney had 'saved the great whales in the early 1970s' and that legacy is one that truly set him apart.



(Photo provided to Sea Shepherd Conservation Society by Tim Holt)

With thanks to **Georg Engelhard**, **John Pinnegar**, **Robert Thorpe** and **Stephen Dye** from Cefas**,** and **Paul Watson** and **Rob Read** of Sea Shepherd.

Celebrating 100 years of tidal science on Merseyside

Philip L. Woodworth

*The first Director of the Liverpool Tidal Institute, Joseph Proudman **(left)** and his successor, Arthur Doodson **(right)***

To mark the 100th anniversary of the Liverpool Tidal Institute (LTI), a celebratory meeting on 'The ocean tide and the Port of Liverpool' was held at the Merseyside Maritime Museum in May 2019. The LTI's buildings at Bidston Observatory in Birkenhead are a well known local landmark, so the meeting attracted great interest from the general public as well as from academia, and there were almost 200 people in the audience.

The LTI was founded at Liverpool University in March 1919 with funds from Sir Alfred Booth and his brother, Charles Booth, to 'prosecute continuously scientific research into all aspects of knowledge of the tides'. Professor Joseph Proudman became its Honorary Director and Dr Arthur Doodson its Secretary. This same year also marked the start of Oceanography as an area of research and teaching at Liverpool University, which established the first university Oceanography department in the UK.

The LTI was initially located in the Holt Physics Building and moved to Bidston Observatory on the Wirral in stages over the following decade. It became the world centre for knowledge of the tides, with Proudman taking the lead in dynamical theories, and Doodson in the analysis of tidal information from around the world, and in tidal prediction. Work on tidal prediction included the construction of analogue computers called Tidal Prediction Machines. Proudman and Doodson were both Fellows of the Royal Society, a distinction that was later also awarded to Dr David Cartwright, Assistant Director at Bidston from 1974 to 1986, for his work on the global ocean tides. The LTI was renamed the Liverpool University Tidal Institute in 1961 and went through other name changes, including the Proudman Oceanographic Laboratory. It became a component of the present National Oceanography Centre in 2010.

One should not forget that research at the LTI took in many topics other than ocean tides. These included the numerical modelling of storm surges (or 'meteorological influences on the tides') for purposes of coastal protection, especially following the 1953 floods in the North Sea; long-term changes in sea level (notably through the Permanent Service for Mean Sea Level); tides of the solid Earth; ocean modelling for studies of water quality, ecosystems and climate change; geodetic measurements; and renewable energy. In addition, the LTI once hosted a large community computer centre; NOC in Liverpool continues to be the main location for the British Oceanographic Data Centre.

The celebration was organised by NOC and the University of Liverpool, in association with the Centre for Port and Maritime History (University of Liverpool, Liverpool John Moores University and Merseyside Maritime Museum) and the Liverpool Institute for Sustainable Coasts and Oceans (NOC, University of Liverpool and Liverpool John Moores University). All the speakers came from NOC, the University of Liverpool and Liverpool John Moores University.

Philip Woodworth began the meeting with an introduction including a brief history of the Liverpool Tidal Institute. That was followed by a talk on the science behind the ocean tide by David Pugh, and then a discussion of opportunities in the UK for extracting tidal energy, by Judith Wolf.

After a coffee break (and a short pause for a fire alarm) there was a presentation on the tides and the oceanography of our neighbouring seas by Jonathan Sharples. The difficulties of the Port of Liverpool in working with the large Mersey tides, even today, were explained by Simon Holgate. Chris Hughes then talked about tides and the Earth's climate, focussing on the work of three scientists with a local connection: Jeremiah Horrocks, Edmond Halley and Reginald Street. Finally, Andy Plater and Jason Kirby gave an overview of how sea levels are measured using geological techniques, taking measurements in Mersey salt marshes as examples, and of how rising sea levels might impact the area in the future.

A young Arthur Doodson in the LTI's first office in the Holt Building on the Liverpool University campus

All the talks mentioned above can be obtained as a pdf or video via the meeting webpage: https://noc-events.co.uk/ocean-tide-and-port-liverpool. I think everyone who attended the meeting enjoyed it, and we were helped by the nice weather. One reason for holding the event was to test whether there is an appetite locally for science talks on a Saturday morning. It seems that there is, so we are now thinking how other topics can be discussed at the Maritime Museum on future Saturdays.

On the same day as the Museum event, there was also an open day at the NOC building itself in Brownlow Street. This was also well attended, including by some people who took in both events. Amongst the interesting things to see at NOC are the two historical Tide Prediction Machines on permanent display. These two machines were used by Arthur Doodson, who succeeded Proudman as Director of the LTI. One of the machines was used to make tidal computations for the D-Day landings in World War II. Both machines can be inspected by signing up at http://www.tide-and-time.uk/

The so-called 'Bidston Kelvin Machine', one of the Tide-Prediction Machines used at Bidston Observatory

Bidston Observatory in 2018 (Photo: Geoff Shannon)

Further reading

Carlsson-Hyslop, A. (2011) *An anatomy of storm surge science at Liverpool Tidal Institute 1919–1959: forecasting, practices of calculation and patronage.* Thesis, University of Manchester. https://www.escholar.manchester.ac.uk/uk-ac-man-scw:119810

Cartwright, D.E. (1998) *Tides: A Scientific History,* Cambridge University Press.

Jones, J.E. (1999) From astronomy to oceanography: a brief history of Bidston Observatory, *Ocean Challenge* **9**(1), 29–35

Woodworth, P. (1999) William Hutchinson: local hero, *Ocean Challenge* **8** (3), 47–51.

Philip Woodworth is an Emeritus Fellow at the National Oceanography Centre in Liverpool. plw@noc.ac.uk

Structures in the Marine Environment (SIME 2020)

Technology and Innovation Centre in Glasgow, 27 May

This interdisciplinary conference will again be jointly hosted by MASTS and INSITE

The programme and presentations from the 2019 event can be viewed at https://www.insitenorthsea.org/sime-2019/

The challenges of predicting the fate of oil from a spill in the Faroe–Shetland Channel

Ryan Gilchrist

The Deepwater Horizon oil spill in the Gulf of Mexico was one of the worst marine environmental disasters in US history. The amount of oil released from the well-head at approximately 1500 m depth was so vast that if you had the same volume in petrol, you could drive an average UK car a distance equivalent to the Sun and back 47 times. The spill caused extensive damage to organisms and habitats, with negative impacts on fishing and contamination of over 2000 km of coastline around the Gulf. A 'dirty blizzard' also formed – a mixture of oil, microbes and algae that stick together in a highly viscous, difficult-to-clean-up mess. In total, Deepwater Horizon cost BP $145 billion in fines and market loss.

The Faroe–Shetland Channel, about 170 km north of the Scottish mainland (Figure 1), is an another area of active oil and gas development with valuable habitats (including those within the Sponge Belt Marine Protected Area) and commercially important fish stocks. There are 162 active well-heads in the Faroe–Shetland Channel; more than three-quarters of these are situated off-shelf (deeper than 200 m) and five are more than 1000 m deep. If a site were to fail, there would be a substantial chance that oil would be released at depths similar to the Deepwater Horizon spill. Furthermore, recent estimates of rates of oil release suggest that the total volume of oil could be similar, too.

It can take weeks to deploy the equipment required to clean up a spill. It's therefore crucial to numerically model how the oil might disperse in the ocean, so that we can maximise the efficiency of the response and direct resources to the right place, at the right time. This is generally quite difficult to do in the Faroe–Shetland Channel, because it's a very complicated and energetic system. Along the shelf area to the west of Shetland and the Scottish continental shelf edge, surface currents transport water from the Atlantic towards the Nordic Seas (i.e. the Norwegian and Greenland Seas, and the Iceland Sea). In the deeper regions of the Faroe–Shetland Channel, strong currents flow from the Norwegian Sea towards the Atlantic Ocean (Figure 1). At approximately 500 m depth there is a strong gradient in density between the warm, more saline water of Atlantic origin in the upper water column and the cooler, fresher water from the Nordic Seas in the lower water column (Figure 2).

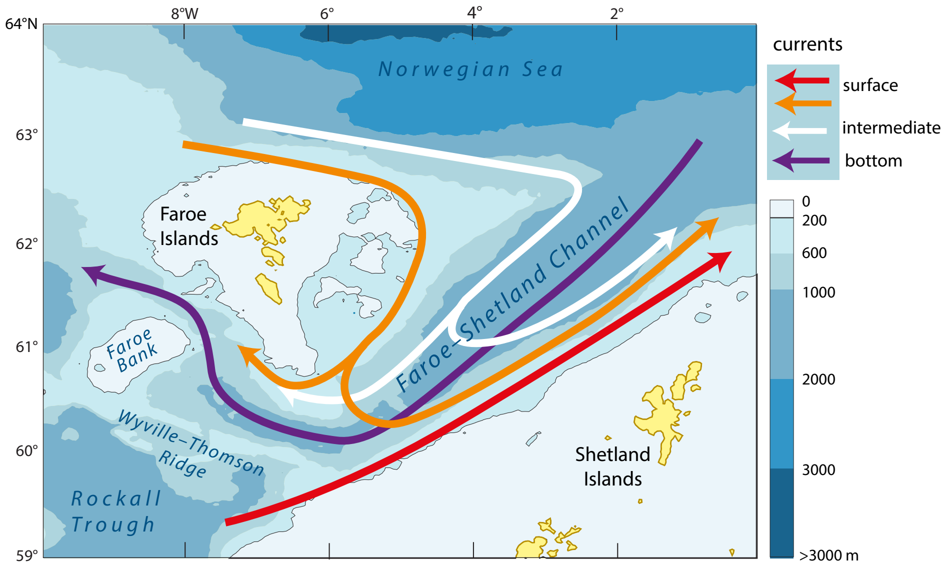


Figure 1 *Simplified map of current flow through the Faroe–Shetland Channel. Surface currents transport water from the North Atlantic. Currents at intermediate depth transport water from south of Iceland, mostly originating in the North Atlantic, and bottom currents transport water from the Nordic Seas, including North Atlantic Deep Water (cf. Figure 2).*

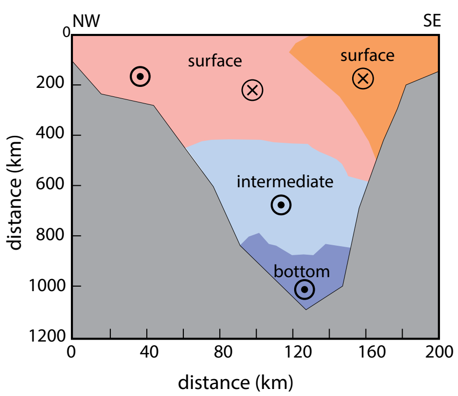


Figure 2 *Highly simplified cross-section showing water masses in the Faroe–Shetland Channel: wamer, more saline water largely originating in the Atlantic (orange and pink) flows above less saline, colder water flowing from the Nordic Seas (light and dark blue). ⊗ = flow 'into the page'; ⊙ = flow 'out of the page'). (The small northward return flow of intermediate water is not shown.)*

Mesoscale eddies and meanders, in addition to frequent stormy weather, act to increase the rate that oil weathers at the surface, for example by increasing the amount of emulsification. At the same time, these energetic processes can make offshore working conditions more difficult, which could delay or prevent any clean-up efforts.

Our research aims to improve prediction of the spread of oil from a spill in the Faroe–Shetland Channel, by furthering knowledge about what happens in the Channel in the event of a large subsurface oil release. We use a state-of-the-art hydrodynamic model from the Met Office, in conjunction with an oil spill model used by institutions such as the Centre for Environment, Fisheries and Aquaculture Science (Cefas) and Oil Spill Response Ltd (OSRL). The ocean model is of the north-west European shelf, with a horizontal resolution of 1.5 km (FOAM AMM15 NWS). This is high enough to resolve features such as eddies and meanders that are not currently represented by the 7 km horizontal resolution ocean model that Cefas and OSRL use at present. The spill model is Oil Spill Contingency and Response (OSCAR), which is maintained and developed by the Norwegian research organisation, SINTEF.

We used these models to investigate how oil would be transported when released in a variety of locations. These scenarios included on the continental shelf, within the central Faroe–Shetland Channel (the location shown as a cross in Figure 3), and directly south of the Faroe Islands. In the models, oil and gas were released from the sea bed at between 150 m and 1200 m depth, depending on the location. In the central Faroe–Shetland

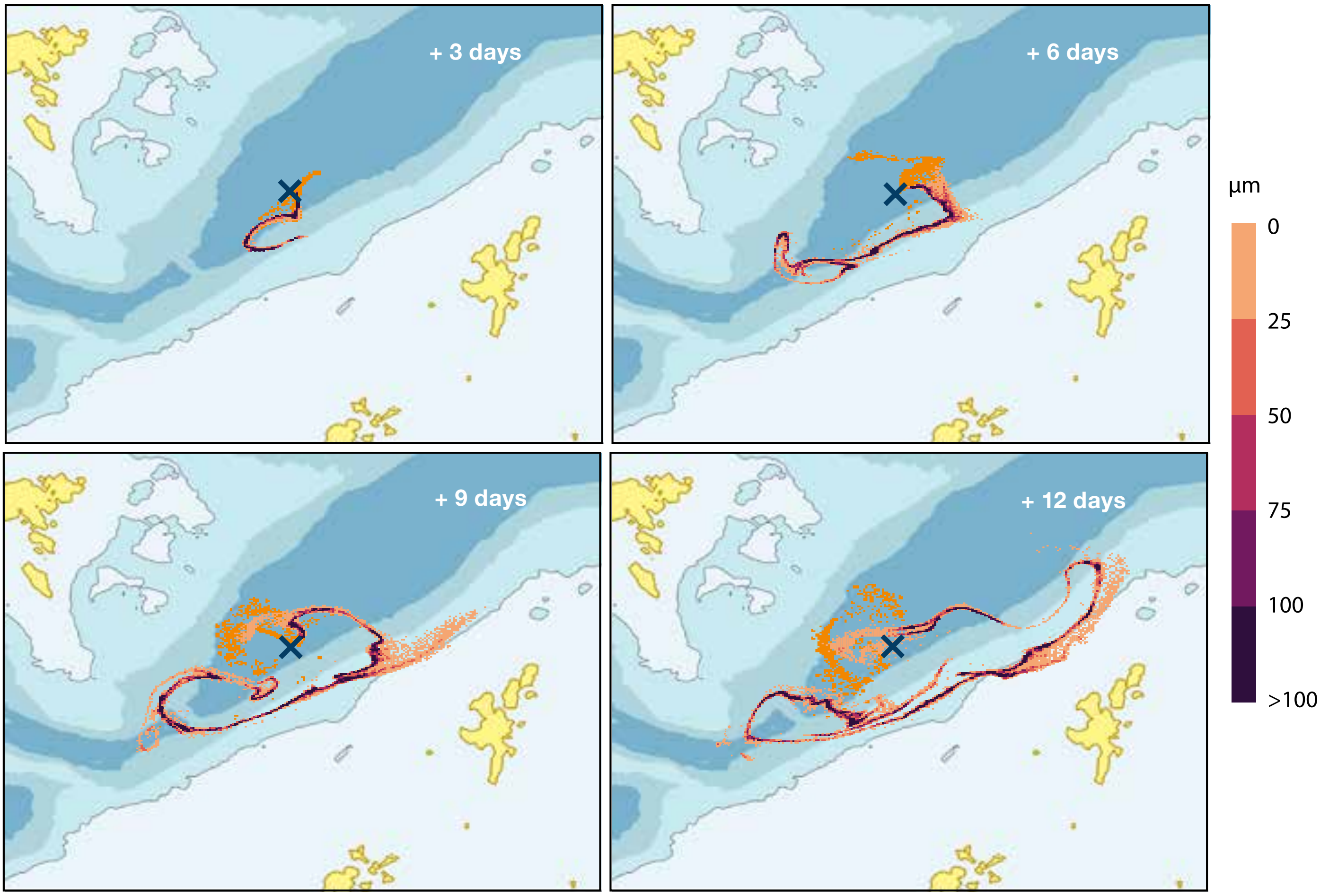


Figure 3 *Modelled horizontal spread and change in thickness of oil emulsion at the sea surface 3, 6, 9 and 12 days after the beginning of the release of oil from a site at a depth of 1122 m in the Faroe–Shetland Channel (marked by X). The simulation shows the impacts of eddies on the break-up of the surface emulsion, but not the effects of surface winds.*

Channel, the release depth was 1122 m. Each release lasted for nine days, and oil transport was simulated for a further three weeks.

Our results show that oil can be transported in a variety of directions. First and foremost, this depends on the depth of the oil. Oil in deeper water (approximately one-eighth of the total mass) travels south-westwards into the North Atlantic, whereas shallower oil and oil that has reached the surface is transported north-eastwards towards the Nordic Seas. Mesoscale eddies and meanders also act to break up the surfaced oil into smaller patches of emulsion (Figure 3). Perhaps more alarmingly, oil that travels onto the continental shelf is advected towards the Shetland Islands and Norway. This will likely lead to the beaching of oil, and considerable damage to coastlines.

Contamination of the sea bed by a sinking dirty blizzard is also possible, but predictions relating to this are currently outside the ability of the models. If a dirty blizzard were to form in the Faroe–Shetland Channel, oil might sink back towards the sea bed and either be carried towards the Atlantic by currents, or damage local marine habitats (e.g. sponge beds).

The predicted rate and extent of the spread of the emulsion indicates the importance of international co-operation when dealing with an incident in the marine environment. By modelling the potential fate and trajectory of oil spills as robustly as possible, we can prepare for a range of conceivable scenarios in advance and make more informed emergency response decisions. Oil spills are sometimes disastrous, and they may be inevitable in a world heavily dependent on fossil fuels, but prediction and forecasting can go a long way to minimising and mitigating their impact.

Further Reading

Berx, B. (2012) The hydrography and circulation of the Faroe–Shetland Channel. *Ocean Challenge* **19** (Spring), 15–19.

Gallego, A., R. O'Hara Murray, B. Berx *et al.* (2018) Current status of deepwater oil spill modelling in the Faroe–Shetland Channel, Northeast Atlantic, and future challenges. *Marine Pollution Bulletin* **127**, 484–504. https://www.sciencedirect.com/science/article/abs/pii/S0025326X17310299

National Research Council (US) (Eds) (2003) *Oil in the Sea: inputs, fates, and effects,* especially Chapter 4. National Academies Press. https://www.ncbi.nlm.nih.gov/pubmed/25057607

Ryan Gilchrist is a former Ph.D student of the University of East Anglia, interested in how modelling environmental processes can help society. Ryan is currently working as a hydraulic modeller at Mott MacDonald and is keen to further develop links between industry and academia. ryangilchrist92@outlook.com

Do our politicians ever read anything?

No-one seems to have spotted some very fishy statistics in a parliamentary briefing paper ...

Tony Rice

The excellent article 'Brexit and UK fisheries' by John Shepherd and Joe Horwood, published in *Ocean Challenge* **23** (2), should surely be required reading for all British fishermen's representatives and prospective fisheries ministers. However, for reasons that will become clear, I have no faith that any of them would bother to read it even if it was given to them on a plate, so to speak.

Based on their extensive knowledge and experience as former Chief Fisheries Advisors, Shepherd and Horwood make a number of important points and post Brexit prophesies. First, they suggest that without the Common Fisheries Policy (CFP), and despite its almost universally bad press, '*the state of most fish stocks would be far worse than it is today*'. Furthermore, they suggest that in a post Brexit world the UK government will have to introduce legislation to control fishing access to British waters to replace the CFP rules and that, when the dust has settled, '*the final outcome will not be all that different from what has gone before*'. Even more tellingly, in view of the then new Prime Minister's claim that Brexit will '*give us control of our own fish*' (PM's questions, Wednesday, 2 October), Shepherd and Horwood forecast that replacing the CFP '*... will not be easy, and ... everyone is almost certain to be dissatisfied – not least the fishermen*'.

