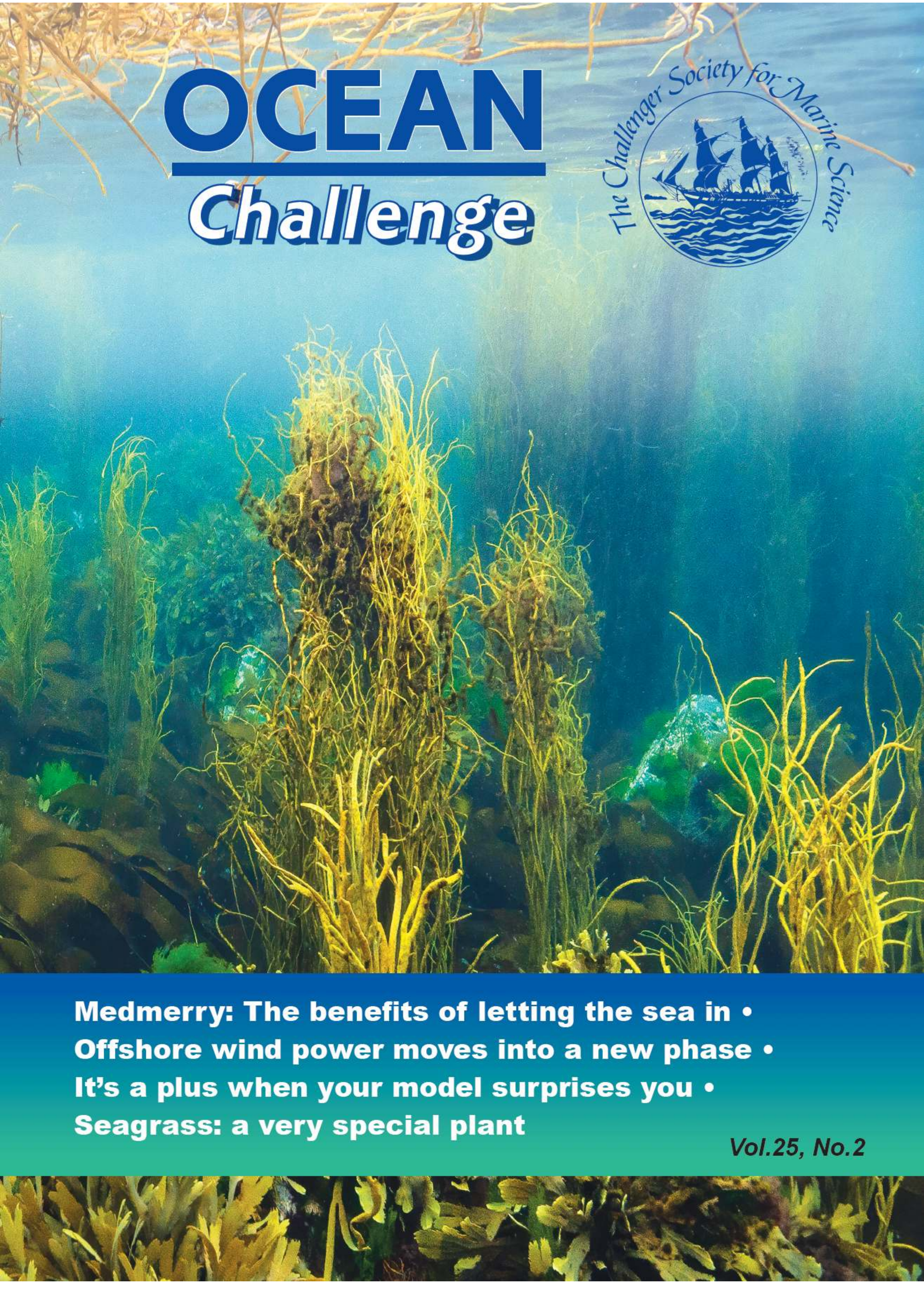
OCEAN Challenge

The Challenger Society for Marine Science



Medmerry: The benefits of letting the sea in •
Offshore wind power moves into a new phase •
It's a plus when your model surprises you •
Seagrass: a very special plant

Vol.25, No.2

OCEAN Challenge

The Challenger Society for Marine Science

Volume 25, No.2, 2019
(published 2021)

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

SCOPE AND AIMS

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

NB *Ocean Challenge* can be downloaded from the Challenger Society website free of charge, but members can opt to receive printed copies.

For more information about the Society, or for queries concerning individual or library subscriptions to *Ocean Challenge*, please see the Challenger Society website (**www.challenger-society.org.uk**)

INDUSTRIAL CORPORATE MEMBERSHIP

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

ADVERTISING

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

AVAILABILITY OF BACK ISSUES OF OCEAN CHALLENGE

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

ISSN 0959-0161 Printed by Halstan Printing Group

OCEAN Challenge

The Magazine of the Challenger Society for Marine Science

SOME INFORMATION ABOUT THE CHALLENGER SOCIETY

The Society's objectives are:

To advance the study of marine science through research and education

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

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

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

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

Holding regular scientific meetings covering all aspects of marine science

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

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

Membership provides the following benefits:

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

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

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

MEMBERSHIP SUBSCRIPTIONS

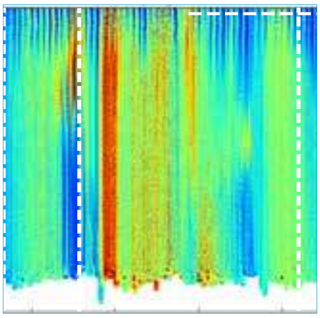
The annual subscription is £50 (£25 for students in the UK only). If you would like to join the Society or obtain further information, see the website (given above).

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 'Guidance for Authors') please contact the Editor:

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

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



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

The cover and heading graphics were designed by Ann Aldred.

Cover photo:
A seaweed meadow in the Inner Hebrides, Scotland © Alex Mustard

CONTENTS

***Stop Press**: See p.40 for information about*
Challenger 150: The Challenger Society Conference 2022

Challenger Society Conference 2021 Virtual Sessions

For more details go to the Challenger Society website https://www.challenger-society.org.uk/Virtual_Conference_2021

Awarding of Challenger Fellowships, 9 September

The new Fellowships were announced by Challenger Society President, Ros Rickaby, who hosted the meeting. The Woodward Fellowship was awarded to **Robyn Tuerena** (Scottish Association for Marine Science) who uses nutrient concentrations, stable isotopes and stochiometric tools to better understand the role of carbon and nitrogen cycles in an amazingly wide range of systems and environments. **Hugh Venables** (British Antarctic Survey) was praised for his leadership in work spanning process-driven numerical modelling and the designing and targeting of observational campaigns; Hugh manages the water-sampling aspects of the Rothera Time Series (RaTS). **Alex Brearley** (also BAS) was awarded his fellowship for being one of our most promising early-career physical oceanographers. His particular research interest is the mixing of warm waters on polar ocean shelves and its impact on the stability of the cryosphere around both Antarctica and Greenland. **Rob Hall** (University of East Anglia) received his award for impressive leadership of the development of a new Shelf Sea Dynamics module and his novel approach to using ocean gliders to understand internal tides, and in many other areas, such as habitat modelling and oil spill risks.

Meeting of the Ocean Modelling Special Interest Group, 9 September

By tradition, an Ocean Modelling meeting is held alongside the Challenger Conference. The meeting went really well: we had >60 people on both afternoons, with some dipping in or out, and there were lots of new faces too, which was good to see. We had 30 talks, slightly fewer than normal, but this helped to make the virtual format less intense. Subjects ranged from long-term effects of the 18.6-year lunar nodal cycle, through eddies being influenced by wind forcing and on to dispersal and connectivity of fish populations and larvae. We also had an update on planned NEMO developments and the use of relocatable workflows to make NEMO more portable.

Dave Munday danday@bas.ac.uk

Equality, Diversity and Inclusivity in the Marine Sciences, 5–6 October

Coinciding with MASTS's Annual Science Meeting, this event began with stimulating and thought-provoking discussions focussing on delegates' experiences with different diversity initiatives (particularly those related to the polar sciences, an area recognised as being historically dominated by straight white men), and presenting an overview of diversity within the Society's membership.

The second part of the event was a more typical conference session, presenting case studies of good practice, such as rethinking diversity within ICES, engaging undergraduates through discussions about protected characteristics, and virtual field courses with ThingLink. The meeting concluded with a summary of 'Unlearning Racism in the Geosciences' (https://urgeoscience.org/).

Engagement of over 30 participants in each session was an extremely encouraging indicator that a cultural shift is beginning within the discipline, and there are some excellent initiatives and networks that can be used as examples of how to promote a wider, more inclusive voice within it. The journey to an equal, diverse and inclusive future within marine science requires everyone to be a part, and these events have really helped to showcase that such a journey has started and is moving in the right direction.

Anna McGregor

For Panel Discussion see: https://drive.google.com/drive/folders/1ewC7YWHHqqVTyH-dYMY6nHG0aRgA-dL0?usp=sharing

For Good Practice see: https://drive.google.com/file/d/1usbBmGNoH2u3to-Oo7a9WhPi0acDJnCj/view?usp=sharing

Science for the UN Decade of the Oceans (2020–2021), 18 November

In an event organised by Chelsey Baker, Judith Wolf and Anna McGregor, early-career researchers came together to talk about their work in the context of the themes of the UN Decade of the Ocean, and consider which topics in marine science should be developed with most urgency – which should dominate marine science, and perhaps their careers, over the next ten years.

The results of a poll showed that most of those who attended the event were not yet involved in the UN Decade of the Ocean but wanted to be, so here are some pointers if you want to get involved.

- The UN Decade team (oceandecade@unesco.org) are very helpful if you have a preliminary idea that needs development. You are advised to put an informative phrase in the Subject box of the email.
- Endorsement by the programme does not confer any funding; addressing this should be a priority of the wider community.
- Look at the recent call for actions and programmes: https://ioc.unesco.org/news/ocean-decade-launches-new-call-decade-actions-no-022021

The full report of this meeting can be found on the Society's website https://challenger-society.org.uk/Decade_of_the_Ocean_Event. Discussion from the meeting fed into a Challenger Council document produced for a G7 Ocean Decade Navigation Plan Workshop on 9 Dec: https://www.g7fsoi.org/event/g7-ocean-decade-navigation-plan-workshop/

See the website for the final Virtual Conference Session, 'Defining the Challenger Society's Role in Marine Science' on 9 Dec 2021

ECSA is half a century old!

Martin Wilkinson

ECSA is the Estuarine and Coastal Sciences Association. It was the brainchild of three young zoology academics at Bristol University, Andrew Dorey, Colin Little and Richard S.K. Barnes. In April 1968 they started joint research on an oligohaline lagoon, the Swanpool, at Falmouth in Cornwall. It became apparent to them that the brackish-water environment was a neglected scientific area lying between the provinces of the two big societies, the Marine Biological Association and the Freshwater Biological Association. With the help of Ronald Bassindale, a senior lecturer at Bristol who was well known for participation in the pre-war landmark studies of the Tees, Thames, Tay and Mersey estuaries, and of Jim Green from Westfield College who had just written *The Biology of Estuarine Animals,* they set about forming a brackish-water association to plug the gap.

The Estuarine and Brackish-Water Biological Association was launched at a one-day symposium at the Zoological Society of London on 13 October 1971. The programme of six invited papers addressed physical and chemical as well as biological features of the estuarine environment and were published as a symposium volume.* The attendance was massive with up to 300 people from various scientific disciplines connected with brackish water, demonstrating a need for a multidisciplinary society. This resulted in a name change at its first AGM in 1972 to Estuarine and Brackish-Water Sciences Association (EBSA). In 1989 the name was again changed, this time to Estuarine and Coastal Sciences Association (ECSA), reflecting the wider membership and the inter-relationship of coastal and estuarine areas in management.

From the start it was felt that we needed a specialised journal. Academic Press was considering launching a new journal, *Coastal Marine Science*. They were persuaded to change its title and broaden its remit, with EBSA nominating one of the editors, and so *Estuarine and Coastal Marine Science* was born. Challenger Society members will now know this better as *Estuarine, Coastal and Shelf Science*.

EBSA rapidly developed on many fronts. Initially its activity was centred on the British Isles, with a regular series of local meetings covering multidisciplinary overviews of different estuarine areas. General scientific conferences were also held, sometimes in association with other societies, including Challenger. Although EBSA was founded by zoologists, they were interested in the application of their pure knowledge in environmental management so membership included staffs of regulatory bodies and consultancies. Low-cost residential training courses were organised to help practitioners. These ranged from biological taxonomic workshops, to help managers identify organisms, to physical and chemical ones. Over the years workshops have broadened out to cover discussion sessions on coastal and estuarine management, sometimes held in association with overseas international conferences.

While ECSA is still largely based in Britain, over half the membership is overseas and our programme of large scientific meetings has moved around the world, becoming a two-yearly event which can attract up to 300 participants. We are only able to do this because of collaboration with the publishers, Elsevier, for which we are really grateful. ECSA organises the scientific programme while Elsevier organises the physical and financial side of the conferences, to mutual benefit. In the first 50 years, EBSA/ECSA have held 182 conferences, meetings and workshops. In all the things ECSA does we have had tremendous support from a group of long-serving Council members and officials who have worked really hard for the Association.

In connection with the success of our large international conferences we should especially mention the star Victor de Jonge from the Netherlands, who was our Meetings Secretary for nearly 30 years and was the architect of our meeting arrangements. Sadly, Victor died suddenly from a heart attack in 2020 and will be sorely missed both for his support and his personality. His obituary can be read in the journal he edited, *Ocean and Coastal Management,* **194** (2020), article no. 105308.

Victor de Jonge

ECSA supports attendance at our conferences through a grants scheme for student members and early-career workers. Recently we have expanded this scheme to include childcare costs to facilitate attendance by those who might otherwise be prevented by family considerations.

Publication has been important. As well as the journal, ECSA became involved with the Linnean Society in recruiting, editing and publishing the many identification guides that make up *Synopses of the British Fauna*. In the 1980s, we published a series of three estuarine methods handbooks which were very successful and are now being updated. The proceedings of many of our larger meetings have been published either as dedicated volumes or in special issues of journals. Contact with members is maintained through a regular email news sheet and an occasional *ECSA Bulletin* which has now gone entirely online.

A recent topical development is support from ECSA for REACH (Restoring Estuarine and Coastal Habitats), an endeavour promoted by Roger Proudfoot of the Environment Agency. REACH started in 2019 with a symposium in London, supported by ECSA and other organisations, and with the establishment of a dedicated REACH area on the ECSA website. REACH now continues with special sessions at the annual Coastal Futures conference in London.

To celebrate ECSA's 50th anniversary it seemed appropriate to publish a volume similar to that which was produced after the initial meeting. The book will review how the various disciplines covered by ECSA have progressed in the last 50 years, and will look forward to what might happen in the future. Sixteen invited chapters have been written covering topical areas including carbon storage, coastal erosion, sea-level rise, pollution problems, non-native species and management approaches. The book is edited by our President, Sally Little, and President Elect, John Humphreys, and is entitled *Challenges in Estuarine and Coastal Science* (see p.21). The chapters in the 50th anniversary volume will be presented by speakers at a celebratory meeting in London in February 2022, which will precede the launch of the publication to the scientific community. Details will be announced on the ECSA website https://ecsa.international where you can also read about the benefits of membership of ECSA.

Martin Wilkinson Treasurer of ECSA
Heriot-Watt University

*Barnes, R.S.K and J. Green (1972) *The Estuarine Environment*. Applied Science Publishers, London. 133pp.

Stepping Stones to a successful career

Reasons to apply for a Challenger Society Early Career Bursary

The Stepping Stones Bursary scheme is designed to support career development for members of the UK marine science research community currently without employment (for how to apply, see p.10). Below, a recent beneficiary of the Award explains how she used her Bursary to improve her chances of obtaining a fellowship.

Developing a fellowship proposal during Lockdown

Laura Hepburn

I applied for the Stepping Stones Bursary in 2019 to support the development of a fellowship proposal to initiate my independent research career. The Bursary has been fundamental in enabling me to establish the collaborative network that will underpin this exciting next stage in my career. Although the unexpected arrival of a global pandemic stopped me from networking in person, as I had originally planned, the relocation of this networking activity to online ultimately broadened my network on an international scale, by allowing me to virtually attend conferences that would otherwise have been inaccessible.

Left *One of the Southern Ocean vent systems that inspired my research path (This is a photomosaic of images collected by the ROV* Isis *during the JC042 expedition and compiled by Leigh Marsh)*

Below *Extracting porewater from a marine sediment core during the 2021 NIOZ MetalGate Expedition, using the 'Rhizons' method which filters and collects the porewater in syringes for later analysis. (Photo: Amber Annett)*

The evolution of my fellowship project

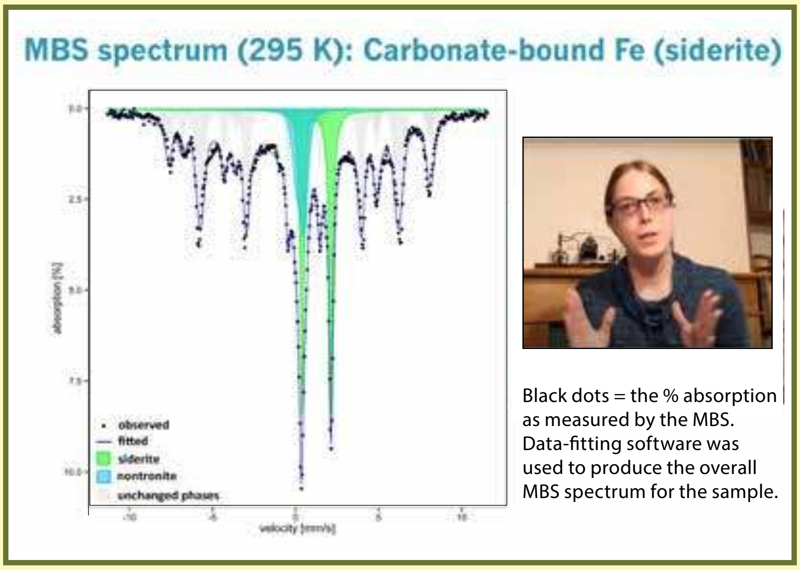
My fascination with iron began during my Ph.D at the University of Southampton. Here, I had the fantastic opportunity to study some of the newly discovered Southern Ocean hydrothermal vent systems, and I became particularly enthralled with the way that iron, and other forms of chemical energy, sustain beautiful and bizarre life-forms in some of the most inhospitable places on Earth. This 'iron-fuelled' research interest led me to a postdoc position at the University of Stirling, where my deep-sea biogeochemistry research career path merged with one in quantum physics and Mössbauer Spectroscopy.

Mössbauer Spectroscopy (MBS) is a very versatile technique which is widely used across the physical, medical and engineering disciplines, but it is often overlooked (and even considered to be something of a 'dark art') within the geosciences. In brief, MBS measures minute changes to the nuclear structure of iron atoms, during the absorption and re-emission of gamma rays. MBS is specific to iron, and it largely 'ignores' interference from all other elements, which explains my interest in the technique. When paired with a synchrotron (i.e. a circular particle accelerator), which produces high energy radiation, MBS can identify the iron mineralogy of environmental colloids (0.02–0.4 μm diameter) and nanoparticles (< 0.1 μm diameter) – this is a brand new method developed by Christian Schröder and Deborah Wood (University of Stirling) within the last two years.

Iron colloids and nanoparticles are a major source of iron to the ocean, supplied by rivers, hydrothermal vents, atmospheric dust, glacial meltwater and marine sediments. It is important to reliably characterise the type of iron that is released by these major sources, since the specific mineralogy of the iron colloids and nanoparticles determines their reactivity in the environment, i.e. the ease with which this iron is dissolved, remineralised, scavenged, stabilised by organic ligands, or otherwise biologically utilised. In particular, better knowledge of the exact compositions of these particles will improve our understanding of the mechanisms by which iron interacts with other elements, such as carbon, to regulate global climate.

The scientific rationale behind my proposed fellowship project is to combine the newly developed synchrotron / Mössbauer Spectroscopy method with radium isotopes (a valuable tracer of porewater discharge from marine sediments*) to quantify the types of iron that are released into the ocean from sediments in different marine environments during diagenesis (the chemical and physical weathering of sediments after deposition), and the rate at which release occurs. My fellowship proposal combines aspects of my previous research experience (working with marine sediments and MBS) with

*Radium isoptopes are produced by decay of thorium isotopes in sediment.



Black dots = the % absorption as measured by the MBS. Data-fitting software was used to produce the overall MBS spectrum for the sample.

Sharing research virtually

A 'Zoom' screenshot of Laura sharing her research during the virtual Goldschmidt Conference in 2020. Here, she is showing that each iron mineral has its own unique Mössbauer spectrum 'fingerprint', so can be easily identified. In this slide, the presence of siderite (green spectrum) and nontronite (blue spectrum) are highlighted against other phases that include a mixture of goethite and magnetite – each of which are individually identified within the overall Mössbauer spectrum.

training in new techniques. These include using radium isotopes to measure marine sediment fluxes with Amber Annett (University of Southampton) and, with Christian Schröder and Alexandr Chumakov, using a combined synchrotron–Mössbauer technique at the European Synchrotron Radiation Facility in Grenoble (France) to identify the type of iron that is released from marine sediments. With the tremendous support of all of my collaborators, I have just submitted an application for a Marie Skłodowska Curie Action Postdoctoral Fellowship.

How I used my Bursary

I have used most of the award to cover the cost of accommodation and train travel between Stirling, Edinburgh and Southampton to set up the academic collaborations and to visit the updated laboratory facilities and equipment that I will require to undertake the Fellowship. Originally, I had also hoped to conduct some preliminary analyses to support the proposal. However, during Lockdown (and beyond) when it became clear that laboratory access for a visiting research scientist was going to prove challenging within the time-frame, I repurposed the remaining Stepping Stone funds towards registration at virtual, international conferences including Goldschmidt, CommOCEAN, and the annual science meetings of the Marine Alliance for Science and Technology for Scotland and the UK Polar Network. It was through the networking opportunities at these meetings that I met Amber and Alexandr, the collaborators who have been so fundamental to getting this project up and running. Amber also collected the samples for this Fellowship proposal on my behalf, during the NIOZ MetalGate expedition earlier in 2021. Part of the Bursary was also used to contribute towards the consumables required for sample collection, storage and transport.

Why I would recommend the Stepping Stones Bursary

I wholeheartedly recommend the Stepping Stones Bursary to other early-career researchers, particularly those who are looking to explore new research paths, for the opportunity that it provides to increase your reputation and visibility as a researcher in your chosen field.

One of the major advantages of the Bursary is its flexibility – it can be used for virtually any activity that will help you to further your career – and this has been incredibly useful during the periods of Lockdown that we have all experienced over the last few years. Establishing a successful funding track-record is a crucial, yet challenging, stage of any early research career. The Stepping Stones Bursary has been a vital first step in establishing this track record for me. From a personal perspective, it has also meant a lot to have the support of the Society behind me during a period of career uncertainty due to Covid-19, which has been hard for us all, but particularly so for early-career researchers.

Further reading

Hepburn, L.E., I.B. Butler, A. Boyce and C. Schröder (2020). The use of operationally-defined sequential Fe extraction methods for mineralogical applications: A cautionary tale from Mössbauer spectroscopy. *Chemical Geology* **543**, 119584. doi: 10.1016/j.chemgeo.2020.119584

Marsh, L., J.T. Copley, and 6 others (2012) Microdistribution of faunal assemblages at deep-sea hydrothermal vents in the Southern Ocean. *PLoS ONE* **7** (10), e48348. doi: 10.1371/journal.pone.0048348

***Laura alongside the ROV* Isis**

Laura is currently working as a National STEM Ambassador. In one of her recent projects she wrote an animated children's story about an iron colloid called Fergus for National Bog Day 2021. She is intending to apply for a Leverhulme Early Career Fellowship (amongst others) in 2022.

leh1g09@soton.ac.uk

The impact of Covid-19 on UK marine scientists

Katharine Hendry and David N. Thomas

The Covid-19 pandemic has impacted millions of people worldwide, with effects ranging from the direct consequences of the illness, including lasting and life-changing effects of 'long Covid', to the unprecedented disruption of working lives. There has been a major upheaval in scientific research, with increasing evidence of harsher impacts on some groups, often those under-represented relative to others.

The shock to marine science has been severe, with significant disruption to sea-going research across all disciplines and sectors. To fully understand the impacts on the UK marine science community, and establish mitigation strategies for both the short term and the longer term, we need more than anecdotal evidence. Without quantitative data and recorded experiences we will not be able to plan ahead so as to avoid significant hindrance to our work, should a comparable situation arise again. Furthermore, any post-Covid strategies need to be framed in the context of other concurrent change: the marine science community – nationally and internationally – is currently undergoing a (re)evaluation of how and why we do our research, especially in the light of improving equality, inclusivity and diversity, the UN Decade of Ocean Science for Sustainable Development, and global targets for net zero greenhouse gas emissions (e.g. the Net Zero Oceanographic Capability NZOC project*).

In October 2020, representatives of the marine science community, through the NOCA† Steering Board, initiated a survey of the UK marine science community to assess the impact of Covid-19. A wide range of stakeholders (commercial, government agency, military, Higher Education Institutes (HEIs) and Research Councils) have been impacted, with both UK and international projects badly affected.

Fieldwork As expected, there were major impacts through changes to fieldwork plans, with 84% of those surveyed reporting cancellations or postponements. Serious concerns were expressed over the uncertainty of fieldwork plans in the future. Both shore-based and laboratory work has been hit hard, with over 90% of respondents reporting moderate or severe impacts due to the pandemic, including challenges relating to sample-processing, welfare of live organisms, experiments, and access to technical resources. There was of course a formidable increase in the administrative burden relating to health and safety. The survey results give a relative estimate of the huge impact of the pandemic on the marine science community, with major implications in particular for the career progression of Early Career Researchers (ECRs) and those on Fixed-Term Appointments (FTAs).

Funding Over half of the respondents who planned to write grant proposals felt that they were negatively impacted by the pandemic. Several reported the loss of small but valuable funding 'pots' due to institutional funding shortfalls. These funding difficulties, and loss of other opportunities, have clear implications not only for the career progression of individual scientists, but also at an organisational level through impacts on future decision-making.

Networking More than half of the respondents attended fewer conferences, and two-thirds reported 'getting less out of' the conferences that they did attend. In particular, networking and informal meetings, which are so important for research overall but also to the development of individuals' careers, were, and remain, incredibly challenging. There were mixed feelings expressed by those answering the survey regarding online conferences: the positive comments related to reduced cost and travel, and enhanced accessibility, and were expressed most strongly by those with caring duties and disabilities. The negative comments (outweighing the positive) related to complications with time zones, connectivity issues, and lack of motivation.

Teaching and training Respondents in universities were impacted by substantially increased teaching loads, although the increase in administrative load was felt uniformly across sectors. About one-third of the respondents concerned about impacts on education reported that marine science field teaching for undergraduate and postgraduate students was cancelled or postponed. Many more reported cancelled or postponed face-to-face classroom teaching. There have been impacts on training opportunities across sectors including volunteers and technicians, as well as a drop in mentoring and supervision of ECRs.

Mental health There has been a clear negative impact on the mental health of the marine science community. A quarter of respondents reported a decline in mental health, and over half felt more isolated than prior to the pandemic. The negative impacts on mental health, productivity and isolation were reported most strongly by ECRs, women, scientists with disabilities, and those in full-time employment and/or on FTAs. Starkly, every FTA employee (n = 46) who responded to the survey felt more isolated from colleagues and were more likely to feel isolated from friends and family.

Lessons for the future

Some important messages have come out of the survey, particularly with respect to supporting ECRs and staff on FTAs, leading to some recommendations that may enhance the working environment for marine scientists in a post-pandemic world. Key recommendations for HEIs and research institutes are:

★ To introduce and maintain mentoring schemes and training; to raise awareness of mental health issues.

★ To ensure the long-term impacts of Covid-19 are taken into account during recruitment, in assessing career progression and in deciding the criteria used for promotion.

★ To plan for changes in post-Covid working practice, including the transition to hybrid working (some in-person and some virtual).

Community organisations, like the Challenger Society, can play their part through the establishment of networks and a best practice guide for flexible working or working from home, should we be faced by another Lockdown or need to be part of a hybrid working scheme. ECRs and those on FTAs need access to field samples, data and laboratories, and working with UKRI/NERC will enhance opportunities for informal networking, partnership building, and engagement with sea-going activities.

The results of the survey have been published as a summary infographic available via NOCA (https://noc.ac.uk/partnerships/our-national-role/coordinating-uk-marine-science/noc-association), and the

*For more information about the Net Zero Oceanographic Capability NZOC project, see https://projects.noc.ac.uk/nzoc/

†NOCA = National Oceanography Centre Association of Marine Science National Capability Beneficiaries

full report is available from the UK Marine Science and Technology Compendium (https://naqbase.noc.ac.uk/).

Further reading

Hendry, K.R. and 17 others (2020) Equity at Sea: Gender and inclusivity in UK sea-going marine science. *Ocean Challenge* **24** (2), 19–30.

Howell, K.L. and 44 others (2021) A decade to study deep-sea life. *Nature Ecology and Evolution* **5** (3), 265–7.

Myers, K.R. and 9 others (2020) Unequal effects of the COVID-19 pandemic on scientists. *Nature Human Behaviour*, **4** (9), 880–83. doi: 10.1038/s41562-020-0921-y

Katharine (Kate) Hendry is an Associate Professor in Chemical Oceanography at the University of Bristol.
K.Hendry@bristol.ac.uk

David N. Thomas is the Professor of Arctic Ecosystems Research at the University of Helsinki and Chair of NOCA.
david.thomas@helsinki.fi

People and the ocean

Emma McKinley *with* the Marine Social Science Network

Regular readers of **Ocean Challenge** *may recall an article in the previous issue about UK marine researchers sharing their scientific skills with Cambodian scientists to help them protect coastal waters in the Bay of Thailand. This interaction seems to have been positive, and the conservation work is continuing – but what human-related factors pre-dispose such a project to success? And how do communities engage with and feel about their local marine environment? These are the kinds of question that marine social scientists are interested in finding answers to. They are also the kinds of question that are now being addressed in large international programmes such as the UN Decade of Ocean Science for Sustainable Development and ATLAS, both also covered in the most recent issue. If you would like to know more about Marine Social Sciences, and how you can engage with others with the same interest, read on! Ed*

People – their values, attitudes and behaviours in relation to the ocean, and the way they use marine and coastal environments – are central to the future sustainability of marine and coastal ecosystems, species and resources. Recent years have witnessed a shift in the discourse around marine and coastal management. This area has traditionally been led by work in the natural sciences, but there has been a growing acknowledgement that society and the global ocean and coasts are inextricably interlinked. This growing awareness of the role of people in the marine system saw the launch in January 2021 of the UN Decade of Ocean Science for Sustainable Development (2021–31) which, among other things, calls for a transformation in the relationship between people and the ocean, seas and coasts, citing an urgent need for improved integration of natural and social sciences to help deliver this change.

Marine social sciences draws on expertise and skills from across the fields of social sciences (e.g. economics, sociology, human geography), while also including other areas of research and insight, such as those from the arts and humanities, to explore and understand the complex relationships between people and the ocean.

Areas of work include, but are by no means limited to:

- Public perceptions of the blue economy, including marine renewables, fishing and other maritime industries; also of issues relating to the overall marine environment, and specific topics, including marine mammals and other charismatic species, and climate change.

Volunteers working in a mangrove forest on the Caribbean island of Bonaire. Amongst the many questions that marine social scientists want to address is why some marine conservation initiatives are successful and others are not.

(Photo: Lorenzo Mittiga / Ocean Image Bank)

- Concepts of marine citizenship (having an understanding of individual rights and responsibilities with respect to the marine environment, along with a desire to have a role in ensuring sustainable management of the marine environment), and ocean literacy (having an understanding of the ocean's influence on oneself and one's influence on the ocean).
- Creation and inclusion of different types of knowledge and values, including local and indigenous understanding; ecosystem services and natural capital; and a myriad of themes relating to ocean and coastal management and governance.

The last 20 years have seen an almost exponential increase in research under the marine social science banner – a clear sign that there has been a growing awareness that this interdisciplinary field is integral to the sustainability of our oceans, coasts and seas. Alongside a resounding call to action from the UN Ocean Decade of Ocean Science for Sustainable Development, this upward trajectory signals a positive change for an already active and engaged marine social science community.

There are, however, challenges to realising full integration of marine social sciences within the wider world of marine sciences. A recent study (https://doi.org/10.1016/j.envsci.2020.03.015) explored these challenges, drawing insight from across the global marine social science community, and highlighting four key priorities:

- **Development of an interdisciplinary, international research agenda for marine social sciences, to support the achievement of international agreements and goals.**
- **Positioning data and evidence from across the spectrum of marine social sciences alongside their natural and physical science counterparts.** While collaborations and interdisciplinary working are happening, there remain further opportunities to build on these foundations. In particular, recognising that social sciences

should not be an 'add on' or 'afterthought', but should be embedded from project inception, will only strengthen interdisciplinarity, and indeed meaningful transdisciplinarity (i.e. working across different disciplines, sectors and/or groups), and capacity-building across the wider marine science–policy–practice interface.

- **Design better ways to ensure that marine social sciences data and evidence can be effectively integrated into decision- and policy-making.** Generally, global trends suggest that governance processes are designed to take only quantitative data into consideration – much of the work done by many social scientists can be qualitative, case-study based, or have small sample sizes (compared with quantitative studies), due to different but equally rigorous methodologies and approaches. These differences in approach to research can make policy-makers reticent to include the data – not necessarily because they don't want to, but because our existing processes don't easily allow for it. The beauty of the social sciences lies in how they bring meaning to data through widely tested concepts and theories. Groups like MARE and the Marine Social Science Network can help to facilitate change, but more action is required from across science, policy and practice.

- **Understand our knowledge and evidence gaps.** For example, do we know enough about how society interacts with, feels about, and behaves towards the coast, ocean and seas? What influences these interactions, feelings and behaviour? How does it vary with geographical, economic, social and cultural context? What can our past tell us about our present and future? Unlike the natural and physical marine sciences, there have been incredibly limited time-series data gathered on many aspects of marine social sciences (e.g. public perceptions of marine issues, knowledge awareness). There is a need to understand what research and evidence exist so that future priorities can be developed and implemented.

- **Nurture and support the growing marine social science community.** Although there is already an active community of researchers and practitioners, there is no denying that the marine social science community is relatively young. There is a need, and also an opportunity, therefore, to ensure the community develops in a way that places accessibility, inclusivity, equity and diversity at its heart. This can be addressed in a number of ways – the location of future events (previous marine social science events have generally been held in north-west Europe) to ensure there is no bias towards certain locations (perhaps the transition to virtual events and meetings can support this); supporting networking, collaboration and mentorship through groups such as the Marine Social Science Network; recognising diversity and interdisciplinarity across marine social sciences, building capacity to address evidence or data needs.

Fishermen in Indonesia prepare traditional nets, which do not result in overfishing. Why do some coastal communities tun away from sustainable fishing practices?

(Photo: Martin Colognoli / Ocean Image Bank)

It is abundantly clear that the field of marine social science is rapidly evolving, encompassing diverse subject disciplines and research communities, each with its own history, methods and ways of engaging with the ocean.

MarSocSci: on the crest of a wave

The Marine Social Science Network (MarSocSci) came to life in 2018, following an initial exploratory workshop held in London in January of that year. Bringing together representatives of the UK's diverse marine science community, the workshop responded to the growing recognition of the role and value of marine social sciences as part of the wider field of marine science. With representatives from 35 different organisations, workshop attendees discussed a range of topics, including the opportunities and challenges of integrating marine social sciences into marine and coastal management.

Perhaps most importantly, we also discussed whether there was a need for a dedicated marine social science network, and if so, what its scope should be. The answer to the first part was a resounding 'YES'! There was an over-riding feeling that those of us working within marine social sciences often felt a bit isolated, and that the community was more fragmented than other areas of marine sciences. It was quickly agreed that there was a need for a community or platform for marine social science researchers and practitioners, and that, crucially, this should be an international and interdisciplinary network. And so the Marine Social Science Network was born: MarSocSci officially launched in September 2018, during the Greenwich Maritime Centre's Society and the Sea conference.

Since then, MarSocSci has gone from strength to strength. Our core goals and aspirations are to support the wide-ranging and interdisciplinary community of those working across (or indeed, interested in knowing more about) all aspects of marine social science. We aim to better understand the complex relationships between all aspects of society and our

What MarSocSci aims to do

★ Provide a 'home' for a growing community of marine social science researchers and practitioners, representing a range of disciplines and nations.

★ Support emerging, novel and innovative areas of research into, and management of, ocean and coastal environments.

★ Provide a platform for dialogue, discussion, and collaboration.

★ Enhance and support co-creation and co-development of bodies of knowledge, and of understanding of values relating to marine and coastal environments.

★ Promote social science as the gateway to embedding wider societal views and values into policy and management, and mapping social sciences against the global challenges.

★ Position marine social sciences, including arts and humanities, alongside natural and physical sciences.

★ Demonstrate the social value of marine systems and support communication and articulation of the complex and complicated relationship between society and the global seas and coasts.

ocean, coasts and seas, and to actively promote the role of marine social sciences within effective and sustainable management.

MarSocSci is not a purely academic network – in fact, we want to hear from and engage with everyone working in any aspect of marine social sciences and have had a lot of support from a number of organisations outside academia, such as the UN Environment Programme World Conservation Monitoring Centre and the Coastal Partnership Network.