As a professional oceanographer, though not a fisheries scientist, I have known fishermen, and on occasion worked with them, over many years. As a result, while I came to admire their skills, tenacity and stoic bloody mindedness working in an often difficult environment, I would never entrust them, as a group, with looking after the marine ecosystem in general, or their target species in particular. Exploiting, as they do, a 'common' resource owned by no-one, the general objective of most fishermen is naturally to catch as much of that resource as possible before anyone else does. Conservation for fishermen therefore tends to be reduced to basics, epitomised by the view of a herring boat owner's suggested solution to the East Anglian herring fishery decline in the 1970s: '*Burn every b.......'s boat but mine*' (quoted by David Cushing in *Fisheries resources of the sea and their management*, OUP, 1975, p.39).

On the basis of admittedly limited direct knowledge of fishing, and starting with this rather unsympathetic mindset, I had assumed that it was the conservation measures of the Common Fisheries Policy, and particularly those aspects limiting the amounts or size of fish caught, that stuck in the craw of most fishermen, British and non-British, and led them, and their political backers, consistently to oppose and/or ignore advice given by fisheries scientists. But having read the Shepherd and Horwood article I thought I should check some of their references to see if my prejudices had any basis in fact.

First, I read Mike Holden's *The Common Fisheries Policy*, published in 1994 after the CFP had been in operation for just over ten years. Though by no means the most scintillating read, its 288 pages contain a wealth of fascinating information about the background to the policy and how it had evolved during its first decade. As one of its principal architects, Holden knew better than most its strengths and weaknesses and, at the end of his book, made a number of suggestions for improvements, including replacing the relative stability principle,* which emphasises national access to the target populations, with one in which individual fishermen would have a more personal 'stakeholder' relationship with them. Sadly, Holden died suddenly at the end of 1995; had he lived, he would be disappointed to see that we still have the dreaded relative stability policy, but he would be delighted to know that the appalling discard practice has finally been banned by the EU. And he would have agreed with Shepherd and Horwood that making rules is one thing, but ensuring that the fishermen comply with them is quite another; for his book does nothing to change my mind about fishermen as conservationists. Time and again he illustrates how the European fishing community consistently thwarted attempts to conserve the exploited communities for the benefit of all. '*The history of ... fisheries conservation ...*' he wrote (p.186), *'is also a history of the constant battle between the inventiveness of fisheries scientists to find new methods and that of fishermen to circumvent them.'*

Moving on twenty odd years, I then looked at the links to the *Fisheries Bill 2017–2019* given by Shepherd and Horton and its accompanying *Briefing Paper*. When their article was published, the bill was still 'active' and apparently about to go to the House of Lords. But since the prorogation of Parliament the website now carries a statement that, since it wasn't completed within the session, '*it will make no further progress*'. This presumably means that it will have to be resurrected once the post Brexit dust has settled. In its original form, although there are brief references to emergency powers in the event of a no-deal crash out, most of the bill assumes a two-year handover period during which current CFP rules would apply. Time will tell.

The bill was sponsored by Michael Gove who is, of course, no fan of the Common Fisheries Policy; you may remember that during the referendum campaign he maintained that the CFP had ruined his adoptive Aberdonian father's fish-processing company. So it is quite interesting to see how many measures mentioned in his draft bill on, for example, fixing fishing quotas and limiting the extent of fishing activity, resemble the similar regulations in the CFP. Of course, they apply only to British waters and expressly exclude 'foreigners' from taking 'our' fish unless we licence them. Presumably, British fishermen who currently fish in non-British EU waters will need similar licences from the EU, but the draft bill says little about that. Nor does it say how the quotas or days-at-sea rules will be formulated.

The 77 pages of the draft bill, originally published in December 2018, make pretty tough reading, being full of legalese and parliamentary jargon. The *Commons Briefing Paper* accompanying it, produced by the Commons Library research service in April 2019, is shorter and a much easier read, containing fascinating statistics about the fishing industry, both British and foreign, and also summarising how the draft bill has been received by various fishermens' organisations and conservation bodies. So it should have been a well read source for the average MP or peer with limited first-hand knowledge of the fishing industry, but anxious to understand its complexities. Sadly, you don't have to read very far to find evidence that it probably hasn't been.

On p.5 it tells us that the UK fishing industry employed, in 2017, a total of 25 200 people (made up of 5650 in fishing, 16 200 in processing and 3350 in aquaculture), compared with about half a million in agriculture. The total economic output

*This states that each member state should get the same percentage of each Total Allowable Catch every year (with some variations).

of the industry was apparently about £1.6 billon, roughly one-third each from fishing, aquaculture and fish processing, but altogether representing only about 0.1% of total UK GDP. Who would have thought that aquaculture, basically salmon farming that only started seriously in the 1980s, would become so important so quickly, with economic output per employee greatly exceeding both of the other sectors? Clearly it is worth looking more closely at the figures involved. But here things rapidly get a bit flaky.

According to a table on p.7 of the document the total landings of the UK fishing fleet in 2017 was some 671 thousand tonnes, of which 448 thousand tonnes were landed by Scottish vessels. So far so good. But immediately beneath the table, the next paragraph states that *'the aquaculture industry in the UK produced 194 million tonnes of fish and shellfish in 2016'.* Clearly, this is just a slip of a decimal point or two. Well, actually three, since it should say '194 thousand tonnes' (as in the cited source), so it is wrong by a factor of a thousand. If it wasn't, then the value of the production given as €995 million suggests pretty cheap fish at about €5 per tonne! But things get worse. The document goes on to say that *'The UK's aquaculture industry was the second largest in the EU in 2015 by tonnage – behind Spain which produced 294 million tonnes.'* But that's not all: *'For context,'* says the document (p.8), *'in 2015, Norway produced 1.4 billion* (my underlining) *tonnes of fish from aquaculture'.* So that pesky moveable point has moved again, so that this number is *also* out by a factor of a thousand!

In the overall scheme of things, of course, none of this is very important; the errors are so blatant that no-one is going to be misled by them. But you would have thought, wouldn't you, that in the six months since the document was published, the odd MP that read it might have popped into the library and suggested a correction? But no-one has, which leads me to the sad conclusion that none of them are likely to read the excellent Shepherd and Horton article. What a shame!

Tony Rice
Alton, Hants

'The control of diatom populations by grazing'

Richard Fleming and the first marine ecosystem model

Tom Anderson and Wendy Gentleman

Marine ecosystem models play a central role in the progress of oceanography, and modelling is usually included as a major component in large scientific programmes to complement experimental and observational work. Today's models often exhibit great complexity in terms of the numbers of variables and processes that are represented, and are frequently embedded in large 3D circulation models. It all seems a far cry from the early beginnings, notably the development of the first ever marine ecosystem model by Richard H. Fleming just over eighty years ago, in 1939. Fleming (1909–1989; Figure 1) was a chemical oceanographer who, at the time, was working at the Scripps Institution of Oceanography at La Jolla in California. Here, we tell the story of Fleming's achievement and highlight how it demonstrated the importance of grazing for the dynamics of marine ecosystems and associated biogeochemical cycles.

The 'grazing hypothesis'

In the early 20th century, marine ecologists were focussing their attention on the 'agricultural hypothesis' which says that primary production (the growth of phytoplankton), and more specifically the timing and magnitude of the spring bloom seen in high-latitude waters, is driven by availability of nutrients and light and that these factors control plankton biomass 'bottom up'. Results were, however, equivocal in that the data showed no straightforward conversion of nutrients to algal biomass. Hildebrand Harvey, working in the 1930s, studied the spring bloom in the English Channel and noticed that most of the diatom crop disappears, without evidence of dead cells in the water. He therefore broke away from the established dogma and proposed the 'grazing hypothesis', whereby the magnitude and timing of the spring outburst of diatoms is controlled by herbivorous zooplankton, i.e. 'top down'.

Figure 1 *Richard Fleming, drawn by John Zane in 1945 (By courtesy of the University of Washington)*

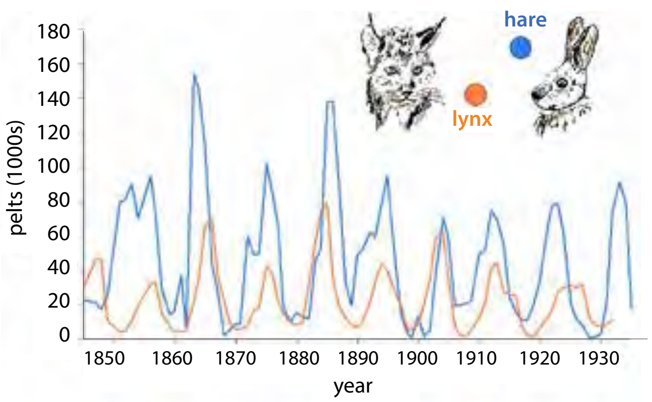


Figure 2 *Oscillation in populations of snowshoe hare and Canadian lynx, based on data from the trapping industry.*

The interplay of bottom-up and top-down factors in food webs had already been subject to theoretical investigation by Alfred Lotka and Vito Volterra in the early 20th century. They built a model of predator–prey interactions that can, for example, be used to explain the iconic oscillations seen in the populations of snowshoe hare and Canadian lynx (Figure 2). The hare population grows quickly (bottom up) when lynx numbers are low. The lynx population then expands as the hares become plentiful as food, leading to a decline in the hare population (top down). In turn, the lynx population is decimated and the cycle repeats itself.

With the grazing hypothesis in mind, Richard Fleming took up the challenge of constructing a mathematical model to study plankton blooms in the ocean. He decided to use Harvey's data and to focus on the diatom bloom that occurred in the English Channel during the spring of 1934.

Fleming's 1939 model

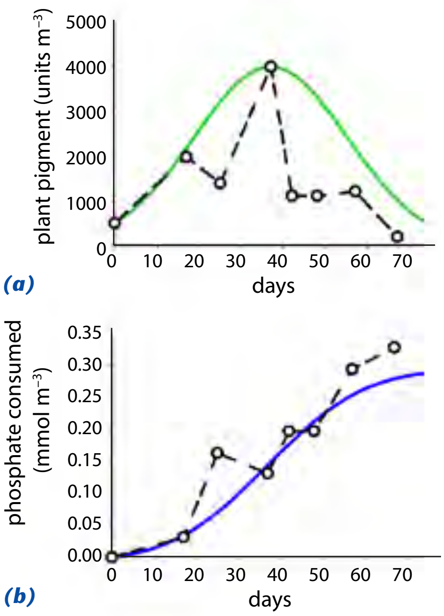
Fleming's model used a single differential equation to describe the rate of change of the phytoplankton population with time:

$$\frac{dP}{dt} = (\mu - m_1 - m_2 t)\, P \qquad (1)$$

where P is phytoplankton biomass in plant pigment units, μ is the constant phytoplankton specific growth rate (day^{-1}), m_1 is a constant baseline mortality loss due to grazing, and coefficient m_2 accounts for the increase in grazing pressure that was assumed to occur (linearly) over time, t, during the progression of the bloom. Note that here we have recast Fleming's equation using modern notation, mathematically equivalent to the original. In the 1930s, there were no computers to generate $P(t)$ from equation (1). The equation is, however, relatively straightforward to solve analytically, although use of this solution would have still required Fleming to calculate exponentials by looking up values in tables.

We recreated Fleming's simulation using his parameter values of $\mu - m_1 = 0.1123$ day^{-1} and $m_2 = 0.003\,038$ day^{-2}, which were derived in order to reproduce Harvey's observed initial and peak diatom biomass, as well as the duration of the bloom. The fit to the data is by no means perfect (Figure 3(a)), but the model does nevertheless capture the boom and bust of the bloom. Fleming also derived a formula for total production, from which he was able to reproduce the observed trend in phosphate consumed over time by assuming that 1 unit of pigment corresponds to 1/9000 mmol phos m^{-3} (Figure 3(b)). He was thereby able to demonstrate that there is no simple correlation between the population size of phytoplankton and change in nutrient concentration. Fleming also showed that, assuming a constant zooplankton 'filtration volume' (modern-day clearance rate), the efficiency of feeding decreases as the number of grazers increases, such that grazing pressure does not vary directly with zooplankton abundance. Overall, Fleming's main achievement was to demonstrate, for the first time, the quantitative importance of grazing in controlling the peak and decline of phytoplankton biomass: 'It is obvious that any large increase in the grazing associated with an increase in the number of grazers will reduce the diatom population very rapidly.'

Figure 3 *Fleming's simulation for the English Channel (coloured lines) compared with data for **(a)** phytoplankton and **(b)** cumulative phosphate consumed.*



Fleming's model is an excellent example of how to develop mathematical representations based on conceptual understanding of processes of interest. He used clear definitions of assumptions and terminology, along with carefully derived metrics to help consider the relative importance of growth versus grazing. The model is undoubtedly simple. Zooplankton numbers, and associated grazing pressure, will not in reality keep on increasing indefinitely with time. Phytoplankton growth rate is not constant but varies with changing light and nutrients, while phytoplankton density is influenced by physical losses due to sinking or vertical mixing. Take-up by the scientific community was limited. Notably, the model was not referenced in the first oceanography textbook, *The Oceans* (published in 1942), which was co-authored by Fleming himself. Gordon Riley, the great marine ecosystem modeller who was to follow on from Fleming, initially thought of the work as 'a burr under my saddle' and that 'it was quite contrary to my point of view about ecological matters'. New ideas are often slow to be accepted in science and, reflecting some time later, Riley acknowledged the importance of Fleming's work: 'I was probably influenced considerably by the paper. I don't know if I would have gone the way I did without it.' Riley went on to great achievements as a marine ecosystem modeller, in the first instance developing a new model, published in 1946, in which Fleming's phytoplankton equation was elaborated to include explicit terms for the influence of light, nutrients and vertical turbulence on photosynthesis, as well as respiration.

Modern perspective

The top-down control of plankton dynamics remains incompletely understood today, and is by no means straightforward to reliably parameterise in biogeochemical models, including those at the global scale. Perhaps nobody has done more to promote the importance of top-down controls in marine ecosystems than Karl Banse, of the University of Washington. His contention is that 'grazing rather than cell division rate regulates the abundance and size composition of phytoplankton'. A good example is the low phytoplankton biomass seen in high-nutrient–low-chlorophyll (HNLC) systems that occur in areas such as the Southern Ocean, and the equatorial and sub-Arctic Pacific. It is well known that shortage of iron restricts phytoplankton growth in these regions and yet many modelling studies, notably those of John Steele and Bruce Frost, have demonstrated the essential role of grazers for suppressing blooms in these systems.

Modelling zooplankton, and thereby top-down controls in the ocean via grazing, is a considerable challenge for two main reasons. First, zooplankton are an immensely diverse group in terms of size, feeding behaviours and rates, life histories, etc. Contemporary marine ecosystem models often separate zooplankton into two groups, microzooplankton (typically 20–200 μm in size) and mesozooplankton (>200 μm), given that the smaller organisms may dominate grazing while larger zooplankton, such as copepods, contribute most to export flux via faecal pellets and vertical migrations, as well as transfer to higher trophic levels. Yet there is great diversity within each of these groups, e.g. microzooplankton include flagellates, dinoflagellates, ciliates, rotifers and foraminiferans. Matters are further complicated by the fact that many microzooplankton are mixotrophs, i.e. combine elements of both phytoplankton and zooplankton by using light for photosynthesis while also ingesting prey.

The second challenge facing zooplankton modellers is the sensitivity of predictions to the precise form of the equations, as well as the parameter values chosen to represent zooplankton processes. Bottom-up controls on plankton growth are, at least to some degree, constrained by the availability of nutrients and light, whereas this is not so for zooplankton grazing on phytoplankton. In support of this claim, we show results from our work in 2010 where we compared the impact of four subtly different grazing functions on predicted phytoplankton distributions in a complex global ocean biogeochemical model that included multiple plankton groups and nutrients, all coupled to 3D physics (Figure 4). The four grazing functions differed in terms of their shapes, but were otherwise set up to be as close as possible to each other in terms of parameter values. As can be seen in the Figure, the small differences among grazing functions, and thereby the top-down impact of zooplankton, become amplified to generate large differences in predicted distributions of diatoms. The predictions of marine ecosystem models are likewise highly sensitive to the parameterisation of zooplankton mortality, which is difficult to measure and is usually poorly constrained by data.

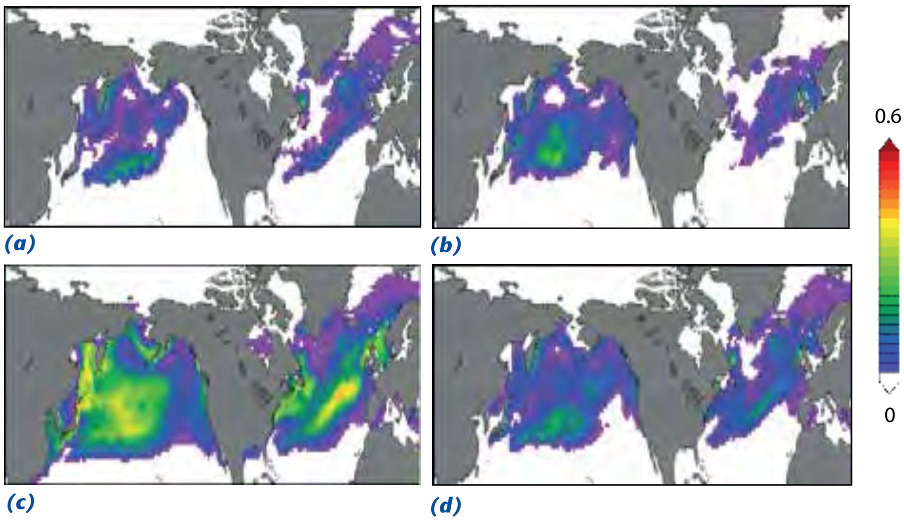


Figure 4 *Predicted diatom concentrations (mg chl m*$^{-3}$*), March–May, in four runs of a global biogeochemical model, each run representing a different grazing function:* ***(a)*** *Michaelis Menten;* ***(b)*** *Blackman;* ***(c)*** *Sigmoidal;* ***(d)*** *Ivlev. (Anderson* et al.*, 2010; © 2010 Elsevier BV)*

Postscript

Zooplankton constitute a fascinating and beautiful group of organisms, such as copepods of the genus *Calanus* (Figure 5) which dominate the zooplankton biomass throughout the North Atlantic and Arctic oceans, where they provide a crucial link between phytoplankton and fish. Zooplankton research continues apace today on a range of topics including vertical migration, export flux, the lipid pump, environmental control of spatial patterns and potential impact of climate change, with models playing a central role. Fleming emphasised the need for synergy between observational and theoretical work: 'The future of oceanography lies in carefully coordinated programs involving work at sea, laboratory studies, and theoretical investigations. The observational program must guide the theorist in his work, and the latter must assist by indicating the kinds of observations and equipment that will lead to the most valuable results.'

World War II intervened shortly after Fleming had published his model and he was recruited to work on under-sea warfare by the Division for Water Research of the University of California, between 1941 and 1946. He never returned to ecological modelling, leaving Gordon Riley and others to pick up the mantle. Fleming nevertheless pursued a successful career in oceanography with many interests including chemical and biological oceanography, ocean currents and sedimentation, as well as naval applications in oceanography. He returned to Scripps as Assistant Director from 1946 to 1950, after which he became the founding Director of the University of Washington's School of Oceanography in 1951, serving until 1967 and thereafter continuing his work as Professor of Oceanography. Fleming was instrumental in the development of curricula, in particular establishing the undergraduate programme in Oceanography, which was the first in the world. He is also well known for progressing the careers of the many oceanographers who came through his educational programmes. When it comes to his 1939 model, however, Fleming is largely an unsung hero of zooplankton modelling. Let us remember that it was he who first quantitatively demonstrated the importance of grazing in the control of phytoplankton blooms, and who acted as the forerunner of the ecosystem modellers that followed.

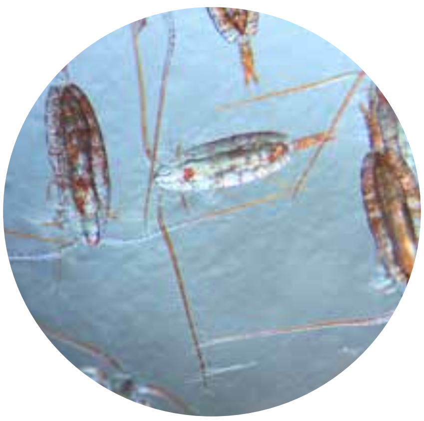


Figure 5 *The marine copepod* Calanus finmarchicus *(main body length 3 mm). (© Daniel Mayor)*

Further reading

Anderson, T.R., W.C Gentleman and B. Sinha (2010) Influence of grazing formulations on the emergent properties of a complex ecosystem model in a global ocean general circulation model. *Prog. Oceanogr.* **87**, 201–13.

Banse, K. (2013) Reflections about chance in my career, and on the top-down regulated world. *Annu. Rev. Mar. Sci.* **5**, 1–19.

Fleming, R.H. (1939) The control of diatom populations by grazing. *Journal du Conseil Permanent International pour L'Exploration de la Mer* **14**, 210–27.

Fleming, R.H. (1948) Oceanography and the oceans. *Science* **108**, 598.

Harvey, H.W., L.H.N. Cooper, M.V. Lebour and F.S. Russell (1935) Plankton production and its control. *J. Mar. Biol. Ass. U.K.*, **20**, 407–41.

Sverdrup, H.U., M.W. Johnson and R.H. Fleming (1942) *The Oceans: their physics, chemistry, and general biology.* Prentice-Hall, N.Y.

Wyatt, T. and I.R. Jenkinson (1993) The North Atlantic turbine: views of production processes from a mainly North Atlantic perspective. *Fish. Oceanogr.* **2**, 231–43.

Tom Anderson is a senior research scientist the National Oceanography Centre, Southampton. His interests include marine biogeochemical cycles, stoichiometry, the microbial loop and dissolved organic matter, model complexity, and the methodology and philosophy of science. tra@noc.ac.uk

Wendy Gentleman is an Associate Professor at Dalhousie University, Halifax, Nova Scotia, Canada. Her interests include modelling of marine population and ecosystem dynamics, zooplankton life history and ecology, physical–biological coupling, individual-based models and mathematical methods. Wendy.Gentleman@Dal.Ca

eDNA: a new frontier in biodiversity research

Phil Lamb

For ecologists, high-quality research involves weeks, months or years in the field gathering data on the species present and the interactions between them. However, for a marine ecologist in particular, achieving this can be extremely challenging. The first, extremely obvious challenge is that all of this work takes place under water, which severely limits researchers' ability to observe species in their natural environment. Additionally, the costs of boat time can be dizzying: it is usually not feasible to design a customised sampling regime – rather sample collection often has to fit in with a predetermined schedule. Finally, even with the time and resources it may be too technically challenging or too dangerous to spend protracted periods gathering data: anyone fancy SCUBA-diving in a busy shipping lane? Over the years, marine biologists have devised some ingenious techniques to get around these difficulties, but new techniques that allow us to rapidly and safely gather data are always in demand.

A new tool that appears to circumvent the aforementioned difficulties is environmental DNA (eDNA). Rather than visually identifying organisms either *in situ* or once they have been hauled onto a research vessel, ecologists can identify taxa using minute amounts of DNA collected from the environment. This is made possible by organisms' DNA constantly entering the environment through processes such as urination, excretion or the flaking off of scales and bits of skin. Once free of an organism, this DNA remains in the water column or settles into marine sediment, depositing tiny traces of the organisms' presence. Ecologists can therefore capture evidence of the presence of the organism by taking a water or sediment sample, passing it through a fine filter to concentrate the eDNA, and finally extracting it in a form ready for molecular analysis. At this point the amount of eDNA is still tiny, swamped by the masses of bacterial DNA present everywhere, so usually a DNA-copying stage (known as PCR) takes place to boost the signal. The post-PCR sample is placed in a DNA-sequencer so the genetic code of the sample can be revealed and matched with a species in a genetic database (Figure 1).

Regrettably, new techniques are very rarely 'magic bullets' and we must acknowledge some key caveats and drawbacks. First, although DNA often breaks down in hours to days in the environment it can also last for thousands of years in the right conditions: scientists have sequenced DNA from giant ground sloth faeces and woolly mammoths! The odds of a Pleistocene beast turning up in a marine eDNA sample are infinitesimal, but eDNA can be protected from breakdown within marine sediment, only to be disturbed and released weeks, months or even years later, falsely suggesting an organism is present. Movement of eDNA is also an issue, as it can be swept many kilometres away from its point of origin. Other problems are more technical in nature: the copying sometimes goes awry, creating 'chimeric' sequences (hybrids of two different strands of DNA) which can artificially inflate species richness. Furthermore, primers (the molecular tools used to copy DNA) have taxonomic biases so can paint an inaccurate picture of the life at the site.

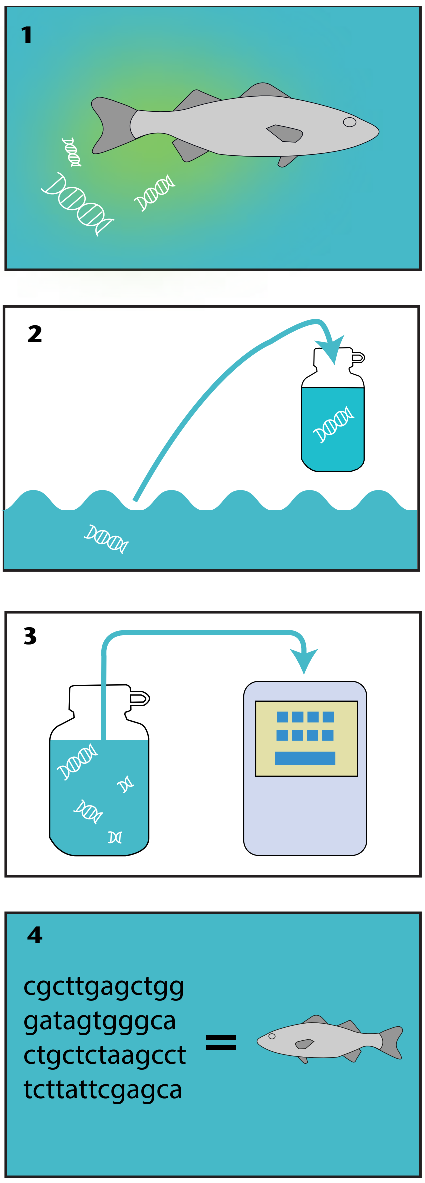


Figure 1 *Key steps in conducting an eDNA survey.* ***1.*** *Organisms shed DNA into the environment.* ***2.*** *This DNA remains in the environment, even if the original species is not seen. Ecologists can draw samples from the environment to capture this DNA.* ***3.*** *Back in the lab the DNA is copied to increase the amount of DNA available for analysis and fed into a sequencer.* ***4.*** *The sequences produced are then matched with the right taxa in a genetic database.*

However, solutions are forthcoming and some of the problems can be turned on their heads to our advantage. For example, sampling from an area with a lot of water movement (like a tidal estuary) can be used to estimate species presence over very large areas, and is especially useful for detecting invasive species. Additionally, the taxonomic bias of the DNA-copying stage can be mitigated by repeating the process using a different set of primers (this usually only takes a few hours). Chimeric sequences can be detected and removed by algorithms during analysis. Alternatively, you can get around the taxonomic biases and chimeric sequences introduced in the copying stage by not including this stage at all. A precipitous decline in the cost of sequencing (the cost in 2012 was about 1/100 000 of that in 2007) has allowed scientists to use this technology liberally: previously undetectable quantities of eDNA can now be identified. Overwhelmingly it is bacterial sequences that are detected, but so much data are produced that even a tiny percentage of relevant sequences is enough for analysis.

Existing sequencing techniques have hit new levels of affordability and new third-generation sequencing approaches are also revolutionising the portability of DNA analysis. Oxford Nanopore's MinION sequencers are slightly smaller than a TV remote and the in-development SmidgION is even smaller, and will attach to the bottom of a phone. These advances could liberate eDNA analysis from the realm of the molecular laboratory into the field itself. This would be a timely revolution as eDNA is particularly well suited to biodiversity assessments, as well as detecting rare and invasive species, allowing proactive management to take place.

Another advantage is the ease of participation in biodiversity surveys for non-specialists and citizen scientists as no taxonomic expertise is required to gather an environmental sample. It's also possible to gather samples without any people present at all using remotely operated

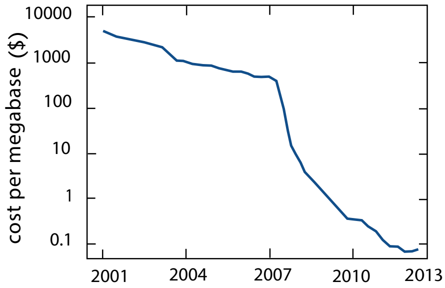


Figure 2 *The cost of sequencing was steadily declining in the early 2000s, and the onset of a new sequencing technologies pushed the price into freefall in 2007.*
(Graph adapted from genome.gov/sequencingcosts)

vehicles or autonomous samplers. This could usher in new 'big-data' approaches in ecology: utilising hundreds of thousands or millions of eDNA data points in conjunction with approaches like machine learning to revolutionise our understanding of species, the interactions between them, and the function of ecosystems as a whole.

Further reading

Creer, S., K. Deiner, S. Frey *et al.* (2016) The ecologist's field guide to sequence-based identification of biodiversity. *Methods in Ecology and Evolution* **56**, 68–74. http://doi.wiley.com/10.1111/2041-210X.12574.

Pedersen, M.W., S. Overballe-Petersen, L. Ermini *et al.* (2015) Ancient and modern environmental DNA. *Philosophical transactions of the Royal Society of London. Biological Sciences* **370**, 20130383.

Thomsen, P.F. and E. Willerslev (2015) Environmental DNA - An emerging tool in conservation for monitoring past and present biodiversity. *Biological Conservation* **183**, 4–18. http://dx.doi.org/10.1016/j.biocon.2014.11.019

Phil Lamb is a molecular ecologist researching food webs and new applications of DNA sequencing at Cefas.
philip.lamb@cefas.co.uk

Macroalgae: a hitherto neglected source of 'blue carbon'

The significant role of seaweed in the sequestration of carbon

Bridie Kennerley

New research led by scientists from Plymouth Marine Laboratory shows, for the first time, the important role that the connectivity between macroalgae (seaweed) and the sea bed could play in permanently removing CO_2 from the atmosphere. This has crucial implications for efforts to reduce CO_2 in the atmosphere in light of the *Paris Climate Agreement*, and for how we manage these environmentally and economically important habitats.

'Blue carbon' is that captured in marine systems through photosynthesis and then trapped within sea-floor sediments (a process often referred to as sequestration). Typically, blue carbon is associated with vegetated coastal habitats such as saltmarshes, seagrass beds and mangroves. However, macroalgae are the most productive marine macrophytes at a global scale and have long been considered likely to make a large contribution to global carbon sequestration. In the case of saltmarshes, seagrass and mangroves, atmospheric CO_2 is absorbed and stored in the same location. However, when seaweed degrades seasonally, its detritus is carried away from the shore and out into the coastal and open ocean, making the storage potential of this carbon more difficult to quantify.

The recent study, part of the NERC and Defra-funded Marine Ecosystems Research Programme, also involved scientists from Florida State University, Ocean University of China, and Aarhus University in Denmark. The team combined a robust sampling design with an array of analytical approaches, using environmental DNA sequencing and analysis of stable isotopes of carbon and nitrogen as complementary biotracing techniques alongside measurements of interactions between the sea-floor sediments and water above. The research focussed on the geographical area around Plymouth Sound and the Western Channel Observatory's L4 stations (Figure 1).

At intervals throughout 2015 and 2016, shore surveys were used to sample the dominant macroalgal species growing off Plymouth Hoe and Rame Head, from where seaweed detritus would likely be carried out to the L4 benthic site, on the sea surface and in the water column. In addition, nets were used to collect

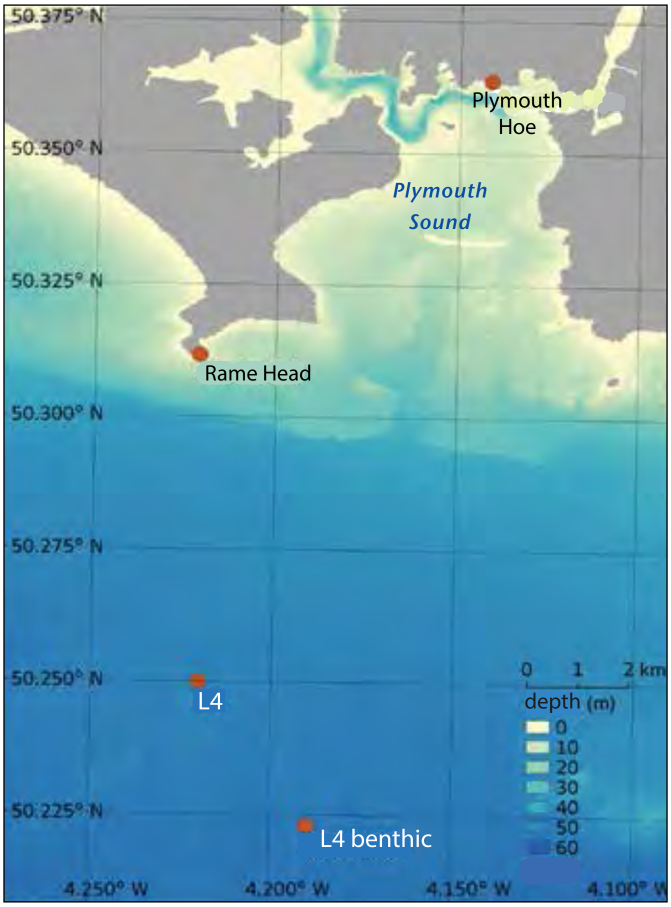


Figure 1 *The coastal macroalgae sampling sites (Plymouth Hoe and Rame Head) and the offshore sampling sites, Station L4 and L4 benthic (all part of the Western Channel Observatory)*

(© 2019 by the Ecological Society of America; Bathymetry data were sourced from the UK Hydrographic Office)

phytoplankton, zooplankon and suspended organic matter from the water column in the vicinity of L4, as these would also eventually contribute to the sediment, along with debris from the seaweed.

Sediment cores were taken from the sea bed at L4 benthic. Complete cores were taken to the laboratory, where measurements were made of various biochemical and biological processes, including carbon uptake by sea-bed sediment through bio-irrigation (flushing of burrows with seawater) and bioturbation (disturbance of sediment and porewater by organisms as they tunnel, travel through and use the sediment) (Figure 2(b)). Loss of carbon from the sediments was assessed by measuring the amount of dissolved inorganic carbon (DIC), produced by the respiration of benthic fauna and bacteria (Figure 2(a)).

Other cores were sampled on deck for further analysis in the laboratory. Some samples were used for Bayesian Stable Isotope Mixed Modelling (SIMM), in which bulk stable isotopes (δ^{13}C and δ^{15}N) are used as biotracers to track the sources of the organic matter already available within the sediment, and that which has entered the sediment after being eaten by benthic animals (which excreted the matter or died). Stable isotope measurements were also made on the seaweed samples and the pelagic samples. Debris from zooplankton, phytoplankton and macroalgae can be distinguished from one another on the basis of characteristic δ^{13}C–δ^{15}N signatures: for example macroalgal debris has a similar δ^{15}N value to phytoplankton, but a higher δ^{13}C value due to the algae's proximity to the shore environment.

Environmental DNA (eDNA – see p.18) was extracted from the sediment samples, and identified using a primer pair known to amplify a diverse range of seaweed sequences, and thus appropriate for assessing the presence of debris from macroalgae. Overall, the study found that, in this area, an average of 8.75 g (or 0.73 mol; Figure 2(b)) of macroalgal carbon is sequestered per m^2 of deep coastal sediment every year as detrital particles, meaning that a football-pitch-sized area of sea bed could annually capture the same amount of carbon as that produced by driving from London to Inverness each year. It is estimated that 4–9% of the macroalgal particulate organic carbon released annually from the coast around this area may be sequestered in the sea bed.

The study also highlighted the importance of macroalgae in supporting sea-bed organisms when other food resources are low through the winter months, and how these sea-bed dwellers also contribute to carbon sequestration. The latter point, often neglected in global 'blue carbon' estimates, has also been highlighted in two recent global studies (Further Reading).

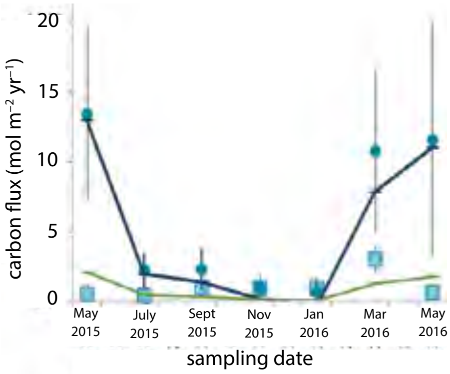
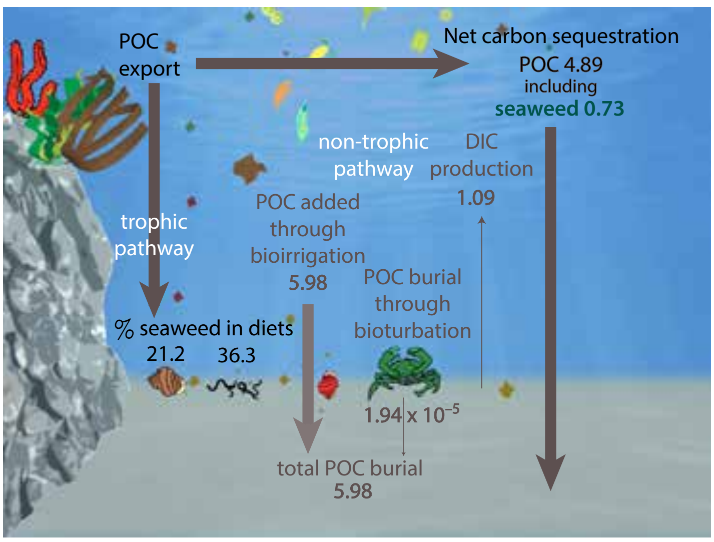


Figure 2 *The macroalgal–sediment system at station L4 benthic.*
(a) *Seasonal variation of biologically mediated processes influencing net sequestration of particulate organic carbon (POC) at the sea floor. Circles show total POC uptake by sediment (through bioturbation and bio-irrigation); squares show dissolved inorganic carbon (DIC) production; blue line (circles minus squares) shows total blue carbon sequestration; green line shows the contribution to that from debris from macroalgae.*



(b) *Simplified diagram to show the pathways of carbon from coastal macroalgae to incorporation in sediments. Widths of arrows are roughly proportional to the seasonally averaged flux of carbon, here given in mol m^{-2} yr^{-1}. Light brown arrows show how the value of 4.89 mol m^{-2} yr^{-1} for net carbon sequestration was obtained.*

Human activities that affect soft-sediment systems can reduce their ability to store organic carbon, both as a direct result of disturbance and by causing changes in the faunal communities that contribute to carbon sequestration; such activities include bottom trawling, aggregate extraction and sea-bed mining. The new research indicates that minimising disturbance to both onshore coastal macroalgae and the sea floor would help to protect the blue carbon stores that these macroalgae–sediment systems support.