Since that small workshop of 35 interested and enthusiastic people in London on a cold January day nearly five years ago, we have grown to a community spanning the globe, with over 4000 people regularly engaging with the Network, and crucially each other, using our social media platforms (@MarSocSci), and over 800 currently signed up to receive our monthly newsletter, which is always full of fantastic updates, new publications, job opportunities and forthcoming events from across the global marine social science community.

Reaching out to the MarSocSci Community

From the outset, MarSocSci has sought to be a global community. Building on this vision, since the launch in 2018 we have seen three thematic or regional groups establish themselves. The creation of regional and thematic groups or 'chapters' means that subject- or location-specific priorities and needs can be addressed and discussed in an effective and collaborative way. Our first regional chapter – Marine Social Science Network Australia (or MarSocSciAus) – was established in 2019, and was quickly followed by Marine Social Science Network Ireland (better known as MARSSI). Most recently, the Adaptive Capacity thematic group has established itself. This chapter is interested in topics relating to adaptive capacity, adaptation, and resilience of people and communities living near the sea.

Find out more about our chapters on the MarSocSci website (www.marsocsci.net) and email us for more information if you're interested in setting up your own regional or thematic chapter.

MarSocSci Book Club In April 2020, as the world began to adjust to the dramatic changes being brought about by the global Covid-19 pandemic, we launched our MarSocSci Book Club. The aim of the Book Club was to create an informal opportunity for networking and communication across the community, during a time when all conferences and in-person events were being cancelled for the foreseeable future. Recognising the very unexpected, and in many cases difficult, circumstances that everyone across the world found themselves in, we also wanted to make sure that we provided something that wasn't a formal commitment, and afforded some light-hearted relief for our marine social science community. Each month, therefore, a book has been selected at random (ocean- or coast-themed, of course) and announced through our newsletter and social media channels.

Our first ocean-themed read was *The Summer Book* by Tova Jansson – a wonderful book about a young girl's summer on a small Scandinavian island and her experiences and connection with her sea and coast. Since then we have covered a really diverse range of themes and topics, and the Book Club has become a much cherished monthly event for all of those who join us. We have already celebrated the first Book Club Birthday, and are excitedly looking forward to setting up more MarSocSci Book Club chats that allow for those in different time zones (i.e. not GMT ± 5 hours) to get involved. If you're interested in knowing more, or joining in, email info@marsocsci.net.

Monthly Webinar Series As it became clear that life in 2020 was going to be more than a little bit different from previous years, we continued to consider what we could do to support networking, collaboration and exchange of ideas across the marine social science community. In July 2020, we started our monthly webinar series (or at least, almost monthly!) aimed at showcasing the breadth and depth of work that is being done across marine social science research and practice around the globe. Since July of last year, we have had sessions covering a broad range of topics including: the importance of social capital for Marine Protected Area governance within Defra's Marine Pioneer project (Sarah Young and Chrissy Ingle); transdisciplinarity for a sustainable blue economy (Patrick Heidkamp); the incredible work being done through empatheatre in South Africa to explore complex relationships between society and the sea (One Ocean Hub) and the use of arts-based research and the creation of coastscapes in the Coral Communities project (Louisa Evans and Dominica Williamson). All of the sessions have been recorded and can be found on our YouTube Channel – along with the recordings from the Marine Social Science Australia bimonthly Seminar Series.

How to get involved with MarSocSci

There are lots of opportunities to get involved with MarSocSci. You can find out more about the Marine Social Science Network by following us on @MarSocSci on Twitter and Instagram, or going to the website, www.marsocsci.net. There, you'll see that regional and thematic chapters are being set up all of the time – if you're interested in setting up a chapter, or in

Books recommended for autumn reading in 2021
*Other reads have covered climate change (*The Beast of Cretacea *by Todd Strasser), the benefits to health and wellbeing of marine and coastal spaces (*The Salt Path *by Raynor Winn and* The Outrun *by Amy Liptrot), the diversity of coastal communities and coastal spaces (*The Many *by Wyn Menmuir and* The Curve of Time *by M. Wylie Blanchet), coelacanths (*A Fish Caught in Time *by Samantha Weinberg), and jellyfish (*Spineless *by Juli Berwald). See https://www.marsocsci.net/marsocsci-book-club/ for discussion of the books we have read.*

For yet more sea-related 'good reads' go to https://beachbooks.blog learning a bit more about how that would work, send us an email! You can contact the team on info@marsocsci.net.

We're always on the lookout for content for our newsletter and our webinar series, and have recently launched a blog series – if you'd like to get in touch about any of our communications, email the amazing Comms Team on comms@marsocsci.net.

Our relationship with the sea, and how we feel about it, affects how we behave towards it.

(Photo: Emma McKinley)

Further reading

Bennett, N.J. (2019) Marine social science for the peopled seas. *Coastal Management*, **47** (2), 244–52.

Borja, A., F. Santoro, G. Scowcroft, S. Fletcher and P. Strosser (Eds.) (2020) *Connecting people to their oceans: issues and options for effective ocean literacy*. Special Issue of *Front. Mar. Sci*. Lausanne: Media SA. doi: 10.3389/978-2-88963-509-2

Brennan, C., M. Ashley and O. Molloy (2019) A system dynamics approach to Increasing ocean literacy. *Front. Mar. Sci*. **6**, 360. doi: 10.3389/fmars.2019.00360

Fletcher, S. and J. Potts (2007) Ocean citizenship: an emergent geographical concept. *Coastal Management* **35**, 511–24.

Jefferson, R., E. McKinley, S. Capstick, S. Fletcher, H. Griffin, and M. Milanese (2015) Understanding audiences: making public perceptions research matter to marine conservation. *Ocean and Coastal Management* **115**, 61–70.

McKinley, E., T.G. Acott and K.L. Yates, (2020) Marine social sciences: Looking towards a sustainable future. *Environmental Science and Policy* **108**, 85–92. https://doi.org/10.1016/j.envsci.2020.03.015

McKinley, E., J.F. Pagès, R.C. Ballinger and N. Beaumont (2020) Forgotten landscapes: Public attitudes and perceptions of coastal saltmarshes. *Ocean and Coastal Management* **187***, 105117.* doi: 10.1016/j.ocecoaman.2020.105117

McKinley, E. and D. Burdon (2020) *Understanding ocean literacy and ocean climate-related behaviour change in the UK: An Evidence Synthesis*. *Final report.* Produced for the Ocean Conservation Trust and Defra. October 2020.

McKinley, E. and R. Jefferson (2020) *Stakeholder engagement and social sciences for the Commonwealth Blue Charter Action Groups: An overview.* A report prepared for the Commonwealth Secretariat. Available on request from the lead author.

McKinley, E. (2020) *Marine Social Science Research and Practice in the UK: A Review.* Report for Defra Marine and Fisheries Team.

McKinley, E. and S. Fletcher (2010) Individual responsibility for the oceans? An evaluation of marine citizenship by UK marine practitioners. *Ocean and Coastal Management* **53** (7), 379–84.

McKinley, E. and S. Fletcher (2012) Improving marine environmental health through marine citizenship: a call for debate. *Marine Policy* **36**, 839–43.

The Laurence Mee Centre for Society and the Sea (2016) *Ocean Challenge* **21** (2), 9.

For more about Marine Pioneers see https://zenodo.org/communities/marine_pioneer_sharing/?page=1&size=20

Emma McKinley is a Research Fellow at Cardiff University and is the founder of the Marine Social Science Network. She is the Co-Chair of the Marine Social Science Task Group of the UK's Marine Science Coordinating Committee, and sits on the International Science Advisory Group for MEOPAR and the IOC–UNESCO's Ocean Literacy Research Community.
McKinleyE1@cardiff.ac.uk

How to apply for a Stepping Stones Early Career Bursary

Stepping Stones bursaries are designed to support career development for members of the UK marine science research community who are not employed. Applications are not accepted from researchers holding permanent positions, but those on fixed-term contracts may apply up to three months before the end of their contract.

Individuals may receive only one bursary in any three-year period and the maximum amount that any individual can be allocated in any one funding round is £1000. Bursaries can be used for research-related activities which could enhance career prospects including, but not limited to, travel, collaborative visits, laboratory time, fieldwork and conference participation. It cannot be used to pay salary.

The Society aims to fund four bursaries per year, and applications will be considered quarterly (deadlines: 15 February, 15 May, 15 August and 15 November).

The application form and full guidance notes for applicants can be found on the Challenger Society website.
https://www.challenger-society.org.uk/Stepping_Stones
Applications should be sent to Sophie Wilmes (s.wilmes@bangor.ac.uk).

See the Challenger Society website for other awards and grants that are available, including the new Virtual Conference Award which aims to cover the costs of registration and administration involved in attending virtual conferences.
https://www.challenger-society.org.uk/Virtual_Conference_Award

Celebrating wind propulsion in Glasgow

As COP26 was coming to an end in Glasgow, just across the river a large group of shipping decarbonisation pioneers gathered virtually, hosted by the Malin group, to announce the winners of the Wind Propulsion Innovation Awards. The awards were created by the International Windship Association (IWSA) to promote wind propulsion for commercial shipping; wind propulsion represents a huge opportunity for decarbonisation of the shipping industry as it is compatible with all other fuel systems and vessels can be easily adapted.

In October, IWSA received some 84 nominations which were then whittled down to a total of just over 30 shortlisted entrants in seven categories; the 27-person judging panel was drawn from across the shipping and renewable energy sectors.

The **Wind Propulsion Innovation Award** for developers of innovative technology and installations was won by Anemoi Marine Technologies and Tufton Investment Management Ltd for the installation of rotor sails on Tufton's *TR Lady* (*below left*). The sails will be fitted onto a rail system to allow cargo operations on the bulk carrier to continue uninterrupted.

The **Wind Propulsion Technology User Award**, presented to the company most effectively championing the use of wind propulsion by installing systems on ships, was won by Vale SA for the five rotor sails installed on the MV *Sea Zhoushan*, VLOC (Very Large Ore Carrier) 325 000 dwt, which is currently the largest ship in the world to have wind-assist systems installed (*below right*).

In the closest vote of the day, the Oceanbird concept (*above*) took the **Wind Propulsion Projects Award**, the category spotlighting innovative projects that are furthering the uptake of wind propulsion,

The Oceanbird car-carrier

tackling barriers, or developing new technology and hybrid configurations. The Ocean Bird concept, developed by Wallenius Marine, is for a 7000-unit capacity car-carrier with primary wind propulsion enabling a reduction in emissions of up to 90%. A car-carrier based on this design, to be called *Orcelle Wind,* will be sailing in 2025.

The **Small Vessel Award** was won by Advanced Wing Systems which has developed a flat panel 'morphing', semi-rigid wing sail system (*right*). This performs well aerodynamically, is cost-effective for various rig configurations, and can be automated.

There were two research categories: the **Completed Research Award**, and the **Proposed Research Award**. The first of these was won by the international team behind the EU-commissioned report *Study on the analysis of market potentials and market barriers for wind propulsion technologies for ships*, with authors based at CE Delft (Netherlands), the Tyndall Centre (UK), Fraunhofer ISI (Germany) and Chalmers University (Sweden) (see www.cedelft). The Proposed Research Award was won by Martina Reche Vilanova, North Technology Group, for a research project focussing on modelling, design and cost optimisation across a wide number of wind propulsion systems.

The final award, for **Outstanding Contribution to the Wind Propulsion Sector**, was given to Diane Gilpin, CEO of Smart Green Shipping, for her long-standing commitment to wind propulsion and continued advocacy work for the technology sector.

Advanced Wing Systems' flat panel, semi-rigid wing sail system, which won in the Small Vessel category

More details of the shortlisted projects, submission videos and the sponsors of the prizes can be found at https://www.wind-ship.org/en/wind-propulsion-innovation-awards-2021/

For more about different kinds of wind propulsion see *Ocean Challenge* **25** (1), 8–11.

Details of the awards by courtesy of Gavin Allwright, IWSA Secretary General and host of the Award Ceremony.

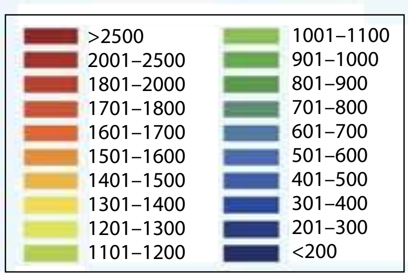
Left TR Lady *with Anemoi's rotor sails, winner of the Wind Propulsion Innovation Award.*
Right *MV* Sea Zhoushan *with its five rotor sails, which won Vale SA the Wind Propulsion Technology User Award.*

All photos are by courtesy of the International Windship Association

Floating offshore wind generation

Kevin Black

The world's first offshore wind farm, comprising just two turbines and located on a rocky promontory about 1.5 km offshore, was built in 2002 near the small, former coal-mining village of Newbiggin, Northumberland, by E.ON. Soon after that, E.ON built the Scroby Sands wind farm on a sandbank off Lowestoft. Since then, domestically, we have seen several rounds of development, with some projects developing extensions, and the latest – Round 4 (in England and Wales) and Scotwind (Scotland) – promise to contribute significantly to an installed offshore wind capacity of 30+ GW, a political target unrivalled by other countries. As offshore windpower has rolled out both in the UK and internationally the levelised* cost of energy for these developments has come down and for many new developments the sector is nearing subsidy-free status.



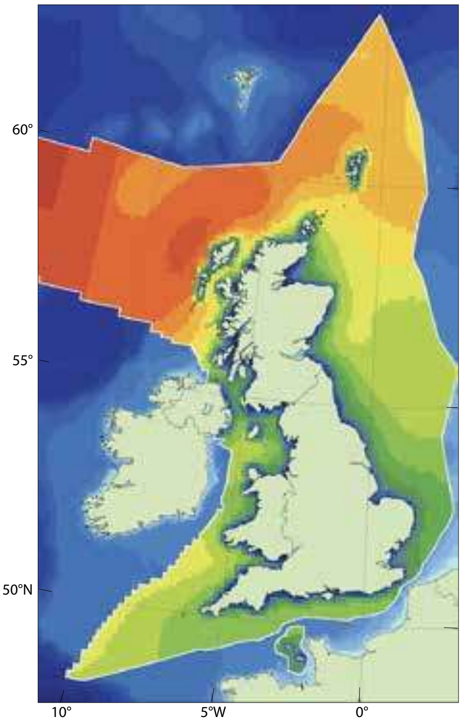


Figure 1 Right *Annual mean wind power density at 100 m above sea level, in W per m² of rotor-swept area (which is ∝ wind speed³) over the UK's legal continental shelf.*

Below *Existing and planned wind farms around the British Isles and locations mentioned in the article. (Several wind farms are also being planned off the west of Ireland.) Floating wind farms that are already operational are labelled in red. FEP = Floating Energy Park.*

Nearly all the developments to date have utilised fixed bottom structures to mount the wind turbines; the monopile design (a slender cylinder) is the most common, but multi-legged 'jackets' (with three or four legs) are increasingly being used (Figure 2) and in a few locations giant, concrete gravity bases have been employed. Offshore wind is set to 'go viral'.

As competition grows for space to develop offshore wind farms, the Crown Estate† is offering areas for lease in deeper water (> 50–60 m), and this has driven a burgeon-

*The levelised cost of energy from a generating plant represents the average revenue per unit of electricity generated required to recover the costs of building and operating a generating plant during an assumed financial life and working cycle.

† The Crown Estate – the private property of the reigning monarch but managed by an independent organisation – leases areas for offshore wind power development around the UK; the surplus revenue from the Estate is paid each year to the Treasury. Areas offshore Ireland are leased by the Irish Government.

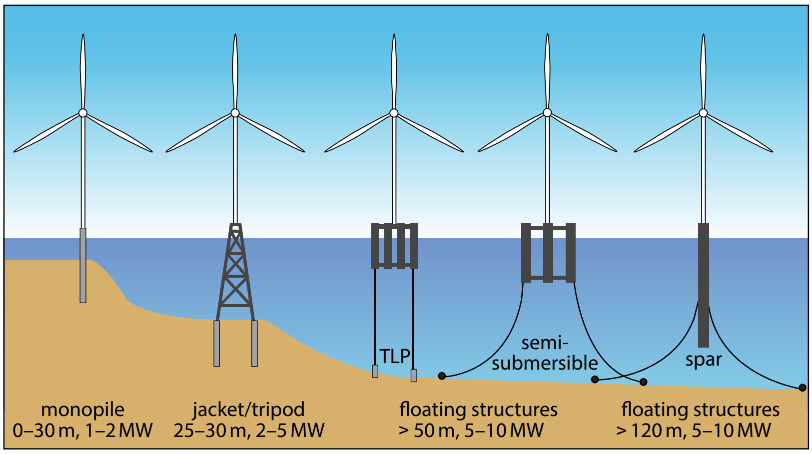


Figure 3 ***Left*** *The main kinds of platforms used for offshore wind turbines, the depths they are used in, and the generating capacity of those turbines. A jacket platform is a fixed steel frame like that used in the oil and gas industry. A TLP (tension-leg platform) is also similar to some platforms used for oil or gas production, and is moored by means of tethers grouped at each of the structure's corners; a group of tethers is called a tension leg. The bottoms of the 'legs' are embedded in the sea bed, in contrast to the ends of the flexible tethers of the 'semi-sub' and spar designs, which move about slightly.* ***Right*** *One of the six turbines forming the Kincardine floating wind farm 15 km off the coast of Aberdeen. The wind farm has a capacity of 50 MW and will generate enough power for ~ 55 000 Scottish households. The turbine is installed on a triangular semi-submersible base. (Photo: R. Wakefield/Flotationenergy)*

ing floating wind sub-sector, which is now gaining momentum. It is estimated that around 80% of the offshore wind resource in Europe is associated with waters of more than 60 m depth.

The main advantage of a floating wind farm is that it can be situated in deeper water than conventional wind farms, and wind speeds some distance from land are typically faster than those close to shore. Small increases in speed result in large increases in energy production. For example, a turbine in a 15 km hr^{-1} wind can generate double the energy of one in a 12 km hr^{-1} wind, according to the American Geosciences Institute. In addition, offshore wind speeds are steadier than those on land, producing a more stable source of power. Furthermore, the installation process for floating offshore wind turbines is less affected by the weather, substrate and sea conditions than fixed bottom developments.

To date, two sites (labelled in red in Figure 1) have been developed commercially and are operational. Equinor's 30 MW Hywind development 29 km off Peterhead in Scotland is the world's first commercial wind farm using floating wind turbines. The 50 MW Kincardine floating wind farm is located in Aberdeen Bay, approximately 15 km off the south-east coast of Kincardineshire, in water depths ranging between 60 m and 80 m (Figure 3, right).

There are a number of other floating wind projects in the pipeline. The Crown Estate works to support the development of floating wind technology through its test and demonstration programme, and last year awarded rights to developers Blue Gem Wind for the proposed 96 MW Erebus floating wind project, in the Welsh waters of the Celtic Sea. The company already have a follow-on project in planning, the Valorous project, also off the Pembrokeshire coast.

When the Crown Estate authorises consent for a development it stipulates a a maximum power output for the completed project. The Crown Estate's leasing process will now be focussing on projects of ~ 300 MW in scale – up to 3 times larger than any previously awarded to floating wind in the UK – demonstrating a new frontier for the sector and an important step towards the Government's ambition to deliver 1 GW of floating wind by 2030.

A few miles to the south of Newbiggin, EDF ER have commenced site characterisation and are planning to build a 5-turbine demonstration floating wind farm which will consume the remaining consented capacity at Blyth. Floating Power Plant are developing a global pipeline of projects, at the head of which are two UK projects: Dyfed Floating Energy Park in Wales and Katanes Floating Energy Park in Scotland (Figure 1). These are interesting projects as the developers of these sites are proposing to use hybrid technologies for extracting both wave and wind energy concurrently. Finally, there is a consented floating wind project called Dounreay Tri, 6 km offshore Dounreay, Caithness, on the north coast of Scotland, which has not yet been developed and whose future presently remains uncertain. Seven sites have been identified as potential floating offshore farms in Irish waters.

The tide is turning for this emerging wind energy sub-sector with its fast maturing technology, decreasing energy costs and increased yield and capacity, and not only in the UK. European companies are the pioneers as they lead three quarters of the 50+ floating offshore wind projects at different stages of development worldwide today. But it is turning into a global sub-sector and we see big strides in development in places as far flung as South Africa, California and Hawaii, and offshore Japan. The oil majors have recently also entered the market; Royal Dutch Shell increased its presence in the North Sea through its acquisition of floating wind specialist Eolfi, in November 2019. Total entered the market this year, and earlier this month procured a 20% stake in the Mediterranean Eolmed project. Freed from the necessity of sitting on the sea floor, floating offshore wind farms present the potential to access areas of sea previously unavailable, further contributing to the green economy and leading the way to a Net Zero future.

Kevin Black is the Technical and Business Development Director of Partrac of which he is a founding Director. He has over twenty years of experience in the marine survey sector, and Partrac have worked on nearly all the UK offshore wind farms to date. kevin.black@partrac.com

Surprising model results help us learn about marine ecosystems

Tom Anderson, Eugenie Cockell and Wendy Gentleman

Science is about learning how the world that surrounds us works. At its heart it involves puzzle-solving and adventures in critical thinking and ideas, often expressed as hypotheses about the underlying causes and mechanisms of observed phenomena. Why do high-latitude copepods accumulate large reserves of lipid? How will animal physiology and growth respond to warming climate? What causes the termination of phytoplankton blooms? One way to address questions like these is to carry out observations and experiments. What is often underappreciated, however, is that as well as guiding empirical studies, simulation models can also be used to test hypotheses and make discoveries (Figure 1). As we will show here, the results of even simple simulations can be unexpected, indeed surprising, leading to new knowledge and understanding of the functioning and dynamics of marine ecosystems.

This article was inspired by an incident that took place when I (Tom) was teaching a course on Ecological Modelling at the University of Southampton. One of the students (Eugenie, co-author here) was running a simple model of the Southern Ocean ecosystem which I had used for the course over many years. She encountered a new and bewildering result when varying zooplankton parameters in the model and so asked me for an explanation. I replied that her result was most interesting and that I could not explain it!

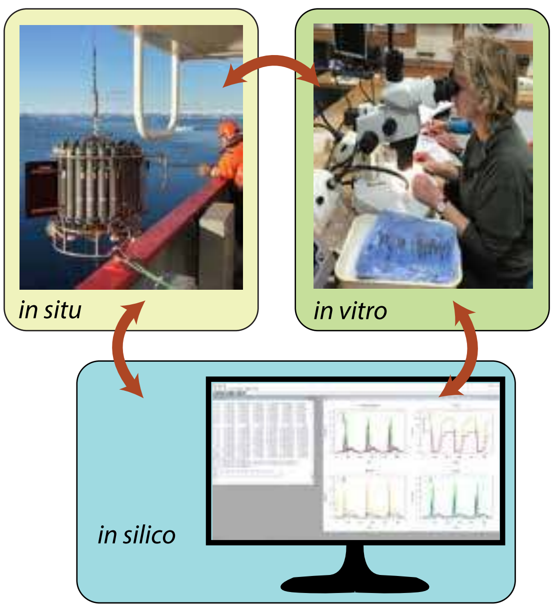


Figure 1 *Progress is made in oceanography through the combined use of observations (*in situ*), experiments (*in vitro*) and models (*in silico*).*

This event showed how even simple models can generate surprising results which help us to think critically about the functioning of marine ecosystems. We pursue this theme here by inviting you to undertake a two-part quiz, of which the second part relates to the above-mentioned unexpected result. A simple marine ecosystem model will be used to demonstrate the importance of grazing pressure by zooplankton in two contrasting marine ecosystems, one oligotrophic (nutrient-poor), the other eutrophic (nutrient-rich). Results will first be shown for a high rate of zooplankton grazing, and you may then make an educated guess, or deduce, what will happen to plankton biomass and production when the grazing rate is decreased. Sounds simple? Let's see how you get on! But first we provide a brief description of the ecosystem model.

NPZ *ecosystem model*

The ecosystem model (Figure 2) has three components: dissolved nutrient (N), phytoplankton (P) and zooplankton (Z), all measured in the common currency of nitrogen concentration (mmol N m^{-3}). Nutrient fuels the growth of phytoplankton (primary production; mmol N m^{-3} day^{-1}) that are in turn grazed by zooplankton that use a fraction of intake for growth (gross growth efficiency), excreting the remainder as dissolved nutrient.

Dead zooplankton are likewise recycled to dissolved nutrient. Nutrient, phytoplankton and zooplankton are confined within a slab of water which nothing can enter into or leave, i.e. total nitrogen within the system is constant. The model is run to equilibrium, at which point the stocks are unchanging and transfer rates (mmol N m^{-3} day^{-1}), represented in Figure 2 by the three arrows, are equal.

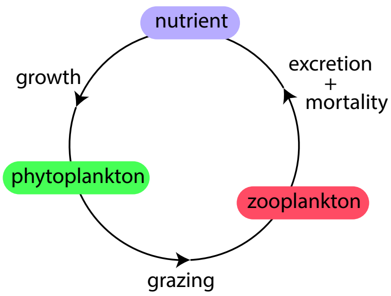


Figure 2 *Nutrient–phytoplankton–zooplankton (NPZ) ecosystem model, with cycling processes indicated by arrows.*

The equations for rates of change of P, Z and N are:

$$\frac{dP}{dt} = \mu_P \frac{N}{(k_N + N)} P - gPZ \qquad (1)$$

$$\frac{dZ}{dt} = \beta gPZ - m_Z Z^2 \qquad (2)$$

$$\frac{dN}{dt} = (1-\beta)\, gPZ + m_Z Z^2 - \mu_P \frac{N}{(k_N + N)} P \qquad (3)$$

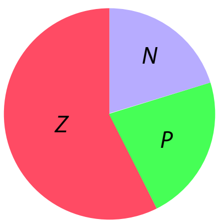
Primary production is calculated as the product of phytoplankton biomass and growth rate (right-hand side of Eqn 1). We use a saturating response curve (so-called Michaelis–Menten or Monod) where the growth rate decreases from a maximum value, μ_P, as nutrient limitation increases. Parameter k_N is known as the half-saturation coefficient because it defines the nutrient concentration at which the growth rate is half of the maximum. Grazing is calculated as a simple linear functional response where specific ingestion rate (i.e. ingestion rate per unit of biomass) depends on the product of P and the grazing rate, g. Gross growth efficiency is specified by parameter β. Zooplankton mortality is a quadratic (squared) function incorporating parameter m_Z. Recycling to dissolved nutrient (the first two terms of Eqn 3) comes from grazed but uningested phytoplankton, and from the carcasses of dead zooplankton and excretion by higher predators. Parameter values are: $\mu_P = 1.0\ \text{day}^{-1}$, $k_N = 0.5$ mmol N m^{-3}, $g = 0.5\ \text{day}^{-1}$ (mmolN m^{-3})$^{-1}$, $\beta = 0.5$, $m_Z = 0.1$ (mmol N m^{-3})$^{-1}$ day^{-1}. Total nitrogen in the system is $N_{tot} = N + P + Z$; we use N_{tot} = 1 mmol N m^{-3} for the oligotrophic system and N_{tot} = 10 mmol N m^{-3} for the eutrophic system.

Quiz 1: Oligotrophic system

Model results for the oligotrophic system (with total nitrogen, N_{tot} = 1 mmol N m^{-3}), with a relatively high grazing rate, $g = 0.5\ \text{day}^{-1}$ per unit of concentration, are shown in Figure 3. Predicted stocks of nutrient, phytoplankton and zooplankton account for 20%, 23% and 57% of total nitrogen respectively, while primary production is 0.065 mmol N m^{-3} day^{-1}, matched in equal measure by zooplankton grazing and nutrient recycling. Note that $Z > P$, an example of an inverse biomass pyramid which may often occur in the ocean.

Figure 3 *Predicted relative concentrations of dissolved nutrient, phytoplankton and zooplankton, and primary production, at equilibrium for the oligotrophic system (N_{tot} = 1 mmol N m^{-3}).*

primary production =
0.065 mmol N m^{-3} day^{-1}



So, it is now over to you. Zooplankton biomass-specific grazing rate (parameter g) is now decreased from 0.5 to 0.1 day^{-1} (mmol N m^{-3})$^{-1}$, i.e. for a given concentration of phytoplankton, the rate of consumption of phytoplankton per zooplankton individual is reduced 5-fold. How will N, P and Z change in terms of their relative share of the pie (increase or decrease), bearing in mind that N_{tot} (the size of the pie) does not change? And will primary production increase or decrease from its value of 0.065 mmol N m^{-3} day^{-1}?

When you are ready, read on …

Answer to Quiz 1 N↓ (from 20% to 2% of N_{tot}), P↑ (from 23% to 65% of N_{tot}) and Z↓ (from 57% to 33% of N_{tot}). Primary production decreases from 0.065 to 0.021 mmol N m^{-3} day^{-1}.

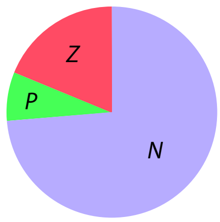
How did you do? Did you score 4/4? It is not surprising that decreasing grazing rate (parameter g) will cause an increase in phytoplankton biomass (less top-down pressure) and a decrease in zooplankton biomass. It is perhaps counterintuitive, however, that this increase in phytoplankton should lead to lower primary production. It happens because decreasing zooplankton grazing slows up recycling of the nutrients that phytoplankton rely on for production. If grazing decreases, then so do all the flows in Figure 2 since the three flows must be equal at equilibrium, as noted above. When grazing rate is decreased, lower primary production is predicted because the impact of diminished nutrient cycling outweighs that of increasing phytoplankton biomass. The model thus highlights the important role that zooplankton play in the cycling of nutrients and maintaining primary production in the ocean, especially in oligotrophic systems.

Quiz 2: Eutrophic system

Next, consider a eutrophic system, with N_{tot} = 10 mmol N m^{-3}. Results with high grazing rate, $g = 0.5\ \text{day}^{-1}$ (mmol N m^{-3})$^{-1}$ are shown in Figure 4.

Figure 4 *Predicted relative concentrations of dissolved nutrient, phytoplankton and zooplankton, and primary production, at equilibrium for the eutrophic system (N_{tot} = 10 mmol N m^{-3}).*

primary production =
0.70 mmol N m^{-3} day^{-1}



Predicted relative concentrations of dissolved nutrient, phytoplankton and zooplankton are now 74%, 7% and 19% of total nitrogen, with primary production equal to 0.70 mmol N m^{-3}day^{-1} – ten-fold higher than the oligotrophic system.

As per the first quiz, decide whether N, P and Z increase or decrease in terms of their share of N_{tot}, and whether primary production increases or decreases, when grazing rate, g, is decreased from 0.5 to 0.1 day^{-1} (mmol N m^{-3})$^{-1}$.

Answer to Quiz 2 N↓ (from 74% to 2% of N_{tot}), P↑ (from 7% to 65%) and Z↑ (from 19% to 33%). Primary production increased from 0.70 to 2.12 mmol N m^{-3} day^{-1} and, in tandem, zooplankton production increases from 0.35 to 1.06 mmol N m^{-3}day^{-1}.

The startling outcome is that decreasing grazing rate leads to an increase in zooplankton biomass and production – this was the counter-intuitive result that Eugenie asked me about! As with the oligotrophic scenario, P increases while N declines because decreased grazing promotes higher phytoplankton biomass. However, unlike the oligotrophic situation, recycling of nutrients by zooplankton is unimportant because nutrient is already present at high concentration, meaning that the predicted decrease in nutrient had little impact on phytoplankton growth and primary production. Higher phytoplankton biomass provides more food for zooplankton and so both zooplankton growth rate and biomass increase, despite the decrease in grazing pressure. Mathematically, if nutrient limitation is rendered unimportant, the equilibrium value of Z is equal to μ_P/g (derived from the model equations), i.e. the maximum phytoplankton growth rate divided by the grazing rate. Thus, for a given maximum phytoplankton growth rate, decreasing g leads to an increase in zooplankton biomass.

Emergent solutions

The results of (computer) simulations are the deductive consequences of the input equations and parameterisation, along with initial conditions. It has been argued since the days of the philosopher Francis Bacon (1561–1626) that deduction merely illuminates things that we already know. The archetypal example of deduction is the syllogism, as championed by Aristotle. For example: All zooplankton are invertebrates. Copepods are a type of zooplankton. Therefore copepods are invertebrates. This kind of logic does not reflect the complexity of the many interacting parts of marine ecosystems, which lead to emergent outcomes, i.e. solutions that are not readily apparent from the parts considered in isolation from each other. As pointed out by the theoretical ecologist Sir Robert May, the logical consequences of even a simple set of differential equations may have extraordinarily complicated solutions whose existence was previously quite unsuspected, and whose behaviour cannot be grasped intuitively.

A great example of emergent model outcomes, and the understanding that can be gained from them, is the Darwin model developed at the Massachusetts Institute of Technology. A global ocean circulation model was seeded with 78 phytoplankton types, each of which had randomised parameter settings relating growth to light, temperature and nutrients. It was

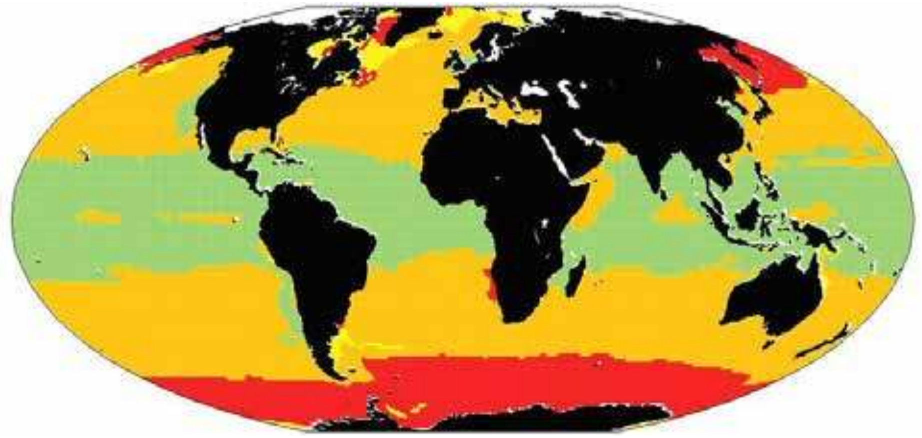


Figure 5 *Emergent plankton biogeography of the Darwin model. Green: analogues of* Prochlorococcus*; orange: other small photo-autotrophs; red: diatoms; yellow (mostly in high latitudes): other large phytoplankton. (Follows* et al. *(2007) in Further Reading)*

nigh impossible to know beforehand which combinations of traits would be successful. When set in motion, competition whittled the number of surviving types down to 18. The resulting emergent community structure (Figure 5) showed good agreement with observed phytoplankton distributions. Examination of the parameter values of the survivors helps us to understand the relations between ecosystems and their environment throughout the global ocean.

Much of the charm of modelling lies in emergent outcomes and the capacity for surprises. A good example is the scenario explored in of our second quiz, where decreasing the grazing rate by zooplankton led to greater zooplankton biomass and production. This result seems totally counterintuitive and I (Tom) was astonished when first confronted with it by Eugenie. We had a thoroughly enjoyable time together puzzling our way to an explanation. Even the best and most experienced scientists can be caught out in such instances. Apparently, the great zooplankton biologist and modeller Bruce Frost once wagered that a model would generate a particular result for a given scenario, only to come into class the next day and confess that he was mistaken. I would certainly have lost if I had made a similar bet with Eugenie regarding what her model would predict.

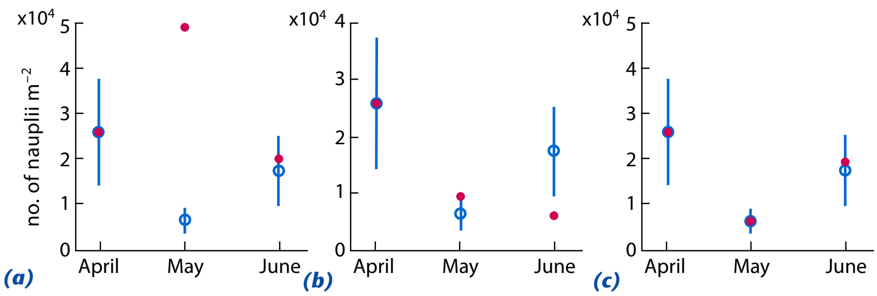
To complete this section, and for those who would like an extra challenge, we invite you to consider Quiz 3, which is an extended version of Quiz 2.

Quiz 3

Using our simple *NPZ* model, we established that for a eutrophic system at equilibrium, decreasing the grazing rate led to higher zooplankton production and biomass. What do you think will happen if a zooplankton population of a different species, *Zooplankton 2*, is added to the model, and this second species has a higher grazing rate than *Zooplankton 1*: 0.5 day^{-1} compared with 0.1 day^{-1}. The two zooplankton populations are otherwise identical and do not graze on each other. Which species achieves the higher biomass and production when the model is run to steady state, *Zooplankton 1* or *Zooplankton 2*?

The answer is at the end of the article.

Figure 6 *Comparison of model results (red circles) and observational data (blue circles, with standard error bars also shown) for the abundance of napulii (larval stages) of* Calanus finmarchicus *on Georges Bank off Cape Cod. The best fit was obtained when copepod development rate was decreased over time (c). (From Neuheimer* et al. *(2009) in Further Reading)*



Learning from model misfit

The predictions of model simulations do not always conform closely with observations, sometimes surprisingly so. Studying the causes of this misfit can provide valuable insight into gaps or weaknesses in our knowledge. An example is a modelling study that Wendy and her coauthors carried out to investigate the pronounced seasonal variation in the abundance of nauplii of the copepod *Calanus finmarchicus* on Georges Bank (Figure 6).