Understanding these less studied but crucial blue carbon habitats helps pave the way towards wider global blue carbon accounting, and better management strategies, such as minimising disturbance and controlling coastal nutrient supply. Future research could focus on improving ability to link specific shore macroalgal communities with sea-bed detritus hotspots, better understanding of how different macroalgal materials leave the shore, when and how they degrade, and improved modelling of sinking detritus. Future management of coastal habitats needs to account for carbon donors, such as macroalgae, as well as carbon sink habitats, such as the deep coastal sediment where detritus accumulates, and recognise the connectivity between the two.

Dr Ana M Queirós, a Senior Benthic Ecologist at Plymouth Marine Laboratory and lead author of the paper (reference below) said: *'These are the first measurements we have of seaweed carbon being sequestered into the wider sea bed, beyond the narrow wetland habitats. They tell us that the global extent of blue carbon-meaningful marine habitats could be much wider than we previously thought. Identifying these areas and promoting their management will let us capitalise on the full potential of the ocean's blue carbon ...'*

Further Reading

Middelburg, J.J. (2018) Reviews and synthesis: To the bottom of carbon processing at the seafloor. *Biogeosciences Discussions* **15**, 413–27.

Queirós, A.M., N. Stephens, S. Widdicombe *et al.* (2019) Connected macroalgal–sediment systems: blue carbon and food webs in the deep coastal ocean. *Ecological Monographs* **33**, 96–105.

Snelgrove, P.V., K. Soetaert, M. Solan, *et al.* (2018) Global carbon cycling on a heterogeneous seafloor. *Trends in Ecology and Evolution* **33**, 96–105.

Bridie Kennerley is Communications Officer at Plymouth Marine Laboratory.
bke@pml.ac.uk

Supertides and supercontinents

How tectonics controls the tidal range

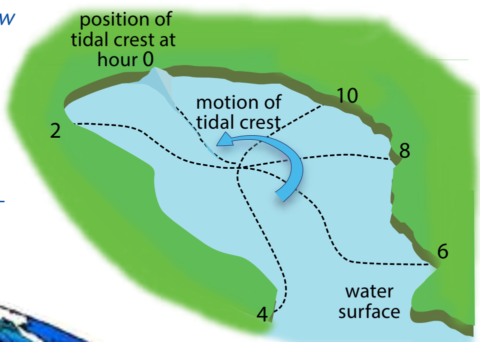
Mattias Green, Hannah Davies and João Duarte

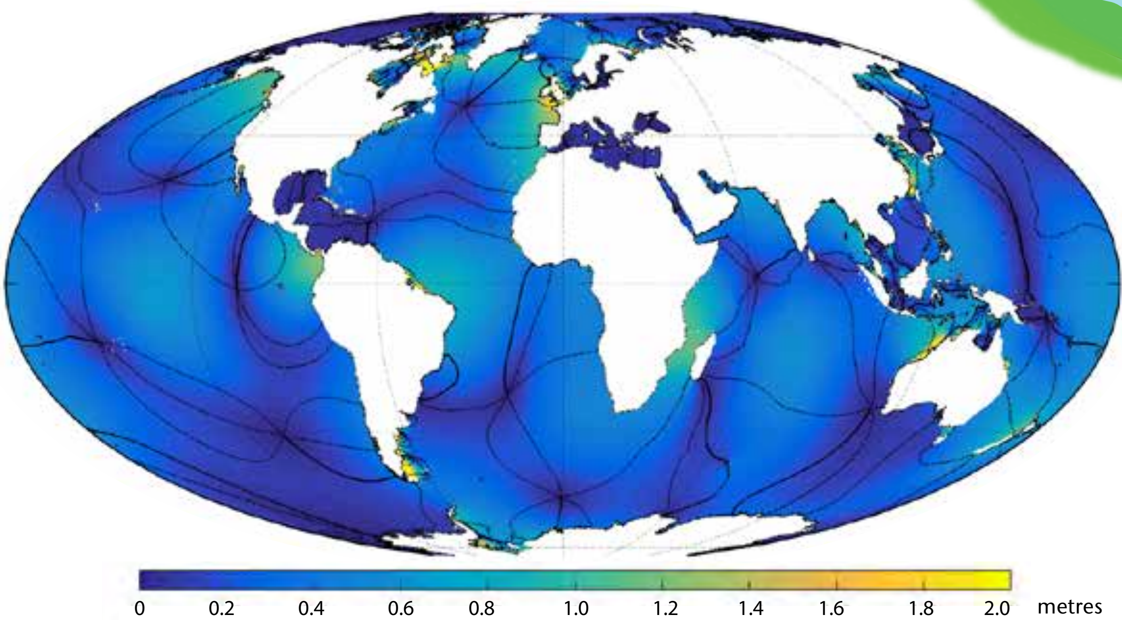
The movement of tectonic plates causes oceans to change shape and size over time. Such changes in ocean morphology have led to large changes in the tides in Earth's past, and it has recently been shown that over the past million years the tides have been the most energetic they have been for 400 million years. We are therefore wondering what consequences the movement of tectonic plates may have for future tides.

Tides change on the geological time scale because the movement of the tidal wave is controlled by the shape of the ocean basin and its depth. If a basin has the right size – if the length of a basin is half that of the tidal wave – the tides can become very large because the basin is resonant with the tidal period. The period of the tide is determined by the motions of the Earth, Moon and Sun, and the natural, or resonant, period of an ocean basin is set by its geometry. Today, the North Atlantic is very near resonance because the dominating lunar tide has a period of 12.42 hours, and the Atlantic, due to its depth and shape, has a natural period of about 12.8 hours. This is why the tides in the Atlantic are much larger than those in the Pacific or Indian Oceans (Figure 1).

Figure 1* *Below *Tidal amplitudes for the dominating semi-diurnal lunar tide. The colour scale saturates at 2 m; the largest tide reaches 8 m amplitude (16 m range) in the Bay of Fundy on the Canadian east coast. The black dotted lines are co-tidal lines, which join points where the tide is at the same state (cf. inset), shown for intervals of 2 hours.* *(Data from TPXO 9; http://volkov.oce.orst.edu/tides/)*

Right *Diagram to show how a tidal wave might travel around an imaginary ocean basin in the Northern Hemisphere. The amplitude of the tide is greatest at the coast and zero where the co-tidal lines meet.*





The motion and amplitude of tidal waves are governed by the shape and depth of the ocean basins they travel around

But this has not always been the case. Periodically, the scattered continents join up to form a supercontinent, which remains aggregated for a few hundred million years before breaking up. The continents then disperse again. Eventually, after another 400–600 million years or so, they come back together again to complete the supercontinent cycle.

The latest supercontinent to form on Earth, known as Pangaea, formed around 310 million years ago and started breaking up around 180 million years ago. A series of investigations all suggest that the next supercontinent will form in 200–250 million years, meaning that we are about halfway through the 'scattered' phase of the current supercontinent cycle. But what form will the next supercontinent take, and how will the tide respond to the tectonic changes?

The supercontinent cycle

There are four possible scenarios for the formation of the next supercontinent, resulting in supercontinents referred to as Novopangaea, Pangaea Ultima, Aurica and Amasia. How each of these supercontinents might form depends on different mechanisms, but the next supercontinent formation is ultimately linked to how Pangaea separated, and how the world's continents are moving today. One major consequence of the breakup of Pangaea was the formation of the Atlantic Ocean, which is still opening today. At the same time, the Pacific Ocean is closing and getting narrower over time. This can happen because the Pacific is surrounded by a ring of subduction zones, where the oceanic plates are subducted into the mantle in the Earth's interior (Figure 2). As the ocean floor sinks into the mantle, parts of it melt and rise to the surface causing volcanism, resulting in the Pacific 'ring of fire'. The rest of the oceanic plate sinks to the core–mantle boundary where it melts fully over time. This is in stark contrast to the Atlantic which, like the Pacific, has ocean ridges producing new ocean crust, but only has two small subduction zones: the Lesser Antilles Arc in the Caribbean and the Scotia Arc between South America and Antarctica (LA and SA on Figure 2). Consequently, in the Atlantic, oceanic crust can only be subducted in these two small regions. Moreover, within the Atlantic realm, the oceanic plates are attached to the continents and the formation of new ocean floor at the ridge is pushing the continents apart. But will this motion continue in the future, or will something else happen with the plate motions?

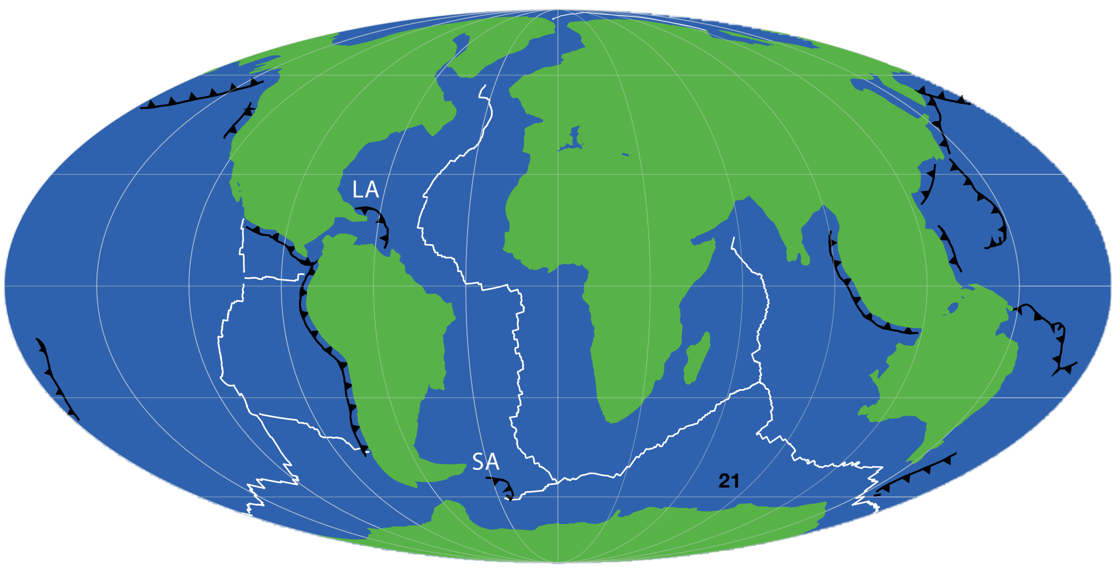
Novopangaea

If we assume that the present-day conditions persist, so that the Atlantic continues to open and the Pacific keeps closing, the next supercontinent will form at the antipodes of Pangaea. The Americas would then collide with the northward-drifting Antarctica, and the fused continents then move into the already merged Africa–Eurasia (Eurafrica in Figure 3). The resulting supercontinent – known as Novopangaea – would be surrounded by the Atlantic Ocean.

Pangaea Ultima

Another option is that the Atlantic opening slows down and the two small arcs of subduction in the western part of the basin start to extend along the east coast of the Americas. This would allow the Atlantic to close and lead to the formation of a supercontinent very much like Pangaea, called Pangaea Ultima. Here, the Americas, Europe and Africa are brought back together (Figure 4), and the supercontinent would again be surrounded by the Pacific Ocean, just like Pangaea was.

Figure 2 *Map showing tectonic plates, spreading ridges (solid white lines) and subduction zones (toothed black lines, with teeth pointing in the direction of subduction). Green = continental crust, blue = oceanic crust. LA and SA are the Lesser Antilles Arc and the Scotia Arc, respectively.*



On today's Earth, only the Pacific Ocean has long subduction zones, which are allowing it to shrink

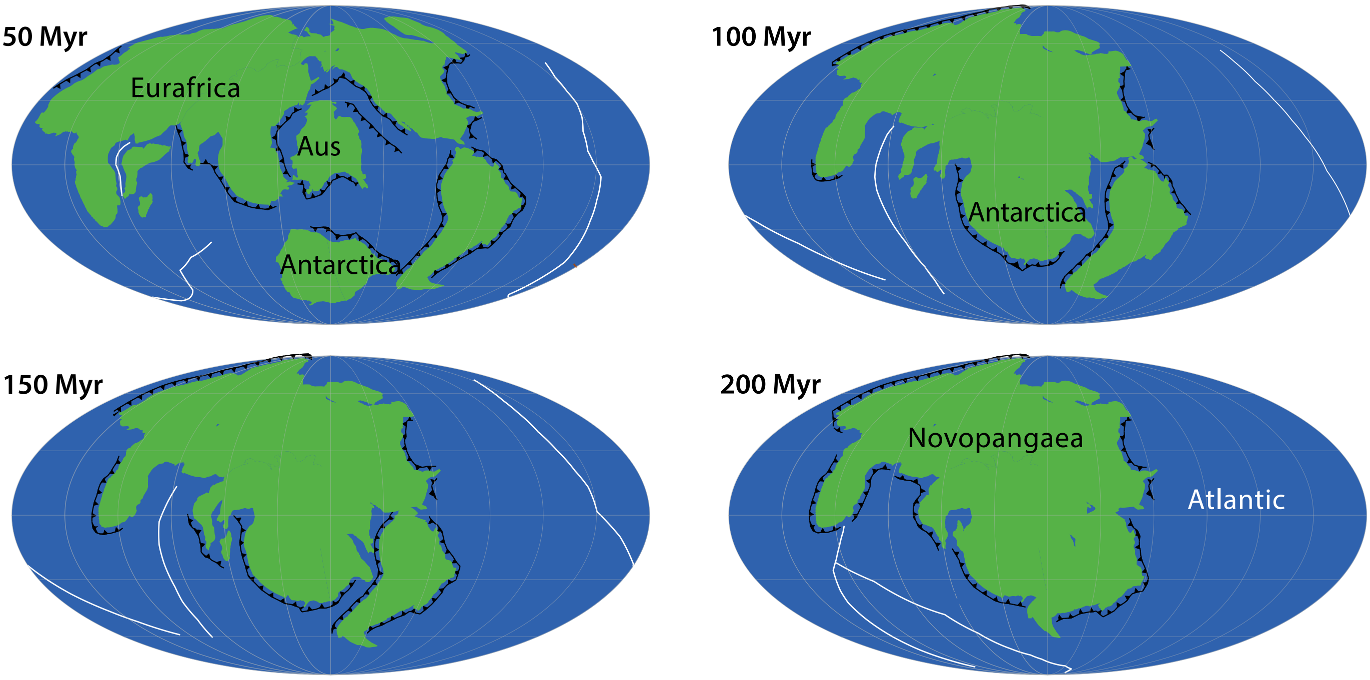


Figure 3 *Schematic representation of the formation of Novopangaea over the next 200 million years.*

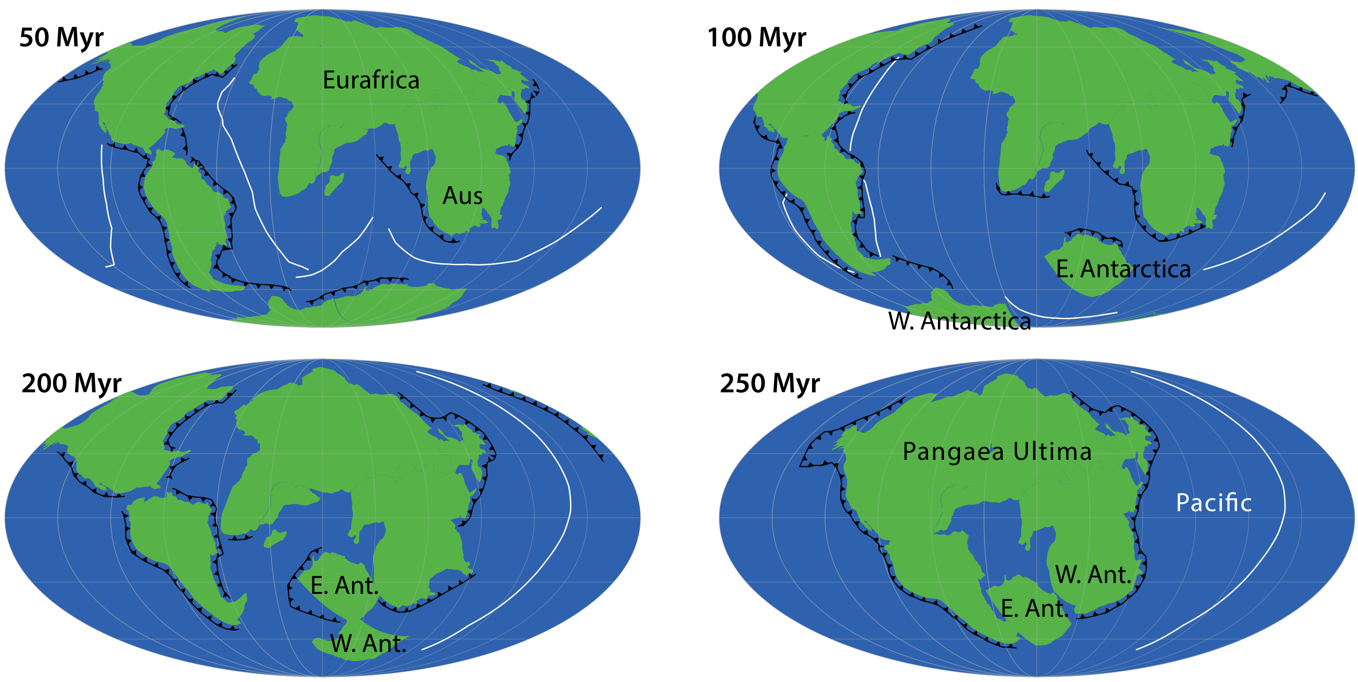


Figure 4 *Schematic representation of the formation of Pangaea Ultima over the next 250 million years.*

Formation of Novopangaea would result in the Atlantic expanding to surround the supercontinent; in the Pangaea Ultima scenario, the supercontinent would be surrounded by the Pacific

Aurica

The formation of Novopangaea or Pangaea Ultima both have one problem: the age of the ocean floor surrounding the supercontinent – parts of the Atlantic and the Pacific are already nearly 200 million years old. This is problematic, because the oldest ocean floor from ancient basins preserved on the planet is only slightly older than this. The oldest portion of ocean floor preserved *in situ*, in the Mediterranean, is around 300 million years old, meaning that very old sea floor may not be stable. There seem to be dynamic reasons for this, such as excess density and weakening of the plates by hydration. It would therefore be comforting to have a scenario where both the Atlantic and the Pacific Oceans close, so avoiding the formation of a supercontinent surrounded by exceptionally old ocean floor. In the case of the Novopangaea scenario, for example, if subduction zones do not eventually form along both margins of the Atlantic to recycle the old ocean floor, that near the continental margins will be over 400 million years old.

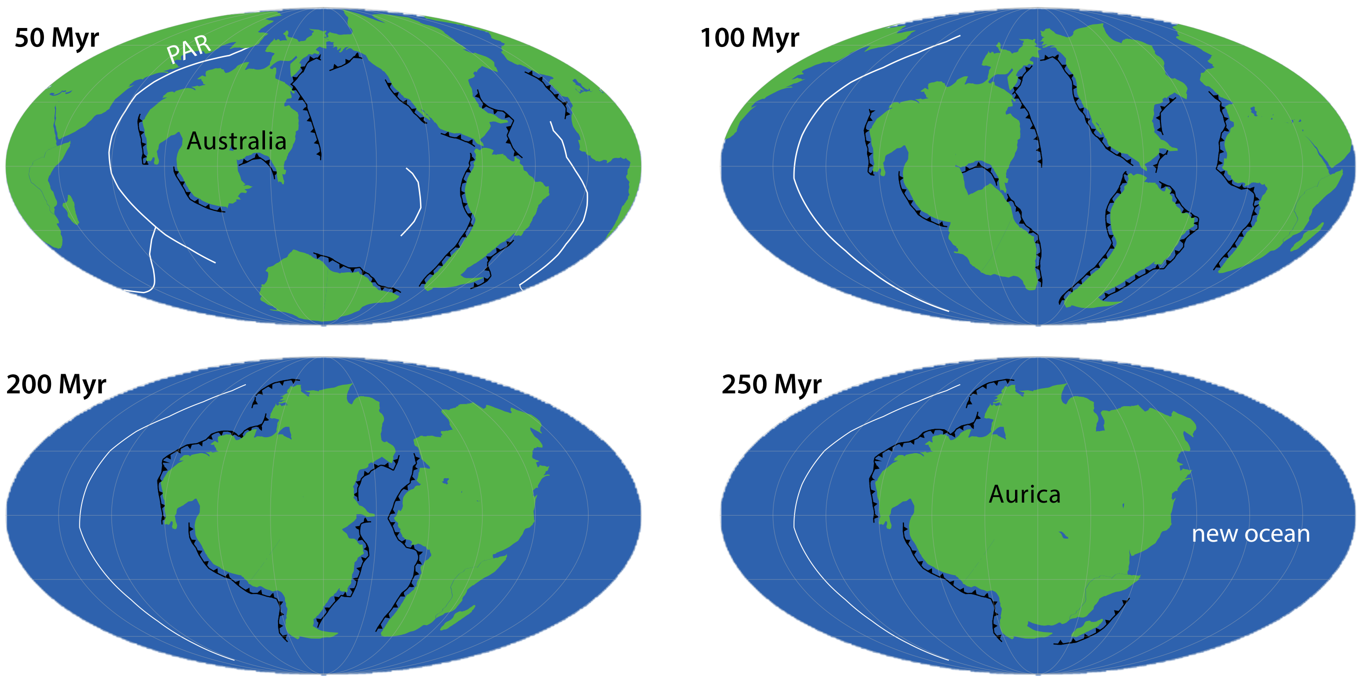


Figure 5 *Schematic representation of the formation of Aurica over the next 250 million years. PAR = Pan-Asian Rift.*

In the Aurica scenario, new subduction zones in the Atlantic would mean that both it and the Pacific could close

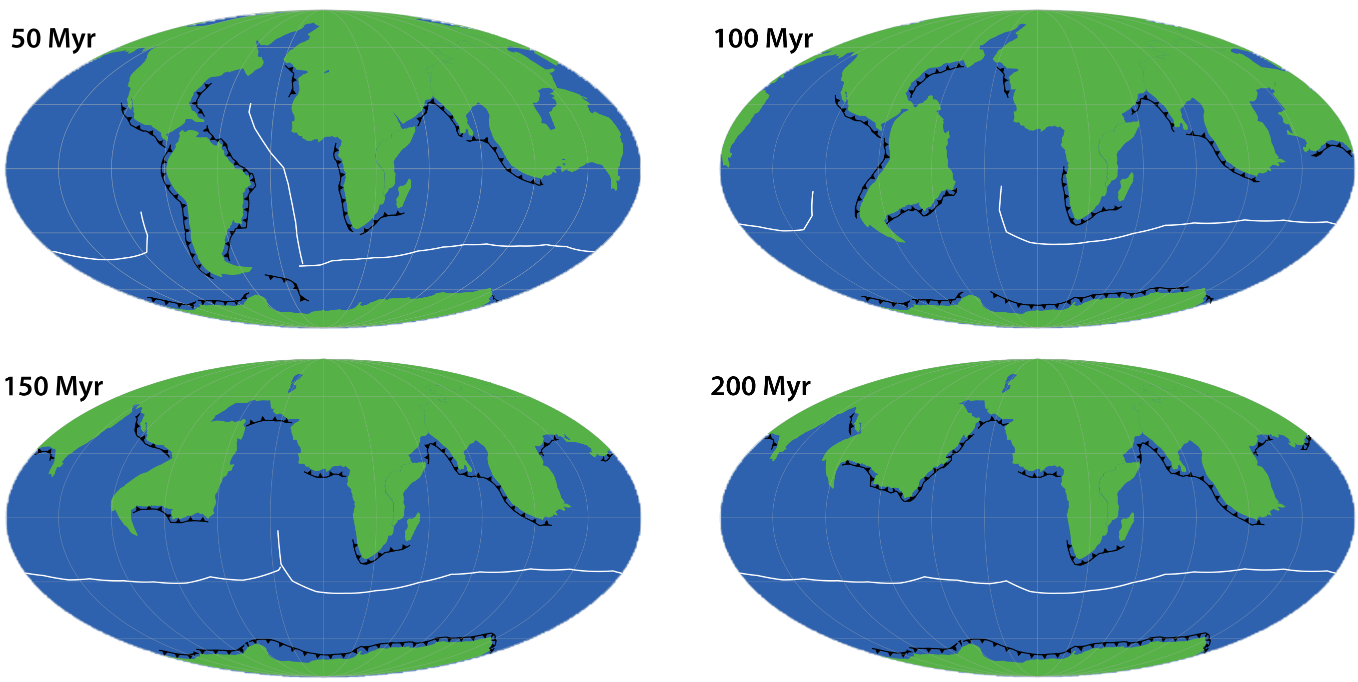
The Aurica scenario could happen if the Atlantic were to develop new subduction zones – something that may already be happening off the Iberian Peninsula, where there is a plate boundary with a lot of seismic activity (e.g. the trigger of the Great Lisbon Earthquake in 1775). Both the Pacific and Atlantic oceans would then be fated to close. This of course means that a new ocean basin would have to form to replace them, and in the scenario presented here the Pan-Asian Rift currently cutting through Asia from west of India up to the Arctic opens to form a new ocean (PAR on Figure 5). The result would be the formation of the supercontinent Aurica around Australia, which has drifted north into the present-day Pacific to become the centre of the new continent. East Asia and the Americas then close the Pacific from either side, and Europe and Africa rejoin the Americas as the Atlantic closes in the later stages of the formation process.

In the Amasia scenario, both the Atlantic and Pacific would stay open, the Arctic Ocean would close, and a new zonal ocean would open

Amasia

The fourth scenario predicts a completely different fate for future Earth's continents. Today, many of the continents are moving north, including Africa and Australia. This drift is believed to be driven by anomalies left by Pangaea deep in the mantle

Figure 6 *Schematic representation of the formation of Amasia over the next 200 Ma.*



in the Earth's interior. Because of this northward drift, it is easy to imagine a scenario where all the continents except Antarctica are driven north, at the same time as some of them, e.g. Europe and the Americas, keep moving east or west. This would lead to a gathering of the continents around the North Pole in a supercontinent called Amasia (Figure 6). In this scenario, both the Atlantic and the Pacific would join and mostly remain open, and the Arctic would be the basin that closes. The concern with this scenario is, again, that the resulting Pacific–Atlantic superocean, and its sea floor, would be very old by the end of the supercontinent cycle.

Consequences for the tides

From experiments with a numerical tidal model, we know that for long periods of the current supercontinent cycle, the tides have been far less energetic. This is because the shape and size of the basins could not support large tides – the basins were not resonant for the lunar tidal period. We have also shown that during the supercontinent phase of the cycle, the tides are very weak, only 1/3 or so of what they are today. In fact, of the past 400 million years (i.e. back to before the formation of Pangaea), it is only the last 2 million years that have seen large tides on Earth (sharp peak* on Figure 7). Since we are approaching the halfway point of the supercontinent cycle, and the tides have suddenly become very large, we asked ourselves another question: What will happen to the tides as the next supercontinent assembles in 200–250 million years? Is it possible that there is a supertidal cycle linked to the supercontinent cycle?

*During the Last Glacial Maximum (21 000 yr ago), sea level was much lower. This meant that most of the continental shelf, particularly along the coastlines of the Atlantic, was exposed. This made the ocean slightly narrower, which allowed it to be closer to resonance with the lunar tide, and the globally integrated tidal dissipation rate peaked.

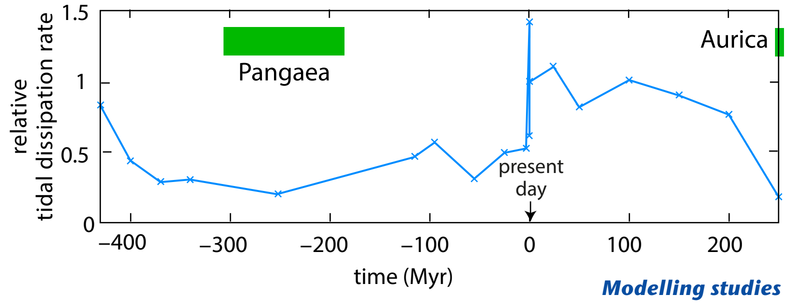


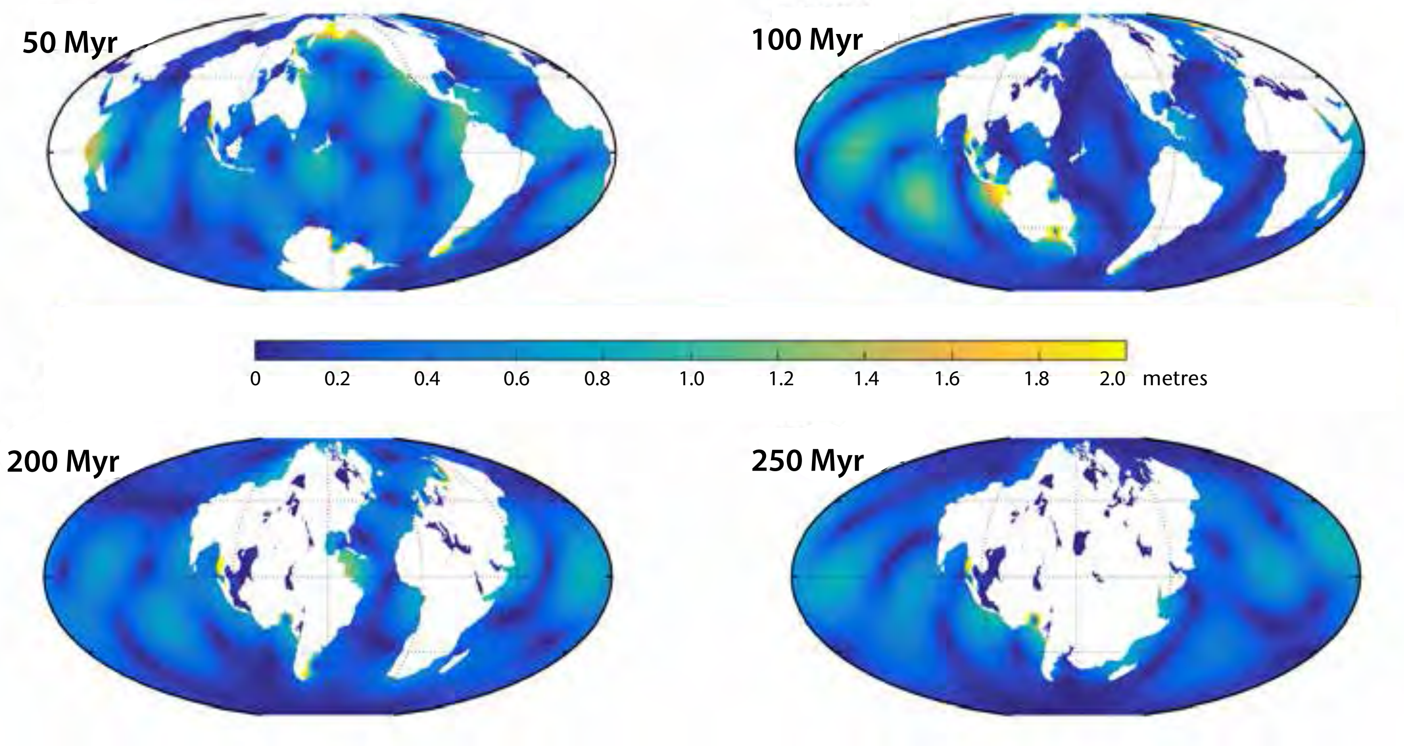
Figure 7 *The globally integrated tidal dissipation rate (i.e. the loss of tidal energy to the ocean, relative to the present-day rate of 2.4 x 10^{12} W) between 430 Myr ago, and 250 Myr in the future. The green bands correspond to the presence of supercontinents on the planet. The tidal dissipation rate is a key measure of the energetics of the tide, and it has significant implictions for the evolution of the Earth–Moon system by controlling the lunar recession rate (the rate at which the Moon is receding from the Earth).*

Modelling studies suggest that supercontinent formation is associated with low energy tides

Our latest tidal model simulations investigated this for the Aurica scenario, and show that there is indeed a supertidal cycle linked to the supercontinent cycle (Figures 7 and 8; initial simulations for the other scenarios show qualitatively similar results). In fact, the tide goes through two supertidal

Figure 8 *Tidal amplitudes (m) for four future time slices as Aurica forms (Figure 5); cf. Figure 1 for present-day amplitudes. The 100 Myr map, with large tides in the expanded Indian Ocean, corresponds to the second of the predicted peaks in Figure 7.*

Ocean basins go in and out of resonance with the tide as their shapes change



cycles during one supercontinent cycle. Earth is currently at the start of a tidal maximum, a period of time when the tides are very large. They will then weaken significantly over the following 25 million years, before becoming large again in around 100 million years from now (Figures 7 and 8). Then, as the next supercontinent forms, tidal energy levels will again drop down to less than half what they are at present. When Aurica has formed there will be only weak tides in a few embayments which have the right shape and dimensions to allow local resonances in the tides (250 Myr scenario in Figure 8).

The double peak in tidal energies emerges because the basins go in and out of resonance as their shapes change. Currently, the North Atlantic is resonant, but depending on the tectonic scenario, other basins can become resonant as they open or close. Or, the North Atlantic may become resonant again, if it starts to close as in the formation of Pangaea Ultima or Aurica. These periods of tidal maxima – when a basin can support large tides – are brief in geological terms: they only last for about 20 million years, e.g. between the present day and 20–30 million years' time in the modelled scenario illustrated in Figures 7 and 8. This means that the tides would be generally far less energetic than they are today, and over the 400–600 million years between the formations of two supercontinents, the tides would only be large for about 50 million years during the two tidal maxima.

Implications for the Earth system

This matters for the wider Earth system, because tides are a major energy source for the ocean. The energy pumped into the tide by the motions of the Sun and Moon dissipates throughout the ocean basins, and the associated turbulence and mixing drive vertical fluxes of nutrients, heat and salt between the deeper layers of the ocean and the surface. Fluxes of heat and salt are key to the large-scale climate controlling ocean circulation, and fluxes of nutrients help sustain biological production, especially in shallow seas.

Of the four tectonic scenarios presented we believe that Novopangaea is the most likely to represent Earth's future. It is a logical progression of the drift directions of the present-day continents, while the other three scenarios assume that another process will come into play. There would need to be new Atlantic subduction zones for Aurica, the reversal of the Atlantic opening for Pangaea Ultima, and anomalies in the Earth's interior left by Pangaea for Amasia to happen – and all of these are somewhat speculative.

Investigating the Earth's tectonic future forces us to push the boundaries of our knowledge, and to think about the processes that shape our planet over long time scales. It also leads us to think about the Earth system as a whole, and raises a series of other questions: What will the climate of the next supercontinent be? How will the ocean circulation adjust? How will life evolve and adapt? These are the kind of questions that push the boundaries of science further because they push the boundaries of our imagination.

We have started investigating these wider questions through our efforts to simulate the tides of the deep past and future. Changes in the tides on any time scale can have large effects on the whole Earth system, as shown by deep time simulations for the Eocene (~55 million years ago) and the Turonian (~90 million years). During the Eocene, tidally driven abyssal mixing was key in controlling the greenhouse climate at the time, and the lack of shelf-sea tides during the Turonian was very likely a reason for large areas of anoxia at the sea floor, leading to a marine extinction event. While the changes like those described here may not have any impact on us in the immediate future, they add to our understanding of how the tides interact within various parts of the Earth system – including plate tectonics, the climate system, nutrient recycling and, ultimately, the ocean's ability to evolve and support life.

Further reading

Davies, H.S. J.A.M. Green and J.C. Duarte (2018) Back to the Future: Testing different scenarios for the next Supercontinent gathering. *Global and Planetary Change* **169**, 133–44. doi: 10.1016/j.gloplacha.2018.07.015

Green, J.A.M., J.L. Molloy, H.S. Davies and J.C. Duarte (2018) Is there a tectonically driven super-tidal cycle? *Geophysical Research Letters* **45**, 3568–76. doi: 10.1002/2017GL076695

Green, J.A.M. Huber, D. Waltham, J. Buzan and M. Wells (2017) Explicitly modeled deep-time tidal dissipation and its implication for lunar history. *Earth and Planetary Science Letters* **461**, 46–53. doi: 10.1016/j.epsl.2016.12.038

Mattias Green is a physical oceanographer at the School of Ocean Sciences, Bangor University. He uses models and observations to explore how the tides interact with other components of the Earth system, and in particular how these interactions change over long time scales. m.green@bangor.ac.uk

Hannah Davies is currently a Ph.D student at Lisbon University, Portugal, and is affiliated to the University's Insituto Dom Luiz. By combining GPlates and numerical modelling she is exploring the link between plate tectonics and tides. Hannah's work is currently focussed on quantifying change in the tides over geological time. hdavies@fc.ul.pt

João Duarte is a geologist working in tectonics, geodynamic modelling and marine geology at the Instituto Dom Luiz and the Geology Department at the University of Lisbon, where he is an Assistant Professor. His main interests are subduction initiation and supercontinent cycles. João is also passionate about science communication. jdduarte@fc.ul.pt

In support of sharks

Sharks have not always enjoyed the best publicity, their image not helped by the movie *Jaws,* which can take some of the blame for enhancing, if not creating, the 'man-eating' myths that surround them. To suggest, against this backdrop of misinformation, that we should be concerned about sharks and that policy-makers should protect them as vulnerable species would have been met with ridicule at the time of the movie. Yet in 1997, just ten years after the final instalment in the *Jaws* franchise, the Shark Trust came to life. Now the Plymouth-based conservation organisation has a membership of around 1200, employs eight full-time staff, half of whom are directly involved with shark conservation, and has become the voice for sharks in UK waters and beyond, into Europe and globally. Most importantly, the Shark Trust has spearheaded regulative and legislative change which has begun to reverse the fortunes of sharks, not just in the UK but also further afield.

To find out more, Kelvin Boot interviewed Paul Cox, the Shark Trust's Managing Director, for *Ocean Challenge.*

Paul Cox, MD of the Shark Trust.
(Photo: Shark Trust)

Was the negative attitude towards sharks the stimulus for founding the Trust?

There is no doubt that Jaws had an impact: while the film might be blamed for creating the wrong stereotype it did also have the effect of getting people interested in sharks, so laying foundations for their conservation. We now know that sharks and their close relatives – the rays, skates and chimeras – are a diverse, but little understood and maligned group of animals. Long-lived, slow to mature and with low reproduction rates, they are especially vulnerable and prone to declines through unmanaged exploitation. Shark conservation really got going in 1999 when the Committee on Fisheries of the UN Food and Agriculture Organisation adopted a voluntary international Plan of Action for the Conservation of Sharks (which included all elasmobranchs: rays, skates and chimeras). This called upon all states to produce a Shark Assessment and, if they had a fishery, to develop and implement National Plans of Action. The UK plan was published in 2004 (http://archive.jncc.gov.uk/pdf/jncc360.pdf), and gave the Shark Trust more of a focus for its activities, including monitoring how the plan was implemented, and it gave shark supporters a stronger voice.