The first simulation (Figure 6(a)) was based on the working paradigm of a constant moderate mortality rate, but modelled May abundance was significantly overestimated so that this month exhibited a maximum in contrast to the minimum in the data (Figure 6(a)). While the May results could be improved when mortality was doubled (Figure 6(b)), such a high rate was not supported by observations because predicted June abundances were then far too low. However, an excellent fit to the data was achieved when copepod mortality rates decreased over time (Figure 6(c)). This result led us to consider what could lead to the decreasing mortality rates and we concluded that this situation could arise from reduced numbers of larval fish and hydroids (tiny tentacled predators). Our findings thereby highlighted the need for further studies on abundances and consumption rates of the various groups of predators on Georges Bank.

Concluding remarks

As Galileo once said, ‘The book of nature is written in mathematical language’. Simulation models tap into that language, permitting the testing of hypotheses and revealing the hidden complexities of the world that surrounds us. Modellers cannot, of course, work in isolation. It takes skill and experience to know what types of equations and parameterisations to use and the process of building models must always be closely integrated with observational and experimental studies. When used sagely, modelling can help direct future empirical work and, in turn, observations and experiments stimulate the development of new theory (cf. Figure 1). Above all, models promote the generation of new ideas and aid their critical evaluation, both of which are essential activities for scientific progress. As the great marine ecosystem modeller Gordon Riley said so aptly, models are quite simply a ‘way of thinking’, carrying us on a journey of enlightenment and discovery.

Answer to Quiz 3 The zooplankton species with the higher grazing rate, *Zooplankton 2*, wins, as might be expected on the basis of competition. At equilibrium, predicted biomasses are 0.36 and 1.80 mmol N m^{-3} for *Zooplankton 1* and *Zooplankton 2*, respectively, and corresponding rates of production are 0.013 and 0.32 mmol N $m^{-3}day^{-1}$, respectively.

Model codes: The Quiz 1 and Quiz 2 *NPZ* model and the Quiz 3 NPZ_1Z_2 model were coded in R and are available on request from the first author.

Further reading

Follows, M.J., S. Dutkiewicz, S. Grant and S.W. Chisholm (2007) Emergent biogeography of microbial communities in a model ocean. *Science* **315**, 1843–6.

Lewin, R. (1992) *Complexity. Life at the edge of chaos*. MacMillan, NY, 208pp.

May, R.M. (1976) Simple mathematical models with very complicated dynamics. *Nature* **261**, 459–67.

Neuheimer, A.B., W.C. Gentleman, C.L. Galloway and C.L. Johnson (2009) Modeling larval *Calanus* finmarchicus on Georges Bank: time-varying mortality rates and a cannibalism hypothesis. *Fisheries Oceanogr*. **18**, 147–60.

Riley, G.A. (1984) Reminiscences of an oceanographer. Unpublished manuscript. Department of Oceanography, Dalhousie University. 136pp.

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

Eugenie Cockell is an MSc. Oceanography student at the University of Southampton. Her interests include the ecology and life history of zooplankton, ocean–atmosphere climate variability and its impact on marine ecosystems. ecac1n19@soton.ac.uk

Wendy Gentleman is an Associate Professor at Dalhousie University, Halifax, Nova Scotia, Canada. Her interests include modelling of marine ecosystem dynamics and zooplankton life history, mathematical methods, and STEM outreach. Wendy.Gentleman@Dal.Ca

Discovery of manganese nodules: Challenger *honour restored*

Keen students of the *Challenger* Expedition (1872–1876) may know that it was responsible for the discovery of manganese nodules – concretions of iron and manganese oxides that also contain significant amounts of other metals, which deep-sea mining companies have wanted to exploit since huge fields of them were found in the Pacific in the 1960s. The initial discovery occurred in February 1873, when HMS *Challenger* dredged up 'a number of very peculiar black oval bodies' from a depth of 2435 fathoms in the western North Atlantic, close to 21° N, 50° W. The Expedition's chemist, John Young Buchanan, analysed one of the 'oval bodies' and found that it consisted of 'almost pure peroxide of manganese'. The scientists were struck by similarities between this and a concretion which a few weeks earlier had been dredged up, with a black coral attached, from a depth of 1530 fathoms in an area we now know as the Canary Island Seamount Province. Charles Wyville Thomson, the chief scientist, included a description of the 'base of the black coral' (along with other mainly biological information) in the first of his 'Notes from the "Challenger"' published in *Nature* on 8 May 1873; the 'oval bodies' were described in the second of these 'Notes', a week later. Preliminary reports concerning the numerous later findings of nodules (with nuclei) and crusts (with no nuclei) were published in the prestigious *Proceedings of the Royal Society of London* in 1875–1876 and 1876.

Part of the first Fe–Mn concretion ever collected from the deep sea bed, dredged up by Challenger *in February 1873. The original caption, in the* Challenger Reports,* *begins: 'Portion of a flattened fragment from the North Atlantic (natural size). The original fragment was over a foot in diameter, and was evidently a piece torn from a much larger mass by the action of the dredge.'*

**Murray, J. and A.F. Renard (1891) Deep-sea deposits (based on the specimens collected during the voyage of HMS Challenger in the years 1872 to 1876). In* Report on the Scientific results of HMS Challenger during the years 1873–76. *John Menzies and Co., Edinburgh.*

Despite these publications (not to mention the eventual *Challenger* Reports, from which the drawing on the right is taken), in 1978 Frank Mannheim wrote in a book review that '... it appears that the *Challenger* Expedition was not the first to find marine concretions'. Mannheim claimed that nodules were first discovered in the Kara Sea in 1868. This belief – easily 'verified' online today – was based on a report published in Swedish by Gustaf Lindström in 1884, of the chemical analysis of a group of 14 sea-bed sediment samples from two Arctic expeditions led by Adolf Nordenskiöld, one in the *Sofia* in 1868, and a later one on the *Vega*. Amongst the 14 samples was one with a very high (24%) concentration of manganese, which included a 5 cm iron–manganese concretion.

A close examination of this report, and other historical evidence, has revealed that the *Sofia* could not have dredged up any manganese nodules in the Kara Sea prior to the *Challenger* Expedition – not least because the *Sofia* never sailed in the Kara Sea, instead working close to Spitsbergen. The sample with a very high content of manganese *was* collected in the Kara Sea, but in 1878 during the *Vega* Expedition (which competed the first sailing of the North-East Passage and the first circum-navigation of Eurasia). The iron–manganese concretion was collected in 50 m of water, near Bely Island, and has been identified as bog iron ore – an ore which forms by precipitation of groundwater flowing into wetlands. *Ed.*

With thanks to Igor Belkin for alerting us to this story.

*Belkin, I.M., P.S. Andersson and J. Langhof (2021) On the disovery of ferromanganese nodules in the World Ocean. *Deep-Sea Research*, Part I, **175**, 103589. https://www.sciencedirect.com/journal/deep-sea-research-part-i-oceanographic-research-papers/vol/175/suppl/C

‘Seaspiracy’: changing the tide or lost at sea?

Bryce D. Stewart

It has now been over 9 months since ‘Seaspiracy’, the Netflix documentary about overfishing, stormed onto our screens and up the ‘most watched’ lists. Rarely has a film about the oceans shocked and divided audiences so much, with its breakneck coverage of issues and key take-home message – that we all need to stop eating fish. But now the initial splash has died down we can ask ourselves – has ‘Seaspiracy’ actually made a difference to the way our oceans are managed? The answer? Not really.

I have no doubt that a number of people in richer countries have followed film-maker Ali Tabrizi’s advice and stopped eating fish. After all, the scenes of shark-finning, dolphin bycatch and pilot-whale hunting were confronting to say the least. So too was the message that if we don’t change then the world will run out of fish by 2048. But that message also highlights a key issue with the film, that it was often based on science that was outdated and/or misinterpreted. The 2048 prediction was an extrapolation from a 2006 paper by Boris Worm and colleagues. However, Professor Worm has since distanced himself from the prediction and written a follow-up paper that painted a much more positive story about the world’s fish stocks. By taking a selective and questionable approach, ‘Seaspiracy’ left itself open to dismissal as an ‘unreliable witness’.

There were many other instances when interpretation of scientific information was careless or misguided. For example, the film implied that nearly half of plastic pollution in the ocean comes from fishing gear, whereas that figure (46%) was from a particular area and only referred to plastic floating on the surface. The reality is that only about 10% of marine plastic pollution is calculated to come from fishing, with 80% coming from land-based sources. That means everyday households like yours and mine. Likewise, opening scenes gave the impression that fertilisation of the ocean by whale and dolphin (cetacean) defecation was vital for stimulating vast amounts of phytoplankton growth and in turn most of the oxygen we breathe. Again, while the ocean certainly does provide over half of the oxygen on Earth (although not the part we breathe), even fully restored cetacean populations would only make a minor contribution. The majority of nutrients originally come from the land via rivers and streams. Why the film-maker decided to stretch the truth in this way is hard to understand. It is not as if most of the public do not already care about whales and dolphins.

It is also crucial to point out that giving up fish is simply not an option for huge numbers of people around the world. Approximately 3 billion people (nearly half the world’s population) get 20% of their protein from fish and seafood. In coastal areas and island nations, fish consumption rates are particularly high because there are few or no other nutritional alternatives. The makers and supporters of ‘Seaspiracy’ countered that the film was only aimed at affluent westerners, but Netflix is viewed globally and that disclaimer was nowhere in the film that I could see. As a result, a number of commentators thought the messages, story-telling and interviewing in the film lacked diversity and at times was anti-Asian.

In island nations like Seychelles, fish provide a vital and irreplaceable food source, and fishing is deeply ingrained in Seychellois culture. (Photo: Bryce Stewart)

This is not to say that there are not huge problems in the ocean. Although the United Nations has calculated that approximately 66% of global fish stocks are currently at sustainable levels, this figure was 90% in 1990. With a growing human population and appetite for fish, we desperately need to get dramatically better at managing fisheries and switching to more sustainable aquaculture. That’s without mentioning the ever-growing threats from ocean warming, acidification and deoxygenation.

Unfortunately, many key organisations and scientists who are working hard to find solutions to the above issues were attacked either in the film, or because of it. This included key NGOs such as the Earth Island Institute, the Plastic Pollution Coalition, Oceana and the seafood eco-labelling organisation, the Marine Stewardship Council (MSC). Indeed, as a result of the film, a number of MSC staff received death threats. In fact, the MSC fishery highlighted in ‘Seaspiracy’ had lost its certification because of the issues described. In reality, although the MSC does have some critics, it has possibly done more than any other single organisation to help tackle the key threats to the world’s fisheries. To date, the MSC has stimulated hundreds of fisheries to improve the sustainability of their practices, and currently certifies over 20 000 seafood products, representing over 14% of the world’s catch.

Likewise, scientists who agreed that the ocean faces major challenges, but took issue with the inaccuracies and exaggerations in the film, were painted as being corrupt and often attacked online. Due to the various media interviews about ‘Seaspiracy’ that I took part in, I had to deal with the worst abuse on Twitter that I have ever received. However, few scientists were silenced. In fact, two of the world’s most prominent fisheries scientists, Ray Hilborn and Daniel Pauly, who frequently disagree about the sustainability of the world’s fisheries, were – amazingly – brought together by the flaws in the film. Such camaraderie and commitment are key, because scientists and NGOs are the main players able to put genuine pressure on the fishing industry and policy-makers, and ultimately generate change.

We know that when fisheries are well managed they have a spectacular capacity to recover and provide sustainable seafood. A recent analysis found that in the intensely managed fish stocks which provide roughly half of the world's catch, abundance is increasing. In contrast, poorly managed stocks are significantly worse off. Where I work on the Isle of Arran in Scotland, enforcement of a Marine Protected Area (MPA) for only three and half years saw the density of scallops increase over 6-fold and overall biodiversity double. Such increases don't just provide benefits within the boundaries of MPAs, they generate high levels of breeding and export of marine life to surrounding areas and fisheries.

Good management works. Marine Protected Areas off the Isle of Arran in Scotland are leading to dramatic recovery of scallop numbers which are reseeding surrounding fishing grounds (Photo: Howard Wood)

So no, 'Seaspiracy' has not changed the tide. Scientists and NGOs are getting on with their jobs and continuing to strive for solutions. The MSC has just seen a record increase in the number of fisheries engaging with its programmes and shows no signs of slowing down. Many governments are still moving too slowly, and illegal fishing is still a huge global problem. But these issues won't be solved with adversarial half-truths. They will be solved by genuine engagement between scientists, consumers, the fishing industry and decision-makers. It is vital that this happens. In a world of growing food insecurity and spiralling climate change, a well managed ocean can provide billions of people with low-carbon-footprint food, indefinitely into the future.

Bryce D. Stewart is a Senior Lecturer at the Department of Environment and Geography, University of York. He has particular expertise in fisheries management and using Marine Protected Areas to balance the needs of conservation and fisheries.
bryce.stewart@york.ac.uk

The road to recovery for Atlantic bluefin tuna

When the International Union for Nature (IUCN) held its delayed 2020 meeting in September 2021, Atlantic bluefin tuna had been removed from the Red List of Threatened Species. This was heartening news of a species whose breeding population began declining around the mid-1970s.

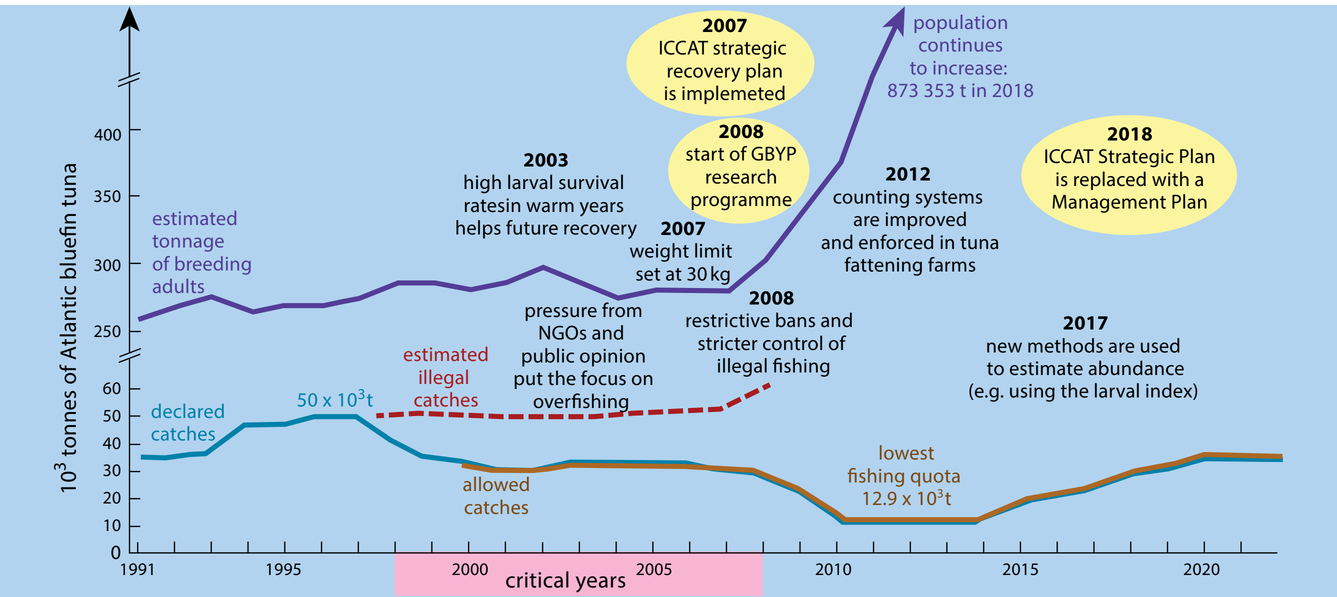
The graph below summarises the path to recovery for the eastern stock of Atlantic bluefin tuna, which spawns in the Mediterranean. This shows clearly that the turning point came in 2007 with the implementation of the ICCAT Strategic Recovery Plan.

Protective measures undertaken in the late 1990s had had little effect, partly due to poaching and a lack of control over catches. In 2007 fishing quotas were drastically reduced, and surveillance and control measures were used to enforce catch quotas, with official ICCAT observers monitoring the operations; systems were implemented to reduce poaching and, crucially, an increase in the weight below which Atlantic bluefin tuna could not be retained on board meant that many more survived to spawn. Locating schools of tuna from light aircraft was banned, and various time and space restrictions were established for certain kinds of fleets (e.g. large long-liners).

For tuna – an iconic fish with a high commercial value – governments and the media, driven largely by social pressure and the activity of several NGOs, contributed to scientific understanding being integrated into the decision-making process, and hence to successful management of the stocks. Sharks are not so lucky.

Ed.

Time-line showing milestones in the recovery of the eastern stock of Atlantic Bluefin Tuna; ICCAT is the International Commission for the Conservation of Atlantic Tunas; the GBYP is ICCAT's Grand Bluefin Tuna Year Programme, largely funded by the EU. (From a diagram produced by Planet Tuna).



Challenging the capability of autonomous gliders in coastal seas

Tim Smyth

As part of the NERC-funded CAMPUS project (CAMPUS = Combining Autonomous observations and Models for Predicting and Understanding Shelf seas), the Plymouth Marine Laboratory (PML) and the National Oceanography Centre launched an autonomous underwater glider within the domain of the Western Channel Observatory, some 20 nautical miles offshore of Plymouth (Figure 1), in late March 2021. The aim of the mission was two-fold. Firstly, to challenge the navigational methodology, which currently requires intervention and continuous supervision from human pilots onshore, and so develop the concept of truly autonomous piloting – so called 'smart' autonomy. Secondly, to capture the 4D variability in the phytoplankton spring bloom in unprecedented detail using multiple sensors.

The first challenge, led by the University of Exeter in collaboration with the UK Met Office and PML, required the use of probabilistic as well as deterministic models,* informed by the environmental data collected by the glider, so that the mission navigational way-points could be automatically updated during the mission.

*A probabilistic model includes randomness, and its results are described as 'stochastic'. A deterministic model does not include randomness, and every time it is run it will produce the same results as long as the same initial conditions are used.