What has the Trust's role been over the last 22 years?

Wherever there are interactions between humans and sharks we try to create positive change. Whether that's changing attitudes, awareness, behaviours or policy, we try to secure change for the better. We take a three-pronged approach. First, there is policy advocacy work such as wildlife protection, controlling trade (through CITES) or fisheries legislation at national, regional and international level. This entails bringing the science evidence base together, putting a good case, and then pushing and pushing and pushing for policy change. Our second pillar, stakeholder engagement, is aligned to policy advocacy. If we are addressing fisheries policy, for example, we work with the fishing industry, so the fishermen have all the information they need and all the resources they require in order to comply with legislation. Another example might be eco-tourism, where we cooperate closely with the Wildlife Safe (WiSE) scheme (www.wisescheme.org) on the basking shark code of conduct, which promotes best practice for watching sharks in general. Recreational anglers are essential collaborators; we foster best practice when handling sharks and rays, encouraging anglers to report their sightings so we can build upon our shark knowledge. The third pillar is public engagement, providing accurate and engaging content to get people involved in the work that we do. The Great Eggcase Hunt (p.28) is an excellent example of citizen science and so far we have almost a quarter of a million records. At the heart of it is getting people connected with issues and solutions.

The blue shark is the most heavily fished of the sharks, but the recent ICCAT meeting adopted ground-breaking new catch limits for blue sharks that represent a first for the world
(Photo: Charles Hood/Shark Trust)

it sounds like the Shark Trust was something of a pioneer?

Yes, there were other countries with similar organisations, but the Shark Trust was certainly one of the first and went on to encourage others to be formed. We tend to be thought of as Shark Trust UK, and in the early days, perhaps that was what it was but its influence has grown from UK to Europe, with growing involvement in European policy advice, and in the last decade we have expanded that further afield into a more global influence. There's no question that the Shark Trust is unique in the breadth of what it does, from very serious policy advocacy through to public engagement – that's what makes it stand out as different.

Above: Shark Trust Conservation Officer, Cat Gordon, with the Winsor family on the Great Eggcase Hunt; https://www.sharktrust.org/great-eggcase-hunt. (Photo: sghaywood photography)

Not all sharks have the stereotypical shark shape. The angel shark lives on the sea bed where it can wait for weeks until suitable prey strays too close. (Photo: Simon Rogerson/ Shark Trust)

The word 'shark' still conjures up a certain image for most people. Would you say that's still a problem?

Yes, one of our key messages is about diversity, and in the past we have made the mistake of talking about sharks in general, so we don't get across that sharks are an incredibly diverse group: some may be apex predators, many are not; there's a massive shark that feeds on plankton, there's one that fits in the palm of your hand; there are sociable sharks and solitary sharks; there are sharks that may swim past 145 countries every year as they migrate, there are some that barely ever move. Language is so important and we have to get it right to put our messages across.

On a more personal note, which shark are you most impressed by?

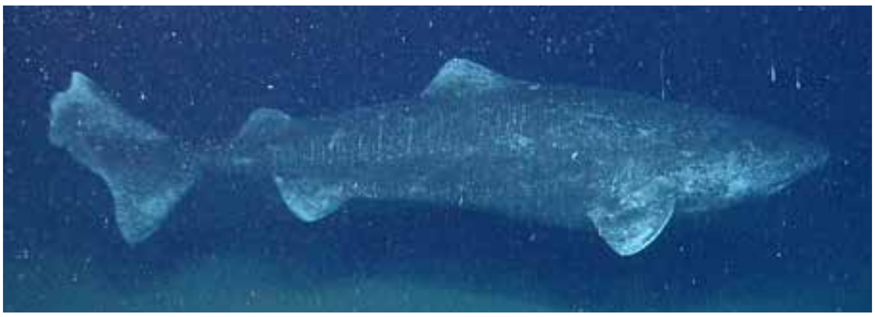
If I have to choose one it is the Greenland shark, it's an amazing creature. We talk about sharks being late to mature, their sparing reproduction and how long they can live. But the Greenland shark takes that to a whole other level. If you caught an old Greenland shark today, that shark could have been around as a pup as the Mayflower *(1620) sailed overhead, and would not have been mature by the start of the American Civil War (1861). It is just mind-boggling. There is so much we still need to know about this shark that lives in deep, dark cold water of the northern Atlantic and moves at the pace of a human toddler yet feeds on some of the fastest fish in the sea. It's the second largest non-planktivorous shark in the world after the great white, so with the basking shark, in UK waters we have the second and fourth largest fish in the sea, along with around another 40 species of sharks, skates, rays and chimeras.*

Have you changed attitudes?

As far as policy and industry are concerned the door is more open than it ever has been, and that's because of our practical, science-based approach to inform policy change. It's about having evidence, being able to promote solutions, rather than just highlighting problems, and being pragmatic and able to compromise on what outcomes you're looking for. There has been a real shift – if we went to a fishing industry meeting 15 years ago the attitude was one of suspicion. That has changed dramatically – the Shark Trust has earned respect. From my first day working at the Shark Trust it became apparent that it is trusted. This places an enormous responsibility on us to make sure we are accurate and up-to-date, so people know that they are getting reliable information.

When it comes to the wider public, there is still a fascinating dichotomy between what the media assumes people think about sharks and the reality of the situation. The print media is pretty much the only place where you still find the

A deep-living Greenland shark, perhaps hundreds of years old. (Courtesy of the NOAA Office of Ocean Exploration and Research, Northeast US Canyons Expedition 2013)



The fight continues

While this interview was taking place at the end of November 2019, Shark Trust Director of Conservation Ali Hood joined with other conservation organisations at the International Commission for the Conservation of Atlantic Tunas (ICCAT) where a ban endorsed by 16 countries was rejected primarily by the EU and the USA. ICCAT includes sharks and their sustainability in its remit.

Prior to the meeting scientists had advised that drastic overfishing had brought the North Atlantic mako shark close to disaster and that a complete ban on fishing and measures to avoid bycatch, was the only solution to halting the serious decline in numbers. The mako is one of the world's most economically valuable sharks and despite being listed by the IUCN as 'Endangered', and CITES stipulating that it should only be caught in legal, sustainable fisheries, little action has been taken. 'The EU's behaviour with respect to mako conservation is a travesty. Their obstruction of vital, science-based protections will allow vast fleets from Spain and Portugal to continue to fish these endangered sharks, essentially without limit, and drive valuable populations toward collapse,' said Ali Hood.

Above right *Ali Hood Director of Conservation, Shark Trust, at the recent ICCAT meeting*
Left *A mako shark (Charles Hood/ Shark Trust)*

tired stereotypes and sensationalist reporting. When you talk to people or when you look on social media, you will find a much more nuanced view and appreciation of sharks than there were 20–30 years ago. Documentary-makers are more honest, showing sharks as they really are rather than exaggerating the danger of being in the water with them; and the availability of quality information is better, particularly for children.

What single achievement is the Shark Trust most proud of ?

The success I am most proud of is the strengthening of the finning regulations. The Shark Trust was involved from the beginning, with the 2003 finning regulation; we got the ban and we could have sat back being very pleased with ourselves, but there were still loopholes. Ali Hood, our Director of Conservation, worked with others for another decade to get a revised and much more robust finning regulation. It is now much stronger, with no loopholes. That was a result of hard work and dogged persistence, and it didn't stop there. Ali was back in 2015 checking how the regulation was being enforced, asking what difference it had made and whether it was being applied properly. Even that was not the end and on the back of the EU regulation the Shark Trust pushed the EU to use its influence for similar initiatives in other parts of the world. It's this tenacity that sets the Shark Trust and its work apart and makes it unique. We don't give in.

The Shark Trust has had many successes but your work is not done. What next?

We were successful with the finning ban but we still have a lot of work to do on overfishing in general and unlimited shark fishing in particular (see blue box). It is still disappointing how difficult it is to get policy-makers to follow the scientific evidence; if you are fishing commercially, you should have science-based management. The science can reduce any uncertainties. We have to get better at getting the right message across; too many sharks are dying at the hands of humans every year – that is simply not sustainable.

Kelvin Boot is a science communicator working with a number of UK marine science organisations. kelota@pml.ac.uk

Bamboo sharks are patterned to help them blend into the coral reefs where they live and hunt for invertebrate prey.
(Photo: Stephen Childs/Shark Trust)

For more about the Shark Trust
including the ongoing Great Eggcase Hunt
see **https://www.sharktrust.org**
Help membership reach 2000 in 2020!

Celebrating 50 years of sea-going science on the RV Prince Madog

Katrien Van Landeghem and Tom Rippeth

2018 saw the 50th Anniversary of Bangor University taking delivery of its new research vessel, *Prince Madog*. Since then, this vessel and then her replacement, which came into service in 2001, have been the platform for training several generations of sea-going scientists, and been used for world-leading research, as well as for regular offshore monitoring work. As a tribute to its service to the marine science community, we provide an incomplete review of the science that has been underpinned by data collected on the *Prince Madog* over the past 50 years, and the impact that science has had.

A research vessel to support marine science in Menai Bridge

Bangor University's interest in marine science goes back to a few decades after its inception, as the University College of North Wales, in 1884. The first honours degrees in Marine Biology were awarded by the University College in the 1930s and the university's commitment to marine science was confirmed by the establishment of the Marine Science Laboratories, across the Menai Strait in Menai Bridge, in 1948. Initially, interest was focussed on helping the sea fisheries of North Wales, but by the 1960s marine science at Menai Bridge had been broadened, with physical oceanographers, marine geologists and chemists joining the developing Marine Science Laboratories, which eventually became the School of Ocean Sciences (SOS). The range of research and teaching activities expanded from near-shore and coastal ecology, to studies of shelf seas and the deep ocean, and access to a large, well equipped research vessel became imperative. The solution was the purchase and commissioning by the university of a new vessel (Figure 1), named after the great Welsh hero, Prince Madog, who is reputed to have discovered America.

Figure 1 *The original RV* Prince Madog *approaching Menai Bridge pier in 1968. The 185-tonne, 28.7-m research vessel, built on the Isle of Man, could accommodate eight scientists and had an endurance of seven days. She was named after the Welsh Prince who, legend says, set sail in 1170 on a westerly course, eventually reaching North America, where he founded a Welsh-speaking tribe.*
(Photo: School of Ocean Sciences, Bangor University)

First Prince Madog *surveys in 1968*

Within the first year of her operation in 1968, the new vessel made over 20 cruises, which ranged from student field trips to full-scale geophysical and hydrographic cruises off the west of Ireland and in the Celtic Sea, and to the west of Scotland and in Loch Ness.

A breakthrough in understanding plate tectonics

During one of the first *Prince Madog* research cruises in 1968, Denzel Taylor-Smith and Bill Bailey carried out pioneering geophysical research in the Porcupine area of the North Atlantic. At the time, plate tectonics was still a relatively recent idea and a new research project had been developed which aimed at better understanding the late Paleozoic North Atlantic supercontinent, and its subsequent break-up. The RV *Prince Madog* undertook geophysical surveys which improved understanding of the geological structure of key parts of the outer shelf to the west of Ireland (Figure 2). The study centred around an area where a new arm of the Mesozoic Atlantic Ocean, the Rockall Trough, was created. Magnetic anomaly contour maps together with seismic reflection profiles recorded during the cruises provided general support for the idea that the Slyne Ridge and Porcupine Ridge represent submerged blocks of marginal continental crust, and that the Porcupine Sea-bight is founded upon crust significantly different in character. The reconstructions of the crustal structural beneath the troughs and ridges to the west of Ireland implied either an early Cretaceous triple junction (where three plate boundaries met) at the southern end of the Rockall Trough, or an earlier phase of sea-floor spreading.

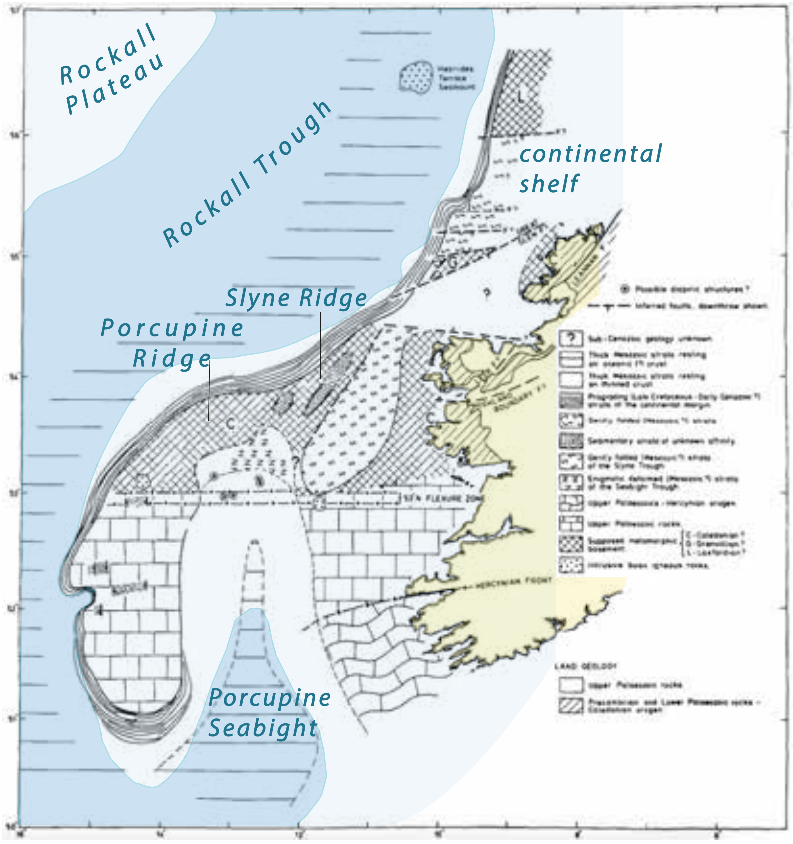


Figure 2 *Speculative offshore sub-Cenozoic geology (> 65 Myr) to the west of Ireland, based on seismic reflection, magnetometer and gravimeter profiles (reproduced from Bailey, 1975). For the purpose of this article we have added the yellow shading (land), pale blue (continental shelf/slope down to a depth of ~1500 m), and darker blue (greater depths) plus the names of some bathymetric features.*

Insight into turbulence and mixing

In September 1968, the *Prince Madog* took John Simpson, Dave Boon, John Woods and Steve Thorpe to Loch Ness via the flight of lochs known

Figure 3 *The second RV* Prince Madog*. In 1999, as a result of a Joint Infrastructure Fund bid led by Ed Hill (then at Bangor) funding became available for a new ship, which came into service in 2001. Built by Scheswerf Visser BV, the new* Prince Madog *(390 tonnes, 34.9 m in length) arrived in Menai Bridge in summer 2001. She is more spacious and stable than her predecessor, and has capacity for 11 scientists and an endurance of 10 days.*
(Photo: School of Ocean Sciences, Bangor University)

as Neptune's Staircase. They measured very fine structure (microstructure) profiles of temperature through the thermocline in this freshwater lake and discovered that the microstructure temperature patterns were very similar to those found in the ocean. Temperature and salinity microstructure had previously been measured in the ocean thermocline and had been attributed to the process of double diffusive convection, which is driven by opposing salt and temperature gradients. However there are no salinity gradients in the lake, so double diffusive convection could be discounted as a cause of microstructure, whether in the lake or the ocean. This insight helped open the way for the development of now very widely used microstructure-based techniques for the measurement of turbulence (from which mixing estimates are inferred) in the ocean.

Long-standing fisheries research

Throughout the 50 years of operation of the two *Prince Madog* vessels, fisheries have remained a core research activity. From the late 1960s the *Prince Madog* has been involved in an annual fish stock survey of target species such as plaice and dab in five contrasting sites to the east of Anglesey. This work represents one of only a few such long-term surveys in UK coastal waters and has been led by Dave Grove and Ian McCarthy.

Figure 5 *Some of the places mentioned in the article. The School of Ocean Sciences (SOS) is indicated by a green cross on the Anglesey side of the Menai Straits. The red line is the transect along which data in Figure 6 were collected.*

Over the past 20 years, fisheries work based on the *Prince Madog* has included pioneering research into the quantification of the wider ecosystem effect of fishing on sea-bed habitats, led by Mike Kaiser, Jan Hiddink and Stuart Jenkins, with Helen Beadman and other Ph.D students. Prior to this research there was virtually no evidence available for fisheries managers, conservationists and policy-makers to assess the effect of fishing. This work has assisted the local economy through improving yield and minimising environmental impacts of the Menai Strait mussel fishery, the UK's largest blue mussel fishery

Figure 4 *Blue mussels from the Menai Strait. (Photo: Bangor University)*

(Figure 4). It also demonstrated that mussel cultivation had no negative effects on other species and that, furthermore, it enhanced populations of oyster-catchers. Follow-up work provided extensive evidence-based advice of value to the Isle of Man scallop fishery and for the management of the Cardigan Bay Special Area of Conservation with regard to its scallop fishery.

Data collected from the *Prince Madog* also fed through to a global meta-analysis of fishing impacts on benthos, and underpinned ecological modelling approaches to the prediction of trawling impacts on benthic communities. For this research, cruises sampled benthic fauna in lightly and heavily fished areas in a wide range of habitats, including the limestone reefs of Lyme Bay (off south Devon and Dorset), the deep muddy bottom of the Fladen Ground in the northern North Sea, and the scalloping grounds in Cardigan Bay. The surveys used a wide range of benthic sampling techniques, such as heavy beam trawls, anchor dredging, sledges carrying cameras (Figure 7) and box cores.

Shelf-sea fronts and biogeochemistry

Through the 1970s, *Prince Madog* surveys of the western Irish Sea revealed the existence of a persistent front separating well mixed and seasonally stratified water columns (Figure 6). The location of the front and its spatial structure, confirmed by aerial survey and satellite infra-red observations, were explained in terms of the competition between surface heating and tidal stirring. This work provided the first quantitative link between the dissipation of tidal energy and mixing in the ocean.

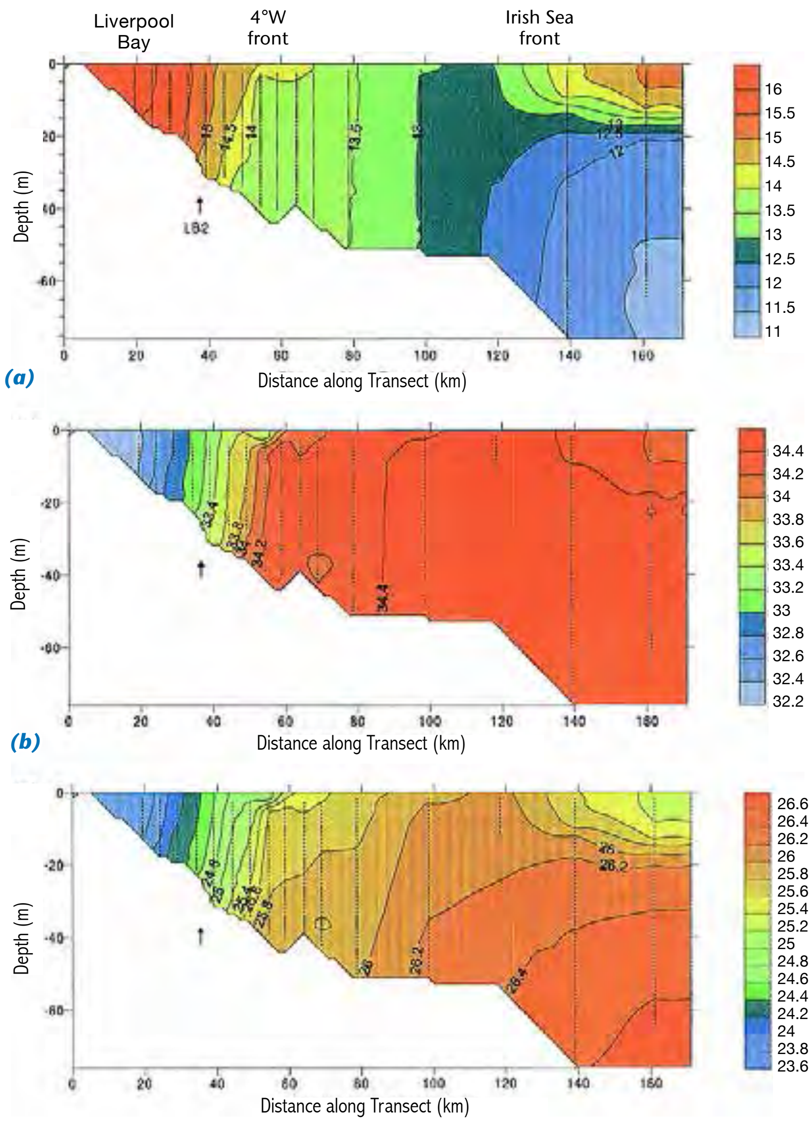
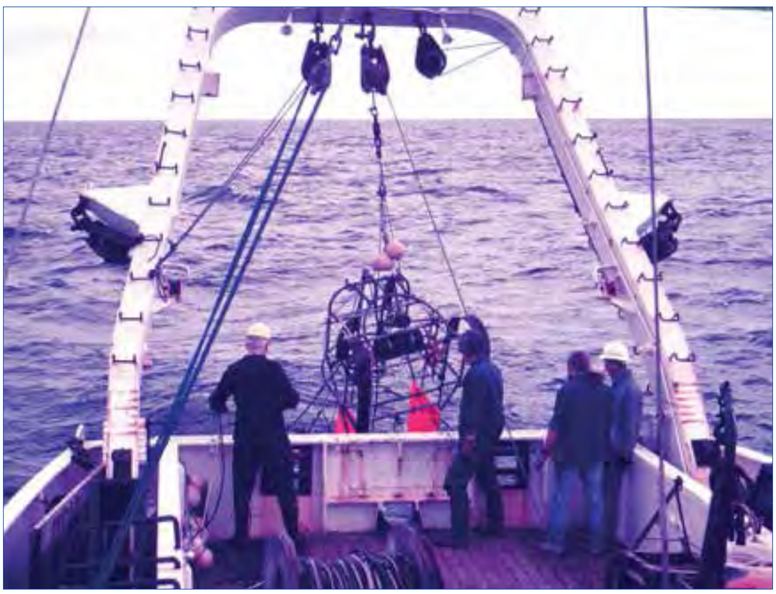


Figure 6 *The water column structure running west–north-west from the mouth of the River Mersey (left-hand side of section) to the north of Anglesey and across the western Irish Sea front to north of Lambay Island (see Figure 5). The three sections are **(a)** temperature (°C), **(b)** salinity (p.s.u.), and **(c)** σ_t (kg m^{-3}). Liverpool Bay, the 4°W front and the Irish Sea front are labelled for purposes of this article. (Reproduced from Rippeth* et al.*, 2001; © 2001 American Meteorological Society (AMS).)*

The existence of fronts in shelf seas as semi-permanent geographical features with the potential for high biological productivity was quickly recognised and led to extensive observational studies of the impact of tidal stirring on the distribution of primary production, zooplankton and seabirds over these regions of strong physical and chemical gradients. Paul Tett, who moved to Bangor from Oban, and Kath Richardson, who came with Tony Fogg from London, were amongst many scientists who joined campaigns on the *Prince Madog* to elucidate the links between physics and biogeochemistry in the shelf-sea system. Further microbiology studies by Fogg, with Karin Lochte and Carol Turley, also focussed on the 4°W front in Liverpool Bay (Figure 6). The results of these, and other frontal studies in shelf seas, were reported at a Royal Society Discussion meeting and published in a special edition of *Philosophical Transactions of the Royal Society*. This international interest helped to generate the impetus for NERC's first Marine Community Research Project, the £15m multi-institutional and interdisciplinary North Sea Project, which ran from 1988 to 1992.

In the early 1980s, shelf-sea fronts also attracted interest for their related biological effects on the sea bed. Norman Holme at the Marine Biological Association in Plymouth was one of the pioneers of the use of towed sledge camera systems (Figure 7) to help record and understand offshore sea-bed ecology. Following collaborations with Ivor Rees, he came up to Menai Bridge with his underwater TV and film camera systems for a cruise on the *Prince Madog* in the Irish Sea about 20 km off Lambay Island. Having gone across towards the Irish end of the front as there was a fresh westerly wind, Holme and Rees serendipitously documented a very rich biotope at a depth of 70 m. Their sledge was travelling over a mass of worm tubes (*Ampharete* sp.) with unusually high numbers of small bivalves and crustaceans living amongst them. The grabs and Agassiz trawl sampling confirmed this, and the tubes were thought to stabilise the sediment and help trap 'marine snow', giving rise to a rather special and localised benthic community. The experience on this cruise led to the acquisition of a second-hand 'Photosea' film camera system which was deployed on the sledge in a series of projects in various locations, from the *Modiolus* (horse mussel) beds off North Wales to Haig Fras, a rocky outcrop in the Celtic Sea, and even the muddy Fladen Ground in the northern North Sea. The sledge is still in use with digital cameras instead of the old 35 mm film camera which had to be opened in a black bag.

Figure 7 *Norman Holme deploying a 'Photosled' in the western Irish Sea in July 1985.*
(Photo: School of Ocean Sciences, Bangor University)



Underpinning hydrodynamic models

In 1978, Bangor University established the Unit for Coastal and Estuarine Studies (UCES), a new commercial unit linked to the School of Ocean Sciences. The central activity of the group was numerical modelling, notably in relation to pollutant dispersion problems. As the unit grew, new staff were increasingly involved in using the *Prince Madog* for their own research. For example, Toby Sherwin, with Miguel Lavin, made a series of pioneering measurements of the evolution of seasonal stratification and time-varying currents which quantified the potential of wind-driven inertial oscillations and internal tidal motions to drive mixing in the summer regime of the stratified shelf seas. With funding from the Defence Science and Technology Laboratory, Dave Bowers used a combination of *Prince Madog* ship surveys and satellite colour imagery to study the seasonal and tidal variations in the concentration of particulates in the Irish Sea. These interests in bio-optical work developed further, with the *Prince Madog* being used to ground truth remotely sensed data, including employing ocean colour to estimate sea-surface salinity and to assess the particle size distribution of suspended sediments.

In the 1980s and early '90s, the main focus of Bangor's sea-going oceanographers was on Regions of Freshwater Influence (ROFIs) and involved Ph.D projects for Jonathan Sharples, Tom Rippeth, Graham Allen, Pat Hyder and Alex Souza and others. Observations in Liverpool Bay (Figure 5), led to the identification of the processes of periodic stratification and tidal straining which are now recognised as key factors influencing estuarine stratification and circulation (Figure 6). Numerical models need to reproduce these processes to correctly predict the dispersion of fresh water in the sea.

Observations from the *Prince Madog* in Scottish sea lochs (fjords) stimulated models of the seasonal cycle of stratification and revealed the role of internal tides in driving mixing in these fjordic environments. The improved understanding of the subtle sets of physical processes operating in these freshwater-influenced regimes led to a series of major interdisciplinary EU-funded projects ultimately aimed at improving water quality models. These involved John Simpson, Tom Rippeth, Colin Jago, Sarah Jones, Paul Tett, Tony Walne, Robin McCandliss and Mal Hearn, together with collaborators from the Proudman Oceanographic Labs (now National Oceanography Centre, Liverpool), the Scottish Association for Marine Science (SAMS) and Napier University.

Ed Hill, with Kevin Horsburgh, Liam Fernand, Juan Brown and others, made a series of drifter and other hydrographic measurements from the *Prince Madog* which they combined with state-of-the-art numerical model simulations to map the density-driven residual circulation in the north-west European shelf seas, with the specific aim of isolating its role in larval dispersal and in the spread of paralytic shellfish poisoning around the UK coast (Figure 8).

Monitoring natural marine systems from the RV Prince Madog

In addition to the more focussed studies, the two *Prince Madog* vessels have also been involved in a number of long-term monitoring campaigns. In the 1970s, with Department of the Environment support, Peter Spencer, along with Ian Millar, and later Dave Mills and others, set up a regular survey grid in Liverpool Bay for sampling nutrients and phytoplankton. The grid was subsequently adopted by the Environment Agency and later taken over as the Proudman Oceanography Laboratory Coastal Observatory, funded by NERC and Defra. This supported the Cefas SmartBuoy Programme which remains operational today.

The long time series of data collected in Liverpool Bay contributed to the radically improved scientific evidence base that underpinned the successful UK Government defence against the EU infraction proceedings mounted under the *Urban Waste Water Treatment Directive*. In essence, the data and evidence supported the UK position that while some UK coastal waters were enriched with river-derived nutrients, this did not lead to eutrophication. The reason was that the coastal waters around the larger UK estuaries are highly turbid, and in consequence the phytoplankton were light-limited in these regions, and so did not show enhanced growth or an undesirable disturbance to the balance of organisms indicative of eutrophication.

Figure 8 *Schematic map of principal summer thermohaline transport pathways on the north-western European shelf and the cold and high salinity pools that drive them. Orange: regions where seasonally formed dense bottom pools are influenced by both low winter temperatures and high salinity oceanic water which has penetrated the outer shelf. Light blue: regions where only temperature is responsible for the density of water trapped below the seasonal thermocline. Green arrow: European slope current. Red arrows: frontal jets associated with bottom fronts at boundaries of dense cold and high salinity pools.* *(Reproduced from Hill* et al.*, 2005; © American Geophyical Union)*

Over the past 10 years the *Prince Madog* has been an important component of Bangor University's programme providing fisheries advice to the Isle of Man Government. Each spring the *Prince Madog* has provided a platform for a two-week survey of Manx scallop stocks, sampling fixed stations covering both king and queen scallop fisheries within the Isle of Man's territorial sea. A set of four survey dredges are towed at each station and the number, age and weights of scallops caught are recorded along with information on bycatch. The data collected during these surveys have been used to undertake quantitative stock assessments for scallops around the Isle of Man which in turn are used to underpin the management of these fisheries.

For nearly three decades the P*rince Madog* has been used as a platform from which to develop the UK's capacity to measure turbulence in the ocean. It has been used to test and validate new acoustic techniques for measuring time series of turbulence. It has also been used to characterise turbulence in the contrasting shelf-sea regimes around the UK (Figure 9), supported by SOS's Electronics Engineering group, and in particular Ray Wilton and Ben Powell. These measurements have since become the gold standard against which the turbulence closure schemes used in today's operational shelf-sea numerical models (ROMS and NEMO) have been rigorously tested.

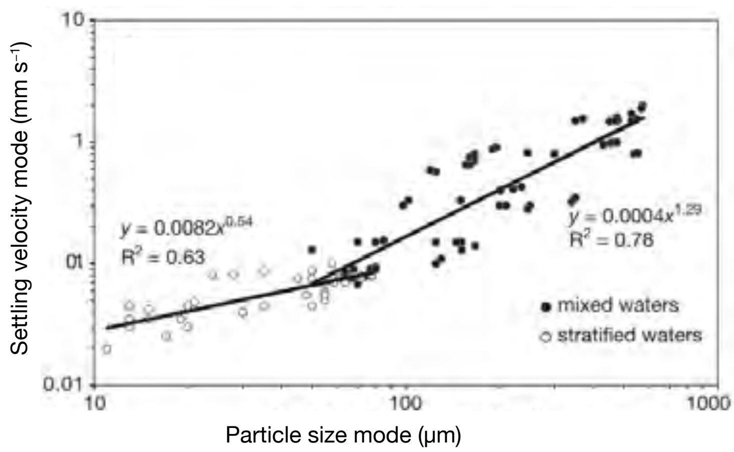
Figure 9 *Tom Rippeth deploying a turbulence profiler, together with Mark Inall, Ray Wilton and Phil 'the bosun' Jones. The* Prince Madog *was used extensively to survey turbulence across the contrasting shelf-sea regimes around the UK. These measurements allowed the testing of state-of-the-art ocean models. (Photo: School of Ocean Sciences, Bangor University)*

Particle settling velocity tubes – a hazard for Prince Madog *crew*

During the 1990s and early 2000s the *Prince Madog* played a key role in the research on suspended sediments in shelf seas. This was the period when optical and acoustic techniques for quantifying suspended matter were being developed, and SOS was at the vanguard of discoveries about, and understanding of, the role of suspended particulate matter (SPM) in biogeochemical cycling in tide-stirred shelf seas. Colin Jago and Sarah Jones made early measurements of SPM concentration, particle size and settling velocity, and related these properties to turbulence and microplankton. Working with Gay Kennaway of the Natural History Museum they showed how SPM settling velocity increased by two orders of magnitude during the spring bloom in the Irish Sea, which explained how rapid fallout takes organic-rich SPM to the sea bed and creates a benthic fluff layer (which in turn dictates biogeochemical fluxes across the sediment–water interface) (Figure 10). The tubes used to measure settling velocity were designed and built by Dave Boon in SOS; they were not popular with the ship's crew as if the sea was at all rough during deployment they had a propensity to crack heads, bruise feet and squash fingers simultaneously!

Working with Ph.D students Andy Campbell and Peter Sykes, Jones and Jago were able to show that the role of turbulence was more complex than previously believed: turbulence controls the temporal variation of particle size through resuspension, aggregation and disaggregation of SPM at any particular location but there are superimposed variations due to advection of waters that carry a spatial signal imposed by regional gradients in turbulence.

Figure 10 *A plot of modal particle size versus modal settling velocity shows that floc strength increases with size, and that the larger, faster-sinking flocs formed in mixed waters where collisions are stronger and where the living algae probably act as a strong glue. (Reproduced from Jago* et al.*, 2007; Copyright © 2007 Inter-Research)*



Palaeoceanography and sclerochronology

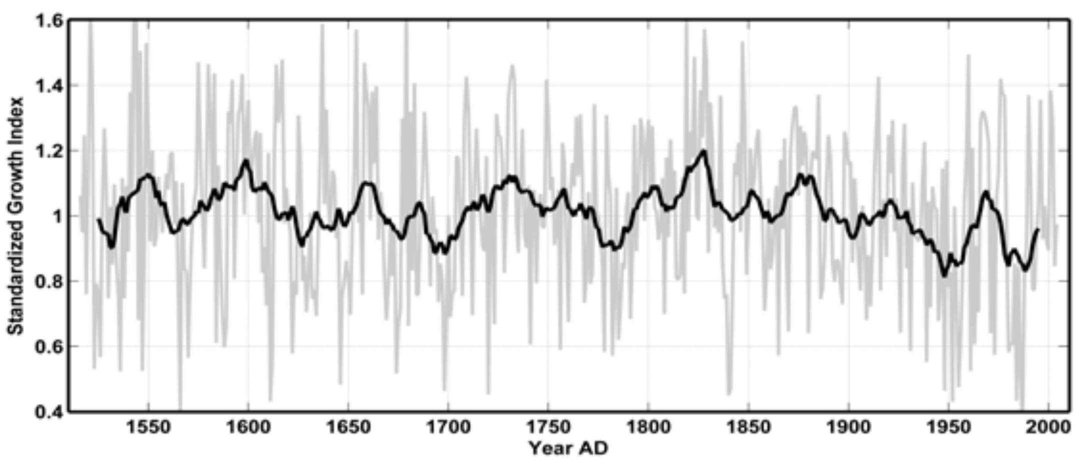
At this time there was also a growing interest in palaeoceanography in SOS, led by James Scourse. Using core samples from the Celtic Sea, the team, including Bill Austin, David Assinder and Dei Huws, was able to map the movement of the Celtic Sea tidal mixing front over the last deglacial transition. These results were to be used later by Mattias Green to validate his global tidal models, which he used for the first predictions of greatly enhanced tidal mixing in the North Atlantic during the Last Glacial Maximum. This period also saw the development of sclerochronology, a new technique for measuring the history of the marine environment (and thus past climate) using growth rings on long-lived bivalve mollusc shells.

This successful collaborations between marine biologists, geologists and geochemists, involving Chris Richardson, James Scourse, Paul Butler and others, resulted in the then longest (489-year) marine chronology based on *Arctica islandica* shells collected from the *Prince Madog* in the Irish Sea (Figure 11). Its success led to EU funding for a Marie Sklodowska Curie Initial Training Network, ARAMACC (Annually Resolved Archives of Marine Climate Change), and saw the *Prince Madog* sample for long-lived molluscs in the North Sea.

Fostering commercial links

The SEACAMS projects and the Smart Efficient Energy Centre (SEEC) use the *Prince Madog* in collaboration with low carbon energy sectors, as new equipment widens options for using the offshore environment as a natural laboratory, for example to study complex fluid dynamics and sediment transport processes.

Figure 11 ***Left*** *The ocean quahog (*Arctica islandica*), a bivalve which can live for 500 years, and which is thus a key species in sclerochronological studies. (Image by David Roberts and Chris Richardson, Bangor University)*
Below *Standardised growth indices for the 489-year chronology. The grey line shows the standardised growth index for each year and the thick black line is a 19-year running mean, used to emphasise decadal variability in the marine environment.*
(Reproduced from Butler et al.*, 2009; © 2009 Elsevier BV)*



Prince Madog's contribution to the marine sciences

Over the past 50 years the *Prince Madog* has provided a key platform for the training of several generations of UK marine scientists, and provided the first sea-going experience for many in the UK marine science community today. Furthermore, marine science students across the globe learn about the key processes in the water column on the basis of the *Prince Madog* work in the Irish Sea and Menai Strait. Closer to home, work on the *Prince Madog* has supported the development of management tools, policies and strategies to sustainably harvest offshore resources and to protect vulnerable marine ecosystems.

The *Madog* has also made an important contribution to the development, testing and validation of new instruments and methodologies for observing the marine environment, from measurements of small-scale turbulence and mixing processes to ones aimed at constraining past climate change. These tried and tested instruments and techniques are now regularly used globally in the pursuance of a greater understanding of planet Earth.

Acknowledgments

Katrien Van Landeghem and Tom Rippeth gratefully acknowledge the contributions by Ivor Rees, John Simpson, Colin Jago, David Mills, Paul Butler, Tim Whitton, Jan Hiddink, Stuart Jenkins, Ian McCarthy and David Roberts.

Key papers which used data collected on the Prince Madog*, mentioned here*

Plate tectonics

Bailey, R.J., J.S. Buckley and R.H. Clarke (1970) A model for the early evolution of the Irish continental margin. *Earth and Planetary Science Letters* **13**, 79–84.

Bailey, R.J. (1975) Sub-Cenozoic geology of the British continental margin (lat 50°N to 57°N) and the reassembly of the North Atlantic late Paleozoic supercontinent. *Geology* **3** (10), 591–4.

Bailey, R.J. (1979) Chapter 2: The continental margin from 50°N to 57°N: its geology and development. In Banner, F.T. *et al.* (eds.) *The North-West European shelf seas: The sea bed and the sea in motion. I: Geology and Sedimentology*, Vol.24, Part A, 11–24.