Figure 1 *The general area studied using the glider in the vicinity of the E1 station in the Western Channel Observatory (glider tracks are schematic)*

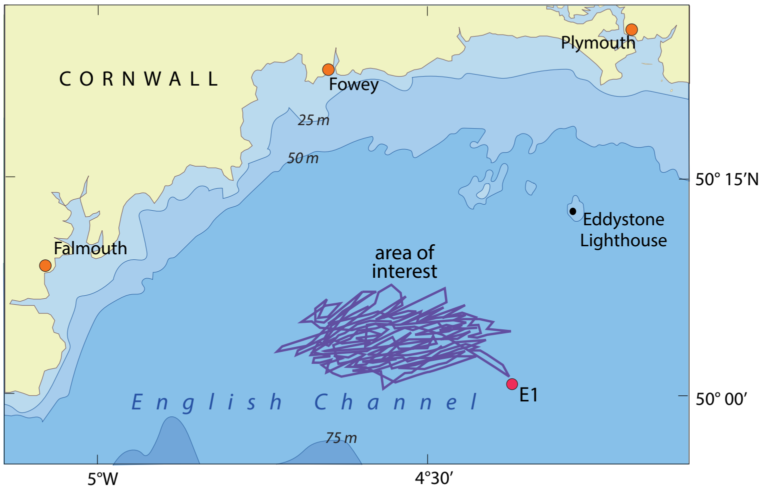


Figure 2 shows how the track of the glider was controlled using a combination of the probabilistic and deterministic models in tandem. At the start of the mission the future navigation points provided by the model forecast were heavily supervised by a human pilot. However, by the end of the mission, as confidence was gained in the ability of the models to produce sensible solutions, this supervision was relaxed.

The second challenge of observing the spring bloom in unprecedented detail in the western English Channel produced some excellent insights into the variability of bloom intensity and extent, which simply would not have been possible without having an autonomous vehicle in the water for over two months. To put things into context: the western English Channel is one of the most scientifically observed pieces of marine real-estate in the world; the station E1 (50° 2' N, 4° 22' W) oceanographic time-series started in 1903 and the site has been continuously sampled at least every month since then, apart from in the two world wars.

During the period that the glider was in the water (22 March–8 June 2021) there were five occupations of the station by the RV *Plymouth Quest* to take CTD profiles; additionally, the E1 buoy was on station from 5 May 2021 taking surface-only measurements every hour (approximately 800 observations). In contrast, the glider performed a vertical snapshot of the environmental conditions in and around E1 (up to 10 miles west of it) every 20 minutes, resulting in a total of 5533 profiles; data were transmitted every 1.5 hours when the glider surfaced. This allowed variability in the bloom dynamics, driven by marked sub-hourly changes in meteorological conditions, to be captured in the glider observations, observations that would have been missed by the boat (too infrequent) and buoy (surface only) observations. This is shown in the preliminary data in Figure 3 (p.21), where the dashed vertical and horizontal lines represent the boat and the buoy observations respectively. It is also worth noting that satellite observations of chlorophyll and sea-surface temperature are similarly constrained to surface only, and that during May 2021 there was a large amount of cloud cover rendering the otherwise daily coverage impossible.

Figure 2 *Graphic to show how the track of the glider is updated in response to changing environmental conditions. The ERSEM is the European Regional Seas Ecosystem Model, which is used to study marine biogeochemistry and the lower trophic levels of the food web. In this project, the ERSEM was linked to the hydrodynamic model NEMO using the coupling interface FABM (Framework for Aquatic Biogeochemical Models).*

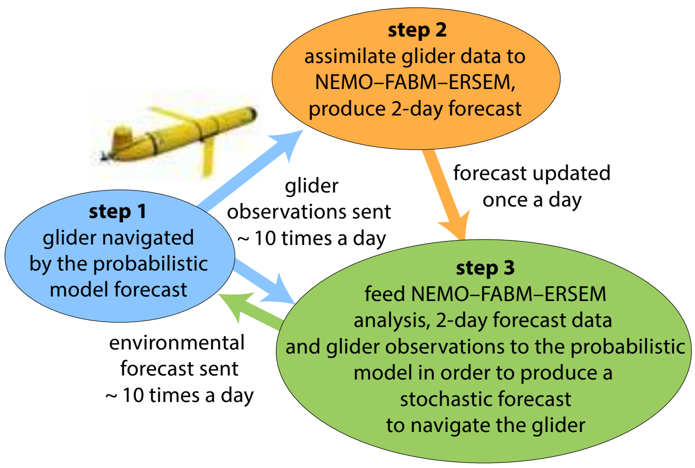
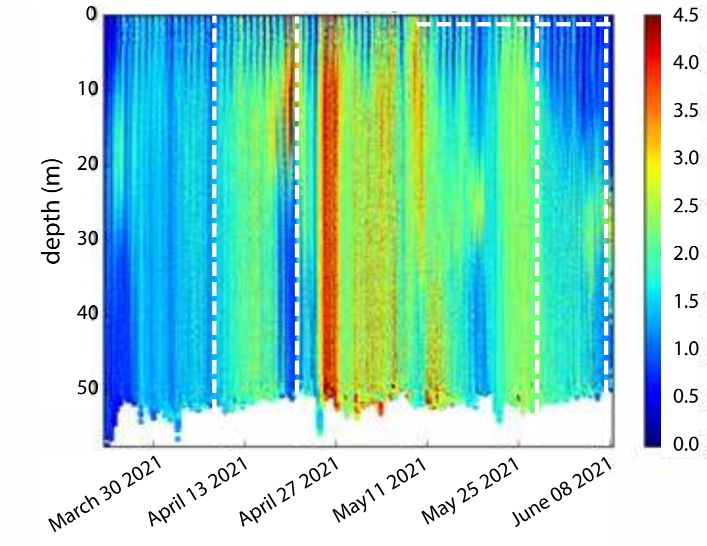


Figure 3 *Chlorophyll measurements obtained using the glider in the vicinity of station E1. The dashed white vertical and horizontal white lines indicate where/when observations were obtained using the boat and the buoy respectively, and show that in the absence of the glider, the peak of the bloom in late April would have been completely missed.*



Further reading

Smyth, T., J. Fishwick, T. Bell and S. Widdicombe (2015) The Western Channel Observatory: Collecting rare and precious time-series – from photons to fish. *Ocean Challenge* **21**, No.1, 32–34.

Finally, the challenges of using autonomous vehicles in the coastal seas should not be underestimated. In contrast to the open ocean, where Autonomous Underwater Vehicles (AUVs) have been routinely used on research cruises, the coastal seas present additional hazards such as congestion caused by shipping, rapidly shoaling and shallow (<100 m) topography, high energy tides, currents and waves combined, and the increased likelihood of biofouling. These risks should be balanced against the obvious huge benefits of using AUVs in the coastal seas, including increased 4D observational resolution and having assets in the field that are relatively accessible, in order to develop the next generation of 'smart' autonomy. In time, 'smart' autonomy will enable us to tackle pressing environmental challenges faced by stakeholders in the aquaculture and fisheries sectors, including the prediction of oxygen depletion and the early detection of harmful algal blooms.

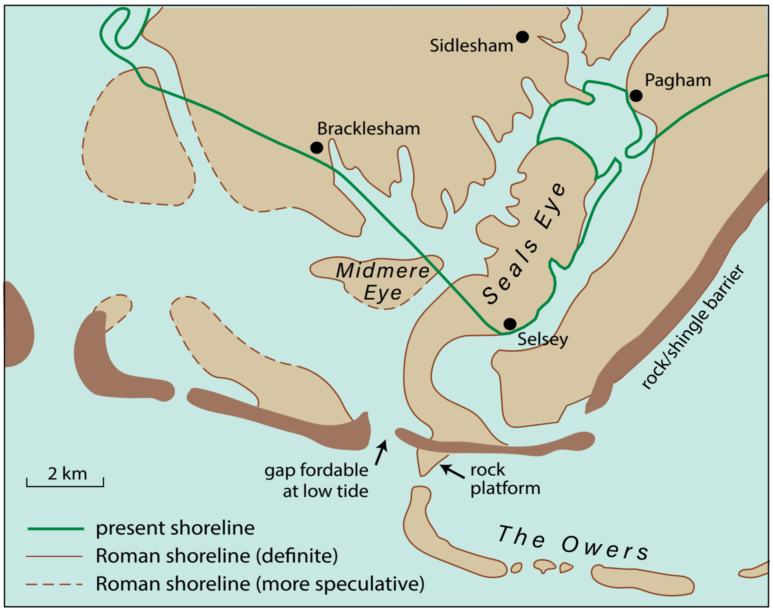
Tim Smyth is Head of Science for Marine Biogeochemistry and Observations at Plymouth Marine Laboratory. tjsm@pml.ac.uk

Necessity is the mother of invention

the value of looking to Nature in our response to sea-level rise

Carolyn Cobbold

At the bottom of a low-lying peninsula protruding into the English Channel lies a breath-taking nature reserve overhung by vast skies and echoing with the sound of birdlife. The haunting landscape of Medmerry feels like something out of Charles Dickens' *Great Expectations*, a marshy wilderness that has existed for centuries. But Medmerry Nature Reserve was created just a few years ago, and its conception reveals both the power of local advocacy and the benefits of recognising the intrinsic value of nature. How Medmerry became a cherished part of Selsey's unique environment, one of the south coast's most important habitat sites and an exemplar of sustainable adaptation to climate change is also a story of dogged determination.



The peninsula that lies to the south of Chichester, and whose tip is Selsey Bill, is known locally as the Manhood Peninsula. Its name is believed to have been derived from the Old English *gemae-newudu* meaning 'woodland held in common'. Selsey, the fishing village that sits at the southern tip of the peninsula and was the former Saxon capital of the Kingdom of Sussex, derives its name from the Saxon *Seals Eye,* meaning the Isle of Sea Calves (or seals). Wilfrid arrived in 680 and converted the community to Christianity, and the island became the site for Selsey Abbey, the first cathedral in Sussex, later moved to Chichester. Since the 16th century the peninsula became increasingly drained and cleared of wood. Selsey no longer was an island, and the marshy lands of the peninsula which included Medmerry were turned into productive agricultural land (Figure 1).

The peninsula is about 300 km^2 in area and has one of the last relatively undeveloped stretches of coastline between Newhaven and Southamp-

Figure 1 *The change in the Selsey area between the 5th and early 18th century.*
Upper *The Selsey area in the Roman and Early Saxon periods. The barrier islands are shingle and rock; they are natural features but may have been built up artificially. 'Seals Eye' and 'Midmere Eye' (which meant Middle Island) are the old names for Selsey and Medmerry. Positions of modern towns are shown for comparison with Figure 2. (Based on an unpublished map by Hume Wallace)*
Lower *A close-up of the Selsey area on Richard Budgen's map of 1724. The hamlet in the marshy area to the west of the area named 'Selsey Peninsula' is labelled 'Medmery'. Bracklesham can be seen at the end of the straight causeway.*

ton. As a result, the area attracts a lot of visitors seeking a rural, wilder experience along a stretch of coast otherwise famous for its bustling seaside resorts such as Bognor Regis and Brighton. Forming part of the coastal plain of Chichester, the Manhood Peninsula is open and flat with huge horizons, bordered by the South Downs National Park to the north, Chichester Harbour to the west and Pagham Harbour to the east – all specially protected areas – and the sea to the south.

There are 16 villages and settlements on the Manhood, ranging in size from 165 residents to 12 000, with a total population of about 30 000. The main employment sectors are tourism, agriculture and horticulture, and marine-related activities.

Over the years, the sea has been held back along the coast of the peninsula by a shingle bank reinforced with groynes. This was the situation when I first met Renee Santema. Our youngest daughters both attended the same nursery school in Bracklesham, a few miles along the coast from Selsey (Figure 2). Renee is a Dutch spatial planner whose husband was working in the West Sussex horticultural sector. At the time I was a risk management journalist, with an engineering degree, and had been researching and writing about the impact of climate change since the late 1980s.

Figure 2 *The southern part of the Manhood Peninsula today. Sidlesham, Bracklesham and Pagham can all be seen in the 1724 map in Figure 1. (Map: Google Earth)*

An unsustainable situation

In 1997, when we took a walk along the ridge of the shingle bank between Bracklesham and Selsey we were shocked. The height of the land behind the bank was at sea level at most, and below sea level in parts. The bank had a one-in-one chance of being breached each year, with the Environment Agency forced to maintain a fleet of diggers on the beach during the winter months to shore up the bank after storms and high tides at a cost of more than £200 000 p.a. Just one large storm could result in large part of the peninsula being flooded, cutting off Selsey – once a small fishing village but now a town of 12 000 permanent residents and a population of up to 60 000 when its huge holiday camps are full.

Renee and I were aware that a planning application for hundreds of homes had been made for a former Pontin's holiday camp almost immediately behind the shingle bank in Bracklesham, on extremely low-lying land that effectively acted as a fluvial and coastal flood plain. The developer was proposing raising the land on which the homes were to be built and, as a result, neither the Environment Agency nor Chichester District Council (CDC) objected to the application, and the houses were built.

As Renee explained to me, in the Netherlands water- and flood-management were prioritised and building in such a vulnerable location with no long-term plan for the water management in the area would be considered absurd. I was also aware that the Association of British Insurers had warned that their member companies would not be able to guarantee the automatic provision of flood risk insurance for all homes in the UK for much longer if local planning authorities and the Environment Agency did not take a more precautionary approach to flood risk.

As a result of our concerns we decided to talk to both CDC and the Environment Agency. After separate meetings with directors at the Environment Agency and CDC, we realised that there was a serious lack of long-term integrated water management, coastal defence and spatial planning for the peninsula. When CDC's environmental director thanked us 'for a very entertaining meeting, ladies' after we had spent an hour explaining why having a long-term plan for water management was crucial for the peninsula, we realised it was not going to be easy to persuade the statutory authorities that they needed to plan much more strategically, and long-term, for vulnerable areas such as the peninsula.

Figure 3 *All that was left of 19th century Thorney Farm when it was photographed in 2016, just before it was destroyed by erosion. (Photo: Peter Murphy).*

A change of strategy

Our first initiative was to bring local residents together to act as as a catalyst for change. We hosted evening meetings in local village halls, persuading residents in with the promise of free tea and biscuits, to outline the challenges climate change would bring for water and coastal management on the peninsula. To successfully plan for the future we urged parishes to work together and recognise the peninsula as a whole. The impetus resulted in the establishment of the Manhood Peninsula Forum, which CDC offered to host, enabling the parishes of the peninsula to meet on a regular basis to discuss common issues.

But how to engage wider stakeholders, including local and national authorities, was a tougher nut to crack. Although Renee and I had knowledge and expertise in planning and climate change it was becoming obvious that we were being viewed as 'locals', 'mothers' and 'campaigners' rather than as 'professionals' or 'experts'. It was then that Renee had the bright idea of bringing in Dutch reinforcement – if they wouldn't listen to two local residents, perhaps they would listen to Dutch experts!

After raising £10 000 to cover travel and accommodation expenses, we invited 30 senior Dutch and British experts in coastal engineering, ecology and planning to come to the Manhood Peninsula to help local residents and authorities confront climate change positively. All delegates at the 2001 brainstorming workshop attended free of charge, working for five full days, from 8.00 in the morning until late at night, in mixed disciplinary groups, devising different future plans for the peninsula. Members of the public and councillors joined them at the end of each day to hear the 'blue sky' thoughts of the visitors and to ask questions and make observations.

Figure 4 *The remains of a Late Saxon/medieval timber fish trap exposed in the beach at Medmerry. There would have been wattle hurdles between the wooden stakes which originally form a V-shape, and the fish would have been trapped and left behind when the tide retreated. (Photo: Peter Murphy)*

At the end of the process Renee and I produced a book titled *Going Dutch* (see Further Reading) describing the variety of possible options the experts had come up with, from turning Selsey into an island, to building lake houses, growing salt-resistant crops, creating a peninsula-wide cycle network, and even banning cars.

While the ideas were varied and ambitious, there was one issue on which all delegates agreed. Letting the sea in between Selsey and Bracklesham was the most sustainable, affordable and practical solution to rising sea level, increased wave heights and increased storminess. Moreover, they argued, a managed realignment of the coast presented an opportunity to create acres of valuable wetland habitat, which would be great for wildlife, recreation, tourism and the local economy. A win, win situation.

The double win became a treble win when the Medmerry realignment scheme was used as compensatory habitat creation for wetlands lost because of the expansion of Associated British Ports' container docks in Southampton. As a result, the £28 million costs of the scheme were borne by Associated British Ports, a move which saved taxpayer funds, boosted Southampton's economy and helped Chichester's economy, environment and coastal defences!

However, when the Environment Agency announced in 2008 that it planned to allow the sea to flood inland as *Going Dutch* had outlined, many residents still needed convincing. So Renee, who had by then returned to the Netherlands, and I organised a second workshop, 'Going Dutch II', persuading the Dutch experts to return again (all expenses paid) to stress-test the Environment Agency's plans and to address locals' concerns. The Environment Agency subsequently established the Medmerry Stakeholder Advisory Group to give local residents the opportunity to engage with the project during its construction phase.

When it officially opened in November 2013, Medmerry was Europe's largest coastal realignment scheme, forging a radical new approach to coastal protection in the UK. It was described by the Institution of Civil Engineers as one of the most sustainable projects ever created by the Environment Agency. By constructing a new 7 km flood embankment on higher ground further inland and breaching the existing shingle banks, the scheme produced more sustainable coastal protection whilst creating 183 hectares (183×10^4 m^2) of new intertidal habitat, including mudflat, saltmarsh and transitional grassland and 300 hectares of 'habitat of principal importance'* according to the *UK Biodiversity Action Plan*.

Throughout construction, care was taken to record features of archaeological interest, including many medieval fish traps (Figure 4), as well as to protect

*A habitat supporting species that are most threatened, in greatest decline, or where the UK holds a significant proportion of the world's total population.

Figure 5 ***Upper*** *Aerial photograph of Medmerry, taken in 2015.* ***Lower*** *Map of Medmerry Reserve today, showing different habitats and areas of housing. For most of its length, the inland embankment is on the 'inner' side of the freshwater stream that flows into the Stilt Pools.*

the existing wildlife on the site. New wildlife, including many species of birds, began to populate the scheme long before its completion, and the whole 500 hectare site, and beyond, is now an oasis for birds and other wildlife, surrounded by recreational footpaths, bridle and cycle ways with long-distance views of the South Downs and the sea. The new defences at Medmerry reduced by 1000 times the flood risk to some 350 homes as well as to local infrastructure including the peninsula's sewage works and the main road into Selsey. The new inland banks are designed to provide protection against rising sea level over the next 100 years.

The 450 000 m^3 of earth required for the new defences were dug from within the site, which avoided more than 40 000 lorry movements on the local road network. By altering the height of land within the site, different areas of habitat were created to increase the biodiversity potential of the reserve. 60 000 tonnes of rock was imported from Norway to build the armour revetment structures at each end of the scheme. The huge rocks were delivered by sea which also reduced the impact of the scheme's construction on the local road network.