Clarke, R. H., R.J. Bailey, and D. Taylor-Smith (1971) Seismic reflection profiles of the continental margin west of Ireland. In Delaney, F.M. (Ed.) *ICSU/SCOR Working Party 31 Symposium, Cambridge, 1970: The Geology of the East Atlantic Continental Margin*. 2. *Europe, Rep. No. 70/14, Inst. Geol. Sci*., 67–76.

Tides and mixing

Rippeth, T.P. and J.H. Simpson (1996) The frequency and duration of episodes of complete vertical mixing in the Clyde Sea. *Continental Shelf Research* **16** (7), 933–47.

Simpson, J.H and J.D. Woods (1970). Temperature microstructure in a fresh water thermocline, *Nature*, **226** (5248), 832.

Fisheries research

Beadman, H.A., R.W.G. Caldow, M.J. Kaiser, and R.I. Willows (2003) How to toughen up your mussels: using mussel shell morphological plasticity to reduce predation losses. *Marine Biology* **142**, 487–94.

Beadman, H.A., Kaiser, M.J. *et al.* (2004) Changes in species richness with stocking density of marine bivalves. *Journal of Applied Ecology* **41**, 464–75.

Hiddink, J.G., S. Jennings, M. Sciberras *et al.* (2017) Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. *Proceedings of the National Academy of Sciences of the United States of America* **114** (31), 8301–6.

Kaiser, M.J., K.R. Clarke, H. Hinz, M.C.V. Austen, P.J Somerfield and I. Karakassis (2006) Global analysis of response and recovery of benthic biota to fishing. *Marine Ecology Progress Series* **311**, 1–14.

Lambert, G.I., S. Jennings, M.J. Kaiser, H. Hinz and J.G. Hiddink (2011) Quantification and prediction of the impact of fishing on epifaunal communities. *Marine Ecology Progress Series* **430**, 71–86.

Shelf-sea fronts and biogeochemistry

Rippeth, T.P., N.R. Fisher and J.H. Simpson (2001) The cycle of turbulent dissipation in the presence of tidal straining. *Journal of Physical Oceanography* **30** (8), 2458–471.

Simpson, J.H. and J.R. Hunter (1974) Fronts in Irish Sea, *Nature* **250** (5465), 404–6.

Simpson, J.H. and D. Bowers (1979) Shelf sea fronts' adjustments revealed by satellite IR imagery. *Nature* **280** (5724), 648–51.

Swallow, J.C (1981) Circulation and fronts in continental-shelf seas – introductory remarks. In Swallow, J.C, R.I. Currie, A.E. Gill and J.H. Simpson, *Philosophical Transactions of the Royal Society A: Mathematical Physical and Engineering Sciences* **302** (1472), 513.

Numerical hydrodynamic models

Binding, C.E. and D.G. Bowers (2003) Measuring the salinity of the Clyde Sea from remotely sensed ocean colour. *Estuarine Coastal and Shelf Science* **57** (4), 605–11.

Bowers, D.G., C.E. Binding and K.M. Ellis (2007) Satellite remote sensing of the geographical distribution of suspended particle size in an energetic shelf sea. *Estuarine Coastal and Shelf Science* **73**, 34, 457–66.

Brown, J, L. Fernand, K.J. Horsburgh *et al.* (2001) Paralytic shellfish poisoning on the east coast of the UK in relation to seasonal density-driven circulation. *Journal of Plankton Research* **23** (1), 105–116.

Sherwin, T.J. (1988) Analysis of an internal tide observed on the Malin Shelf, North of Ireland. *Journal of Physical Oceanography* **18** (7), 1035–50.

Simpson, J.H., J. Brown, J. Matthews and G. Allen (1990) Tidal straining, density currents, and stirring in the control of estuarine stratification. *Estuaries* **13** (2), 125–32.

Fostering commercial links

Jago, C.F and M. Robertsn (2018) SEACAMS: Collaboration between marine research and business in Wales. *Ocean Challenge* **22** (2), 30–32.

Monitoring natural marine systems

Hill, A.E., J. Brown and L. Fernand (2008) Thermohaline circulation of shallow tidal seas. *Geophysical Research Letters* **35** (11), L11605.

Simpson, J.H., W.R. Crawford, T.P. Rippeth, A.R. Cambell and J.V.S. Cheok (1996) The vertical structure of turbulent dissipation in shelf seas. *Journal of Physical Oceanography* **26** (8), 1579–90.

Wiles, P.J., T.P. Rippeth, J.H. Simpson *et al.* (2006) A novel technique for measuring the rate of turbulent dissipation in the marine environment. *Geophysical Research Letters* **33** (21), L21608.

Particle settling velocities

Jago, C.F., S.E. Jones, P. Sykes and T.P. Rippeth (2006) Temporal variation of suspended particulate matter and turbulence in a high energy, tide-stirred, coastal sea: relative contributions of resuspension and disaggregation. *Continental Shelf Research* **26**, 2019–28.

Jago C.F., G. Kennaway, G. Novarino and S.E. Jones (2007) Size and settling velocity of suspended flocs during a *Phaeocystis* bloom in the tidally-stirred Irish Sea, NW European shelf. *Marine Ecology Progress Series* **345**, 51–62.

Palaeoceanography and sclerochronology

Butler, P.G, J.D. Scourse, C.A. Richardson, A.D. Wanamaker, C.L. Bryant and J. Bennell (2009) Continuous marine radiocarbon reservoir calibration and the 13C Suess effect in the Irish Sea: Results from the first multi-centennial shell-based marine master chronology. *Earth and Planetary Science Letters*, **279** (3–4), 230–41.

Butler P.G., C.A. Richardson, J.D. Scourse, A.D. Wanamaker Jr, T.M. Shammon and J.D. Bennell (2010) Marine climate in the Irish Sea: analysis of a 489-year marine master chronology derived from growth increments in the shell of the clam *Arctica islandica*. *Quaternary Science Reviews* **29**, 1614–32.

Green, J.A.M., C.L. Green, G.R. Bigg, *et al.* (2009) Tidal mixing and the Meridional Overturning Circulation from the Last Glacial Maximum. *Geophysical Research Letters* **36**, L15603.

Richardson, C.A. (2001) Molluscs as archives of environmental change. In: *Oceanography and Marine Biology* **39**, 103–164.

Scourse, J., W. Austin, B.T. Long, D.J. Assinder and D. Huws (2002) Holocene evolution of seasonal stratification in the Celtic Sea: Refined age model, mixing depths and foraminiferal stratigraphy. *Marine Geology* **191**, 119–45.

Katrien Van Landeghem is a Senior Lecturer in Marine Geology and Geophysics at the Bangor University School of Ocean Sciences. She specialises in sea-bed morphodynamics. k.v.landeghem@bangor.ac.uk

Tom Rippeth is the established Chair in Physical Oceanography at the Bangor University School of Ocean Sciences. He specialises in turbulence and mixing in the marine environment. T.P.Rippeth@bangor.ac.uk

Two ships and a lady

... inspired by Mrs Brassey's A Voyage in the Sunbeam

John Phillips

On 6 July 1876, six weeks after HMS *Challenger* returned to England from her three-and-a-half-year voyage round the world, a private yacht sailed from Cowes on the Isle of Wight to begin a circumnavigation whose style would be very different. This enterprise was probably the first of its kind.

The yacht *Sunbeam* RYS* was a three-masted topsail schooner with auxiliary steam power. Her dimensions are shown in the Table, together with those of HMS *Challenger* for comparison. She was owned by Thomas Brassey MP, a naval enthusiast and himself the holder of a Master's Ticket. Also on board for this voyage were his wife Anna (usually known as Annie), their three small daughters and thirteen-year-old son, five male friends (including a surgeon), the sailing master and a crew of twenty-two, and nine servants (four stewards, two cooks, a nurse, a lady's maid and a stewardess). A total of forty-three souls, plus 'two dogs, three birds and a charming Persian kitten belonging to the baby'. They all travelled in spacious luxury, particularly when compared with the cramped quarters available to the 233 men who had sailed with the *Challenger*.

Undoubtedly the motivation behind *Sunbeam*'s voyage was her owner's love of the sea and sailing. It also gave him the opportunity to pursue his business interests, particularly in Hong Kong and the Argentine. But there was a more pressing reason for the series of lengthy cruises in distant waters undertaken by the couple between 1862 and 1887: to escape the British winter for the sake of Annie's delicate health.

The Brasseys were wealthy and well connected; they were welcomed with offers of hospitality and entertainment at almost every port they visited. Annie, who celebrated her 37th birthday at Punta Arenas in Patagonia, was no mere socialite: between formal occasions and shopping expeditions she swam in the sea, rode and scrambled through the landscape, however rugged, and regardless of the climate; when back on board she dresses for dinner and awaits the dinner bell. She was a competent horsewoman and a keen photographer. All this did not prevent her from keeping a detailed diary on several of their voyages, including this one, whose

Sunbeam ***RYS at anchor, 'dressed overall'. The funnel and masts symbolise the transition from sail to steam during the 19th century.*** *(Beken of Cowes)*

record was published in book form soon after their return.

Despite a constitution that had never been robust, Annie gamely withstood many hardships, including frequent bouts of sea-sickness. She emerges as a tireless observer with a restless appetite for travel. This combination of fortitude and curiosity is illustrated by her reaction to an encounter with a plague of locusts in the Argentine: '*They got into one's hair and clothes, and gave one the creeps all over ... I have, however, secured some fine specimens for any one who is curious about them*.' There were moments of real danger: only ten days into the voyage one of her daughters was almost washed overboard, and, just nine days before it ended, *Sunbeam* almost ran aground near Sagres in Portugal. Storm damage, fire at sea, a case of smallpox on board – at one point the vessel was mistakenly reported as lost with all hands!

The voyage did include some long, relatively peaceful passages, during which Annie passed the time in reading. *Sunbeam* carried a library of 700 books, probably as many as there were on *Challenger*. Scattered references to Buckland, Cook, Dampier, Darwin and Humboldt are suggestive of its scope. Annie rarely admits to *ennui*, but in Penang she wrote *'The tropical vegetation is even more striking here, but, alas! it is already losing its novelty to us. Those were indeed pleasant days when everything was new and strange; it seems now almost as if years, not months, had gone past since we entered these latitudes.'* If there were occasions when her enthusiasm waned, it would be hard to imagine that she was ever less than stoical.

Sunbeam saw many of the ports that *Challenger* had visited a few years earlier, including Funchal, Valparaiso and Yokohama, but their tracks differed in several important respects, the most obvious

***The dimensions of* Sunbeam *compared with those of* Challenger**

	Sunbeam RYS	HMS *Challenger*
Length overall*	160 ft	225 ft
Beam	27 ft 6 ins	40 ft 6 ins
Draught	13 ft 9 ins	18 ft
Displacement	531 tons	2137 tons

*Approximately length of hull; excludes bowsprit and jib-boom.

* The prestigious Royal Yacht Squadron.

being that, unlike the *Challenger*, she sailed westabout, by-passing North America, Australasia and the Cape. Instead she followed, more or less, *Challenger*'s homeword track in reverse as far as Hong Kong before crossing the China Sea, the Bay of Bengal and the Arabian Sea, returning to England via the Suez Canal (opened in 1869) and the Mediterranean. Her outward track across the Atlantic was more like that of HMS *Beagle* in 1832, whose primary object had been to survey the coasts of South America before continuing westward round the world.

Sunbeam's cruise had been well planned, given the itinerary the Brasseys had chosen to follow. It made full use of the Trade Winds in both hemispheres and was timed to avoid the Asian monsoons and the typhoon season in the western Pacific. The heaviest weather was encountered in the North Pacific on passage from Hawaii to Japan in mid winter. *Sunbeam* reached her highest southern latitude (54° S) in the Straits of Magellan early in the southern spring, and was fortunate to transit from Atlantic to Pacific through their restricted and often storm-swept waters in only three days, albeit under steam. Taking her outward passage from the English Channel to Rio de Janeiro as an example, the *Sunbeam* made good time: 35 days compared with the 45–60 days for commercial sailing vessels quoted in *Ocean Passages for the World,** and equivalent to an average speed of 7 knots as against roughly 4 knots. This was at least partly due to the availability of steam power: although it was only used for about one fifth of the distance, it made her largely independent of the vagary of the winds. The *Beagle*, a significantly smaller vessel, had spent 52 days at sea between Plymouth and Rio, in winter.

Challenger took more than three times as long to sail a little less than twice the distance covered by *Sunbeam*, reflecting the length of time she spent in dredging and sounding. The average speeds of *Sunbeam* and *Challenger* while at sea were about 7 and 4 knots respectively. Under steam alone, *Challenger* could make almost 11 knots, whereas *Sunbeam*'s cruising speed in fair weather was 8 knots and her maximum speed just over 10 knots; in strong winds her sails alone could drive her up to 15 knots. *Challenger*'s performance under sail was probably not much different, although with a lower maximum speed of around 12 knots, her spars having been reduced for ease of handling by a crew whose number was limited to make room for the scientists and their gear.

*Admiralty Hydrographic Department, 1923.

Thomas Brassey's study aboard **Sunbeam** *(Beken of Cowes)*

The relative merits of steam and sail were still a subject of debate at the time. *Sunbeam*'s engine developed 350 horsepower, whereas *Challenger*'s was rated at 1450. *Sunbeam* had a range of up to 3840 nautical miles under power, consuming eighty tons of coal at the rate of four tons per day, but *Challenger* normally carried only enough coal for 2880 nautical miles of steaming at 5 knots (equivalent to 24 days). Her engine was mainly used to keep station and to assist manoeuvering in harbour or occasional emergencies, *Sunbeam*'s to maintain her schedule in calms and light winds. In these different ways, steam was essential to the success of both voyages.

On the other hand, both vessels spent around 40% of their time at anchor, either in port or lying off the coast of foreign lands. In addition to routine victualling and coaling, this time was used for social and sightseeing activities by the Brasseys, but mainly for repairs and exploration ashore for *Challenger* and her scientists. Shared circumstances, such as port visits and the availability of steam, were exploited to serve the separate aims of the two enterprises.

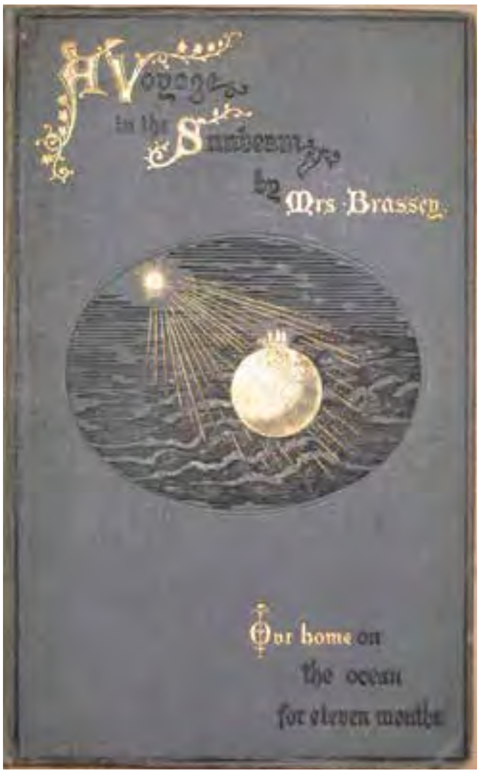
Brassey was determined to make as much of the voyage as possible under sail. So the following passage is a rare expression of Annie's independent opinion of the enterprise and gives a hint of

Lady Brassey in 1883 (National Portrait Gallery, London) her spirited nature: *'[Tom] is anxious to do* the whole voyage *under sail, and we are therefore taking very little coal on board, in order to be in the best trim. If we do not pick up a wind, however, there is no knowing how long we may lollop about. I suppose till we are short of water and fresh provisions, when the fires will be lighted and we shall steam away to the nearest island – uninhabited, we will hope, or at any rate peopled by friendly natives, which is rather the exception than the rule in the south-east corner of the Low [Tuamotu] Archipelago'*. Brassey largely succeeded: most of the voyage was made under sail, 20 517 nautical miles, or 58% in terms of distance.

After eleven months away, the Brasseys arrived back at Cowes on 26 May 1877, one year after the return of the *Challenger*; Mrs Brassey's account of the enterprise – *A Voyage in the Sunbeam* – was published less than a year later. It was based on a series of long letters sent home to her father, so the arrangement is chronological and without discussion of the reasons for the voyage or the background of its characters. She was a diligent diarist and hardly a day went by unrecorded. The style is clear and lively; she describes her experiences with enthusiasm aided by some gentle irony and a lot of implicit fortitude. Her social attitudes seem to have been essentially conventional, consonant with her background as an upper-class lady of the time. She was considerate toward the ordinary people of the countries they visited, although not without a degree of unintended condescension. The Brasseys' hosts were usually their social equals, so they often appear by name only, without further explanation, in the discreet Victorian manner. On board the *Sunbeam* things were naturally rather different. In that less formal environment her concerns were mainly domestic as she focussed on running the 'household' in the role of wife and mother. The book's subtitle – *Our home on the ocean for eleven months* – is a clear sign of the importance of this side of the story.

A detailed folding chart showing *Sunbeam*'s track around the world is placed at the front of the book, which contains seven other coloured maps. It is illustrated with 118 wood engravings, nine of them full page.* *Sunbeam*'s log is summarised in tables at the back of the book, followed by a list of all those on board.

*Details refer to the first edition.



A Voyage in the Sunbeam
by Mrs Brassey
Published by Longmans
in March 1878,
price one guinea

The only scientific measurements taken during the voyage were daily air and sea-surface temperatures, which are displayed in graphical form at the end of the book. In a letter to *The Times*, reprinted as an appendix, Thomas Brassey provides a more technical description of his yacht and her performance, together with a brief summary of the voyage from a mariner's point of view, showing some justifiable pride in the achievement.

HMS *Challenger* is never mentioned in the text, but there is an indirect link between her and the *Sunbeam*. Lord Brassey (as he became in 1881) was Governor of Victoria from 1895 to 1900, based in Melbourne, where John James Wild, the artist and secretary of the *Challenger* expedition, had been living since 1881. In a relatively small community like Melbourne at the end of the 19th century it seems unlikely that the sea-going Governor would have been unaware of the presence of a *Challenger* veteran in the city. Wild attended several official levées at Government House, where he would have been presented, albeit briefly, to Lord Brassey. At the very least, they shook hands.

Sadly Annie was not there to see this. Lady Brassey had died of malaria on board *Sunbeam* in 1887 during a voyage homeward from Australia, aged 47. She was buried at sea.

A Voyage in the Sunbeam was very popular with the reading public. On 10 April 1878, *The Times* carried a lengthy and effusive review which was echoed in the provincial press. It went through many printings and remained continuously in print for more than twenty years. Translations appeared in France (1878), Germany (1879) and in several other countries. By 1895 it was available in five English editions, ranging in price from two shillings to one guinea. More than a century after first publication it was reprinted in paperback. Not so long ago hardback copies were widely available in secondhand bookshops; indeed it was regarded as something of a 'dog', as such common titles were known in the trade. Today decent hardback copies published later in the 19th century can still be had for under a tenner, alongside overpriced print-on-demand versions. And it remains a jolly good read!

Further Reading

Drummond, M. (1979) *Salt-Water Palaces,* Debrett's Peerage Ltd.

Micklewright, N. (2003) *A Victorian Traveler in the Middle East: the photography and travel writing of Annie, Lady Brassey*, Ashgate Publishing.

Ryan, J.R. (2006) 'Our Home on the Ocean': Lady Brassey and the voyages of the *Sunbeam*, 1874–1887. *Journal of Historical Geography* **32** (3), 579–604.

John Phillips is a marine bibliophile.
periplus@btconnect.com