The scheme was estimated to provide around £90 million of direct economic benefits, including: reduced maintenance costs for the Environment Agency; a new tourist attraction to boost the area's green tourism and help to extend the tourist season; and the provision of fish-spawning and nursery areas for the local fishing industry. The environmental benefits include the creation of new habitat areas enhancing the peninsula's already rich biodiversity so creating a stepping stone for wildlife between Pagham Habour and Langstone and Chichester Harbours and, important for combatting climate change, the establishment of an environment that will sequester carbon. Meanwhile, the social benefits include the provision of recreational footpaths, bridleways and cycleways, and a reaffirmation of the area's sense of place.

Figure 6 *Sea defences old and new.* ***Left*** *The remains of groynes to the east of The Breach.* ***Right*** *Boulder revetments at the eastern end of Medmerry's shingle beach.*

Indeed, Medmerry is now delighting locals and visitors of all kinds (Figure 7), including skylarks, avocet, lapwing, Brent geese, wheateaters, swallows, redshanks, corn buntings, yellowhammers, owls, nightjars, merlins, peregrines, goldfinch, linnets, water voles, deer, dragonflies, dolphins and dog hound sharks!

The Medmerry realignment scheme is included in the British Geography GCSE and A level syllabi. It has also won more than 16 major engineering, community engagement and conservation awards including the Prime Minister's Best Building and was showcased at the IUCN (International Union of the Conservation of Nature) World Conservation Congress in Hawaii.

Meanwhile, the legacy of the 2001 Going Dutch workshop has also stretched further inland. As well as recommending a large-scale managed realignment of the coast, the workshop participants advocated the formation of a partnership between the stakeholders involved in the day-to-day life and future of the peninsula, including residents and local and national agencies.

A few months after the workshop the Manhood Peninsula Partnership was formed, comprising representatives from communities across the peninsula, as well as Chichester District Council, West Sussex County Council, the Environment Agency, the National Trust, Chichester Harbour Conservancy, Natural England, the Manhood Wildlife and Heritage Group and the Royal Society for the Protection of Birds. The Manhood Peninsula Partnership has attracted European and national funding for various projects, ranging from increasing awareness of climate change to improving drainage. More importantly, it has helped the community to face change and work together with local authorities to embrace it.

In 2011, the Manhood Peninsula Partnership published a *Towards Integrated Coastal Zone Management*, making the the Manhood Peninsula one of the first areas in the UK to produce a working ICZM document which was accepted as a material planning document by the local authority.

Subsequent developments

Enhancing the local economy, particularly the vital tourism economy, has always been an important part of the Manhood Peninsula Partnership's work, and it has worked closely with local residents and businesses, and Chichester University's geography and business departments, over the years developing a tourism strategy that seeks to promote and enhance the area's environmental attractions as the basis for a visitor economy linked to outdoor activities such as walking, cycling, water sports and bird watching.

Other initiatives that the Manhood Peninsula Partnership is currently involved with include:

- Selsey and Bracklesham/East Wittering Visions – consulting with local residents to establish visions for the coastal communities on the peninsula.
- Sea's the Day – a project funded by the National Lottery Heritage Fund which celebrated the local fishing industry, and produced a fascinating oral history film and exhibition, local events and sets of recipe cards.
- FLOW – another project funded by the National Lottery Heritage Fund, undertaken by the Manhood Wildlife and Heritage Group to improve the ditches, rifes (streams or channels) and ponds on the peninsula, helping wildlife, habitat and drainage.

Figure 7 Left *Some of the visitors who enjoy the wildlife of the peninsula.* ***Below*** *A black-winged stilt and chick. A pair bred on the reserve in 2014 just after it was completed; this was only the third successful breeding of black-winged stilts in the UK and the chicks were the first to successfully fledge in the UK since 1987. The birds gave their name to what are now known as the 'Stilt Pools' on the western side of the reserve (map in Figure 2). (Photos: Left: Carolyn Cobbold; Right: Bishnu Sarangi/Pixabay)*

• CHASM (Crab Habitat and Sediment Migration) project, examining the changes that have affected the Selsey fishing industry in recent years, such as a reduction in the local lobster and crab catch, increased sediment in fishing grounds, reductions in kelp and species changes.

• The appointment of Manhood Peninsula Partnership and the Manhood Wildlife and Heritage Group as a Nature Recovery Network Delivery Partner to help increase nature recovery throughout the peninsula and wider coastal plain.

• SWISH, a Surface Water Issues subgroup of the Manhood Peninsula Partnership, which seeks to improve drainage and reduce flooding on the peninsula, working with local Flood Action Groups and the Environment Agency and local and parish councils.

• GLAM – Green Links Across the Manhood – is a Manhood Peninsula Partnership subgroup seeking to extend the network of cycle paths and other sustainable transport routes across the peninsula.

With sea level, storminess and rainfall intensity all predicted to continue rising for the rest of the century and beyond, the importance of the Manhood Peninsula Partnership and long-term integrated planning for the peninsula will only increase. National and local authorities and the community will need to continue to work closely together to ensure that risks from climate change to local residents, and to the area's important ecology and economy, are minimised as much as possible. Recognising both the importance of reducing CO_2 levels and the vulnerability of its coastal plain to climate change, Chichester District Council declared a climate change emergency in 2019.

Figure 8 *The Stilt Pools at the western end of the Reserve. The fencing is to ensure that dogs do not disturb nesting birds.*

Local residents are concerned that legislation still is not strong enough to ensure sufficient long-term planning in the face of climate change. Residents argue that building on land which the authorities know will be subject to inundation from the sea in the future would be irresponsible and increase the number of people who will be exposed to potentially catastrophic flooding. The building of more homes in locations vulnerable to flooding also provides a false sense of security, making it far more difficult for statutory authorities to educate people about the possibility and danger of flood risk. Parish councils argue that building on farmland and countryside surrounding the coastal and harbour settlements, which attract many campers and holidaymakers seeking a rural, coastal experience, will also adversely

Figure 9 *An aerial view of Medmerry taken in 2013, showing the shingle and evolving mudflats and saltmarsh. Interestingly, the breach was widening faster than expected. (Photo: John Akerman)*

impact the area's vital tourism and agricultural economy.

Creating and maintaining a balance between safety and security, the economy, environment and social wellbeing will become increasingly difficult for vulnerable coastal locations such as the Manhood Peninsula but will continue to be achievable in our children's and grandchildren's lifetimes if all stake-holders work together.

Further Reading

Bede's *Ecclesiastical History of the English People* (1990) translated by L. Sherley Price and edited by D. Farmer, Penquin Classics. Chapter 13.

Salzman, L.F. (1953) 'Selsey' in *A Victorian History of the County of Sussex, Volume 4: The Rape of Chichester.* London, Institute of Historical Research (originally published by Victorian County History).

Horsfield, T.W. (2009) *The History, Antiquities and Topography of the County of Sussex,* Vol II, Bakewell, Derbyshire, Country Books, p.20.

Stephenson, P. (2014) *Archaeological Excavations at Medmerry Managed Realignment, Selsey, West Sussex. A Post-excavation assessment and updated project design*. Archaeology South East Report No. 2014268. Portslade: Archaeology South East.

Mawer, A. and F.M. Stenton (1929) *The Place Names of Sussex, Part 1.* Cambridge University Press.

Anderson, O.S. (1939) *The English Hundred-Names, the south eastern counties.* Lund, Gleerup, p.72.

Stephenson, P., K. Krawiec, E. Allison and 31 others (2019) *A View From The Edge: Archaeological investigations on the Manhood Peninsula, Selsey, for the Medmerry Managed Realignment Scheme*. SpoilHeap Monograph (available in paperback).

Related websites

https://www.ice.org.uk/knowledge-and-resources/case-studies/managed-realignment-at-medmerry-sussex

Going Dutch on the Manhood Peninsula, Carolyn Cobbold and Renee Santema, in cooperation with NIROV. http://peninsulapartnership.org.uk/abd/wp-content/uploads/2012/12/Going-Dutch-book-a.pdf

Going Dutch II: Towards a safe and sustainable future of the Manhood Peninsula, Carolyn Cobbold and Renee Santema. http://www.chichester.gov.uk/CHttpHandler.ashx?id=5799&p=0

Managed realignment at Medmerry, Sussex, Report by the Institution of Civil Engineers https://www.ice.org.uk/knowledge-and-resources/case-studies/managed-realignment-at-medmerry-sussex

Unless stated otherwise, photographs were taken by the author.

Manhood Peninsula Partnership website https://peninsulapartnership.org.uk

Sea's the Day: The Selsey fishery. The story of the Selsey fishery told by local fishing families: https://www.thenovium.org/article/33826/Seas-the-Day---The-Selsey-Fishery; http://www.solentforum.org/networking/meeting/SeastheDay102019.pdf; https://www.selseytowncouncil.gov.uk/article/31377/Seas-The-Day

Acknowledgments

For advice, and assistance with images, our thanks go to: John Akerman, Hugh Fiske; James Kenny, Archaeology Officer, Chichester District Council; Peter Murphy; Zoe Neal, Selsey Town Council; Adam Taylor, RSPB Pagham Harbour Visitor Centre.

Carolyn Cobbold is a Research Fellow at Clare College, Cambridge, investigating food in the 19th and 20th centuries, and the interactions of science, commerce, industry, government, journalism, culture and law. From 1986 to 2003 she worked as Associate Editor of the US risk journal *Business Insurance*, where she covered climate change and other risks and liabilities facing international companies. Carolyn is a Project Leader of the Manhood Peninsula Partnership.
cacobbold@gmail.com

Stop Press

In association with COP26, the United Nations Climate Change Conference, Medmerry's managed realignment project has been highlighted as successfully piloting the IUCN's new Global Standard for Nature-based Solutions.

The Reserve was showcased at the Conference in a film called 'Coast: Nature-based solutions for climate, biodiversity and people – lessons learned and stories from the ground'. The film also includes other examples of good practice including the Central Mangrove Wetland in the Cayman Islands, Shanghai Chongming Dongtan National Nature Reserve and Jiangsu Yancheng Yellow Sea World Heritage Site in China, and the South Korean Yellow Sea Getbol World Heritage Site.

You can see the film at https://www.youtube.com/watch?v=skbB5HxI6x0

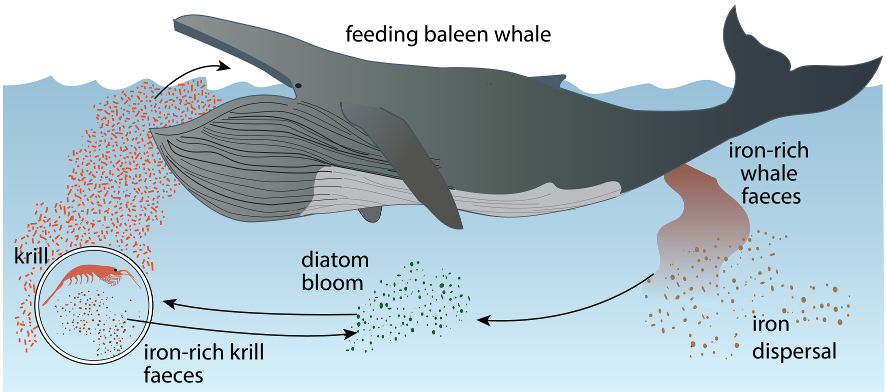
Are whales ecosystem engineers?

Those of us keen on wildlife documentaries will have learnt how the reintroduction of wolves to Yellowstone Park demonstrated the importance of predators in maintaining a healthy ecosystem on land. In a recent article in *Nature*, Savoca *et al*. have re-evaluated the role played in the oceanic ecosystem by baleen whales – whales that feed by filtering seawater though bristle-like combs that fringe their mouths – beginning by calculating how much they consume. In the past, making such calculations has been a challenging exercise, but by tagging whales with sensors and making acoustic measurements of prey density, the authors made estimates of the prey consumed by two groups of whales: blue, fin and humpback whales, which feed by lunging at dense aggregations ('swarms') of krill (and in the case of fin and humpback whales, also shoals of small fish); and right whales and bowhead whales which feed continuously by swimming open-mouthed through dense aggregations of copepods, a technique known as ram feeding.

The authors found that previous estimates had underestimated baleen whale prey consumption in some ecosystems by three-fold. They calculated that in the Southern Ocean alone, pre-whaling populations of baleen whales consumed 430 million tonnes of Antarctic krill (*Euphausia superba*) annually, twice the current total biomass of *E. superba* and more than twice the global catch of marine fisheries today. According to records, about one million whales were killed during the whaling years, and from calculations based on their new findings, the authors estimate that while alive these whales would have consumed about 400 million tonnes of krill annually.

Whales have evolved to be enormous and eat enormous amounts of food – they are the biggest animals ever to live on Earth – and before whaling they had large populations and been successful animals. This raises (at least) two questions: Why have they adopted such an energetic way of feeding? And if there are so many fewer whales today, why aren't there more krill?

The authors suggest that the answer to both questions is 'iron'. Oceanographers commonly refer to the Southern Ocean as being a 'high nutrient, low-chlorophyll' (HNLC) region, because despite the availability of the main nutrients, nitrate, phosphate and silica, numbers of phytoplankton remain low, because of the extremely low concentrations of the micronutrient iron, supplied from land elsewhere in the oceans.



By gulping down huge numbers of krill, and defecating in surface waters, whales fertilise the surrounding ocean, and support more diatoms and hence more krill. The mixing caused by the feeding whales, and their vigorous tail movements, also helps to disperse the iron-rich faeces of both whales and krill.

But the Southern Ocean hasn't always been this way. In the 1920s and 1930s, observations from *Discovery* and *Discovery II* found large populations of phytoplankton, especially diatoms. Krill began to decline after whale populations had been decimated, with the last large-scale surface swarms being recorded in the 1980s. It is still possible to see areas of the sea-surface red with swarming krill, but before the whaling era (which in the Southern Ocean began in 1904) such areas were much more common.

A large proportion of the iron that is in the Southern Ocean today is in living biomass, including krill, which can live for 10 years. The authors argue that by eating enormous numbers of iron-rich krill, and discharging iron-rich faecal plumes, baleen whales fertilise the surface ocean and enhance the growth of diatoms and hence the krill and other zooplankton that feed on them. Furthermore, by their highly energetic methods of feeding they cause a large amount of tubulence – all the more so as they are so enormous. The more krill they eat, the more blubber they can lay down and the more their feeding activities mix up the suface ocean. This mixing not ony disperses the whales' slurry-like iron-rich faeces, and those of the krill, but also keeps the any declining diatom blooms (also containing iron) in surface waters.

The present day scenario of low phytoplankton production could also explain why there are fewer krill – it's thought that the present day krill population is only 20% of that pre-1980, and there is little evidence that other predators of krill (e.g. certain seals and seabirds) have been benefitting from increased availability of krill, as might have been expected.

These findings suggest that if populations of the great whales were to increase significantly, populations of krill, other zooplankton and fish, and their predators, would benefit enormously. This process could be kick-started by increasing populations of phytoplankton by fertilising surface water with iron in soluble form. The increased primary production could have the welcome side-effect of increasing carbon draw-down – one of the ideas asssociated with early iron fertilisation experiments like EisenEx (carried out in 2002), which were widely criticised for various reasons.

So if whales are engineering their ecosystem, should we lend a helping hand? With this thought in mind, Savoca and colleagues propose a small and carefully controlled experiment to test the effects of iron fertilisation on the whales' food webs. Wouldn't it be glorious if there were spouts of feeding whales as far as the eye can see, as was the case before whaling began?

Ed.

Further Reading

Hardy, A. (1967) *Great Waters: A voyage of natural history to study whales, plankton and the waters of the Southern Ocean*, Harper and Row.

Nicol, S., A. Bowie, S. Jarman, D. Lannuzel, K.M. Meiners and P. van der Merwe (2021) Southern Ocean iron fertilization by baleen whales and Antarctic krill. *Fish and Fisheries.* doi: 10.1111/j.1467-2979.2010.00356.x

Savoca, M.S., M.F. Czapanskiy, S.R. Kahane-Rapport and 17 others (2021) Baleen whale prey consumption based on high-resolution foraging measurements. *Nature* **599**, 85–105. doi: 10.1038/s41586-021-03991-5

Smetacek, V. (2021) A whale of an appetite, *Nature* (News and Views), **559**, 33–4.

The seagrass Zostera marina *growing in the Pen Llŷn a'r Sarnau Special Area of Conservation in North Wales (Photo: © WWF)*

In our coastal seas grows a wonder plant which provides a nursery for new marine life, sequesters carbon and armours our coastlines against erosion. The plant, commonly known as seagrass, forms large meadows which are some of the most productive ecosystems on the planet. Seagrass meadows are one of the most widespread coastal habitats on Earth, and just a single hectare ($10^4\,m^2$) can harbour up to 80 000 fish and as many as 100 million invertebrates. The same area could produce up to 100 000 litres of oxygen per day and can sequester more carbon than the equivalent area of pristine rainforest. Seagrass meadows are often described as the 'lungs of the sea', but their value to planetary health has not been as well articulated as that of other ecosystems, something that 'seagrass scientists' – including those of us working for Project Seagrass – are seeking to change. Like so many other valuable ecosystems, seagrass meadows have been in global decline since the early 20th century. Despite groundbreaking research into seagrass meadows in recent years, this key marine habitat remains threatened and under-appreciated, but the tide may be turning.

What is seagrass?

Seagrasses are angiosperms – flowering plants. They are found in shallow, sheltered parts of coastal seas, as well as estuaries and lagoons, and usually require sandy or muddy substrates. Some species can be exposed at low tide, but seagrass should not be confused with saltmarsh vegetation which grows in the upper intertidal zone. Seagrasses vary in appearance dependent on species but many resemble the grass found in an uncut lawn. The UK native *Zostera noltei* particularly fits this description. Others, such as *Halophila ovalis,* found in the Indo-Pacific, have broader and much rounder leaves.

Figure 1 *Male and female flowers on adjacent blades of* Zostera marina*. The female flower has pollen attached to its style, and the male flower behind it has a thick petal a few millimetres long, with an anther, which produced the pollen. (Photo: Richard Lilley)*

Seagrass evolved from terrestrial plants that re-colonised the ocean 70–100 million years ago. There are approximately 60 recognised species, belonging to four families: Cymodoceaceae, Hydrocharitaceae, Posidoniaceae and Zosteraceae. Seagrasses are found on every continent except Antarctica, and can be divided amongst six seagrass bioregions; four (including the Mediterranean bioregion) are temperate and two are tropical (Figure 2). Growing in and around temperate intertidal estuaries and lagoons, *Zostera marina* dominates many of the seagrass communities and so has been the focus of restoration efforts across the temperate North Atlantic, most notably those

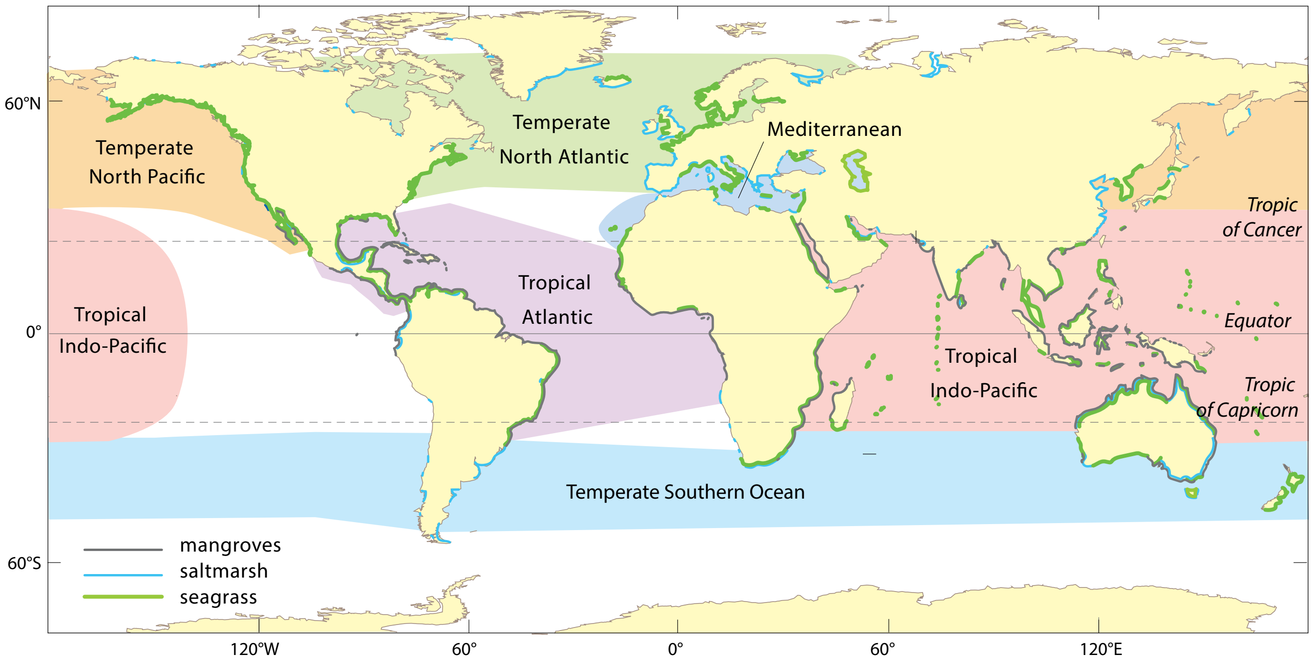


Figure 2 *The six seagrass bioregions, and generalised distributions of the three coastal 'blue carbon' habitats. The map does not necessarily reflect present-day distributions as many habitats are damaged, but it does show that the length of coastline where seagrass could flourish is greater than those for saltmarsh or mangroves. (This map combines information from the Blue Carbon Initiative website, and from Short* et al. *2007; see Further Reading)*

in Chesapeake Bay, Virginia. Both temperate and tropical species flourish in the Mediterranean; the endemic *Posidonia oceanica* is a deeper growing species and thrives in clear, warm water, so is prevalent throughout the Mediterranean. *P. oceanica* also has a very high carbon absorption capacity, with some studies finding that it can absorb carbon 15 times more efficiently than primary (i.e. pristine) rainforest.

Seagrass meadows in the tropical bioregions support mega-herbivore grazers such as dugongs and sea turtles. *Thalassia testudinum*, sometimes known as turtle grass, is highly prevalent in the tropical Atlantic; in contrast, the Indo-Pacific has the highest seagrass diversity in the world – in some regions up to 14 species may grow together in one area.

Because it photosynthesises, the spatial extent of seagrass is limited in part by the clarity of surrounding water. In productive temperate North Atlantic and North Pacific regions, where phytoplankton blooms may prevent sunlight penetrating very far into the water column, seagrasses are found no deeper than 10 m, whereas in the nutrient-poor, less productive Mediterranean, where sunlight can reach much deeper, *P. oceanica* beds can be found as deep as 50 m. Similarly, tropical species, such as *Halophila decipiens* (Caribbean seagrass or paddle grass) have been recorded as deep as 60 m. Some researchers suggest *H. decipiens* could grow even deeper in areas of exceptional water quality.

In the UK, there are two species of seagrass: *Zostera marina* and *Zostera noltei* (commonly known as eelgrass and dwarf eelgrass respectively), both of which are perennial. *Z. marina* is usually bright green in colour and has a long stem with several thick leaves. Mature plants usually grow to be around a metre tall and when submerged they stand upright and move with the current, much like a field of grass moves with the wind. Like other seagrasses, *Z. marina* plants anchor into soft sand or mud using their rhizomatic networks; the leaves are then able to 'catch' particulates from the water column which in turn collect around the foot of the plant, further securing it into the sea bed. *Z. marina* usually grows in the 3–6 m depth range, but it has been known to grow in water as deep as 10 m in places with outstanding water quality. In shallower areas it can be entirely exposed at low tide, and provide a feeding ground for many bird species, which eat the small crustaceans found in and around the now flat blades of seagrass. The smaller, narrow-leafed *Z. noltei* can reach ~22 cm, and grows extensively around the Thames estuary, the Wash and the Firths of Moray and Cromarty (cf. Figure 5). It prefers finer, muddier sediment and grows either permanently submerged or, if the sediments retain sufficient water to prevent the rhizomes drying out, above the low-tide mark. Sometimes, *Z. marina* and *Z. noltei* can be found growing together.

In its healthiest state, seagrass grows in vast meadows, sometimes covering thousands of hectares. The word 'meadow' was adopted because of the resemblance to terrestrial grasslands, and coining this description has proven an effective way of conveying the rich biodiversity that thrives within the complex three-dimensional environment seagrass creates.

Ecosystem goods and services

The importance of seagrass meadows for people and the planet makes them one of the most valuable ecosystems globally. When undisturbed, these habitats can thrive and have the capacity to support a complex and fragile system of goods and services that communities around the world depend on for food security, livelihoods, carbon sequestration and coastal protection. Unfortunately, as the ever-changing coastal landscape has become increasingly industrialised, seagrass communities have become fragmented, damaged and in many cases, entirely destroyed.

Biodiversity and fisheries Seagrass meadows are biodiversity hotspots, full of diverse and productive marine life. A meadow provides a 3-dimensional structure in what might otherwise be a barren seascape, offering refuge and nursery grounds for commercially and recreationally targeted fish, crustacean and bivalve species. They provide vital nutrition to 3 billion people and 50% of the animal protein consumed by some 400 million people; their presence underpins countless local economies.

Globally, seagrass supports around 20% of the world's largest fisheries by providing nursery habitat to many commercially important species. Whilst few species will remain in seagrass for the entirety of their lives, a great many benefit considerably from its existence, with meadows providing food, shelter and for some species a safe environment in which to breed or lay eggs. Recent studies have found that 50 species of fish live amongst or visit UK seagrass at some point in their life cycle (Figure 3) and that undisturbed meadows can support 30 times more animals than a nearby 'naked' habitat.

Carbon sequestration Although they only occupy 0.1% of the sea floor, seagrass meadows are responsible for up to 18% of organic carbon buried in the ocean globally. Alongside mangroves and coastal wetlands, some extremely productive species of seagrass can sequester carbon at rates several times faster than tropical rainforests. These species absorb CO_2 in excess of their needs and transport it into the root and rhizome network within the sediment where it can be stored for millennia. The exceptional CO_2-capturing ability of these productive species (of which *Posidonia oceanica* is an extreme example) offers a unique opportunity to combat the growing climate change problem.

When seagrass meadows are destroyed, the fact that they are no longer there to take up CO_2 is only part of the problem. Loss of seagrass, much like the loss of forests, mangroves and other carbon sequestering ecosystems, is contributing towards the vast amount of carbon being released from sinks where it has been stored for millenia. It has been estimated that present rates of seagrass loss globally could result in release to the atmosphere of up to 299 x 10^6 tonnes of carbon per year.

A restored hectare of *Z. marina* could capture around 0.4 tonnes of CO_2 annually (minimum estimate), and over a century this could equate to 40 tonnes of CO_2 per hectare (i.e. per 10^4 m^2). However, even a 'natural' (non-restored) meadow could contain up to 380 tonnes of carbon per hectare, and given the lack of scientific data in this area it's possible that in some cases this number could be even higher. In the UK, seagrass meadows are believed to have historically had the capacity to store 11.5 Mt of carbon, whereas recently mapped seagrasses (8493 ha) have an estimated carbon storage of only 0.9 Mt (around £22 million in the current carbon market).

Water filtration Seagrass also offers a natural 'filtering' mechanism, trapping sediment and removing excessive nutrients from the water column. The leaves of the plant physically slow down the movement of particulates and encourage deposition of sediment, detritus and foreign bodies, perhaps even microplastics (research into the ability of seagrass to 'trap' microplastics is still ongoing). The plant can also take up nutrients from the ambient water column and the interstitial water of the sediment. By removing waste of both natural and human origin, seagrasses effectively clean the surrounding environment through

Figure 3 ***Left*** *A young plaice (*Pleuronectes platessa*) sheltering in* Zostera marina. ***Right*** *A great pipefish (*Syngnathus acus*) peers out from filamentous algae that is overgrowing a seagrass bed (*Zostera marina*) in Studland Bay, Dorset. (Photos: Left, Paul Naylor; Right, © WWF UK)*

nutrient cycling. However, loading of nutrients has been seen to exceed the capacity of estuarine seagrass meadows to 'filter' the water, often leading to degradation. In some areas of the UK, algae-rich, anoxic and muddy conditions, resulting from excessive agricultural and industrial runoff, have wiped out seagrass communities in extremely short time frames. With decreased water quality and loss of water clarity, basic plant functions such as photosynthesis are inhibited. This can result in a dieback (different from the annual dieback expected in perennial species), which results in a permanent reduction of its spatial extent and ultimately with complete loss of the meadow.

Ocean acidification Recent research has also highlighted the ability of seagrasses to regulate the chemical composition of surrounding seawater by photosynthesising. Work on *Zostera marina* meadows has shown that seagrasses can alleviate low pH conditions by decreasing the hydrogen ion concentration [H^+] of seawater by 30% (equivalent to a rise in pH of > 0.1) for extended periods of time, including night, when photosynthesis is not occurring. This buffering can temporarily bring water chemistry in seagrass meadows back to pre-industrial pH conditions, and so protect certain marine animals from the harmful effects of acidification, which makes it harder for them to grow shells or skeletons, and means that shells are more susceptible to dissolving.

Coastal protection The complex web of roots and rhizomes creates a structural network that holds together areas of finer coastal sediment. The intricate three-dimensional seagrass system helps combat coastal erosion and creates a thick canopy above the sea bed that traps sediment particles and dissipates wave energy (an effect also seen with mangroves). In areas affected by frequent and powerful storms this can provide a much needed defence. The absence of seagrass, and its associated wave-calming effect, results in a barren seascape, free of obstacles, that allows wave energy to build up, with potentially disastrous consequences. As major storm events become more common, areas that have suffered mass loss of seagrass will likely become subject to increasingly rapid coastal erosion and flooding.

Tourism and recreation Seagrass meadows offer opportunities for tourism and recreational activities, and not just in tropical waters. British seagrass offers a unique opportunity to observe many wild animals and birds. Wildfowl such as wigeon and brent geese graze on exposed seagrass at low tide making intertidal meadows a unique spot for birdwatchers. Seagrass meadows are attractive places for diving and snorkelling, because of the presence of popular species such as cuttlefish, pipefish (Figure 3) and on occasion, the UK's two species of seahorse: the short-snouted seahorse (*Hippocampus hippocampus*) and the spiny seahorse (*Hippocampus guttulatus*). The habitual use of meadows by fish targeted by recreational anglers makes them popular fishing spots, and the sea-calming effect of meadows also makes them appealing for paddleboarding, kayaking and other watersports.

Seagrass loss and ecosystem degradation

The best global estimates suggest there has been a 35% loss of seagrass worldwide, with the most recent census estimating an annual 7% loss, the equivalent of a football pitch every 30 minutes. Unfortunately, poor historical records, combined with seagrass being overlooked in conservation agendas, means there is no comprehensive picture of seagrass distribution around the world. Around 300 000 km² has been mapped globally, but it's hoped that actual coverage could be significantly higher. Through further research, remote sensing, and the use of citizen science platforms (*discussed later*), the hope is to gather more data globally to help to verify these estimates.

There is some good news. Figure 4 shows some results from a study of the European coastline that found that decades of efforts to reduce nutrient inputs, improve coastal water quality and conserve and restore seagrass meadows, have led to some remarkable reversals in seagrass decline. Following sustained losses of seagrass all around Europe throughout the 20th century, between 2000 and 2010 there was a substantial increase in coverage.

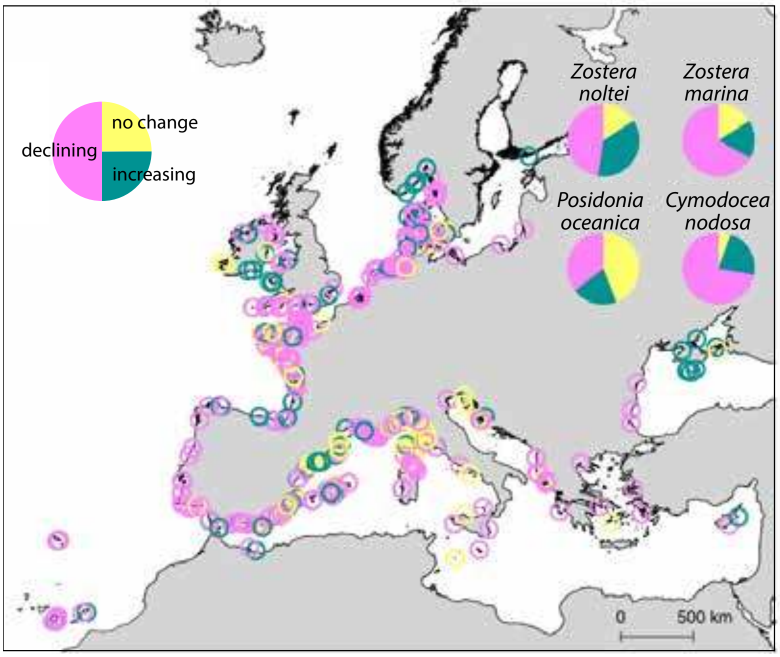


Figure 4 *Seagrass sites in Europe showing no change (yellow circles,* n = *213), increase (green circles,* n = *160), and decline (magenta circles,* n = *364) based on the available time-series reports between 1869 and 2016. Numbers of sites showing decline/increase/no change are, respectively: 128/72/158 for* Posidonia oceanica*; 146/37/35 for* Zostera marina*; 39/12/3 for* Cymodocea nodosa*; and 51/39/17 for* Zostera noltei*.*
http://creativecommons.org/licenses/by/4.0/

Loss of seagrass meadows around the UK

There is now extensive evidence to suggest that in the course of the last century, as much as 92% of the UK's coastal seagrass has been lost. Anecdotal distributions suggest seagrass was once well established in the River Severn and Bristol Channel, but information regarding past distribution on the western shores is extremely limited. Large expanses of intertidal seagrass have been lost in areas of Cornwall and similar loss has occurred in the estuaries of the rivers Stour and Orwell. There is evidence to suggest that extensive loss has also occurred in the Humber, and off Hampshire and the Isle of Wight, including the Solent, which is currently the focus of a number of restoration projects.

Figure 5 *Estimated seagrass cover around England, Scotland and Wales in 1933, based on incomplete surveying, and some of the locations mentioned in the article. An assessment made using data collected since 1998 found that the most extensive seagrass meadows are still around mainland Scotland and the Scottish islands. (Seagrass distribution is from Butcher 1934, see Further Reading; map based on original image created at University College London)*

Whilst the exact extent of UK seagrass loss will remain unknown, many studies still cite the wasting disease of the 1930s (caused by the pathogenic organism *Labyrinthula zosterae*) which probably infected seagrass meadows already weakened by multiple stressors, as responsible for the drastic reduction of seagrass around the British coastline. However, quantitative data to clarify whether *L. zosterae* dealt the final blow to already weakened meadows are largely unavailable.

The reasons for the decline of seagrass meadows vary from meadow to meadow, and include unmonitored and mismanaged boating and fishing practices (Figure 6), pollution and coastal development. Anthropogenic impacts, and in particular historically poor water quality, have caused considerable loss of seagrass. As discussed earlier, effluent and other nutrient-rich runoffs can, in large quantities, inhibit the productivity of seagrass and eventually lead to mass decomposition and loss. In some instances, extreme nutrient levels promote the growth of competing seaweed blooms, and the seagrass suffers the effects of light-reduction and hypoxia. In certain areas, coastal infrastructure driven by centuries of mining activity has resulted in contamination of coastal and inland waters, likely acting as a significant driver behind the loss of seagrass.

In general, seagrass can recover from physical damage to the above-sediment vegetation within relatively short time frames. However, damage to the roots and rhizomes can seriously impede plants' ability to produce new growth, and so in some cases they may never be able to recover. When a meadow faces infrequent stressors but is otherwise healthy, it is able to recover rapidly; when the stressors persist, seagrass will reach a tipping point beyond which a meadow will fail to recover. There is also no doubt that the continuing anthropogenic stressors of coastal development and pollution have hindered the natural recovery of seagrass meadows.

Efforts to protect seagrass around Britain

Seagrass meadows around the British Isles are recognised as a Priority Habitat under the UK Post-2010 Biodiversity Framework, and as a Feature of Conservation Importance, an attribute that can be used in the designation of Marine Protected Areas (MPAs). The OSPAR Commission lists seagrass under 'Threatened' and 'Declining Species and Habitats' (OSPAR is the Convention for the Protection of the Marine Environment of the North-East Atlantic). However, despite growing recognition of their importance, to date there has been little attempt to seriously protect the remaining naturally occuring meadows or to invest in large-scale restoration at viable sites. In 2016, the UK Government set out to protect 4×10^6 km^2 of marine environment across the UK Overseas Territories through the Blue Belt Programme, but to date there has been no equivalent programme for the British Isles. In 2020, the Joint Nature Conservation Committee

(JNCC) found that 29% of MPAs in the UK were intended to protect carbon-sequestering habitats such as seagrass meadows. However, the data suggest that although MPAs were introduced in the 1970s, unsustainable practices that degrade the benthic environment are still prevalent in many of these protected areas. Over 50% of UK MPAs were set up under EU laws, and so now, post-Brexit, it is critical that the UK sets out to maintain and improve upon the management conditions established during the UK's membership of the EU. We find ourselves at a point when the UK Government has an opportunity to enhance policies and protections that will safeguard our coastlines from further over-exploitation, or roll back environmental protections and undo some of the gains made in recent years.

What is being done? Conservation and active protection of remaining seagrass meadows are vital. Restoration efforts such as those being undertaken in Chesapeake Bay have provided some basic principles for restoration that can be applied across the globe, but each case is unique and what works in one restoration area cannot always be reproduced elsewhere. Restoration of seagrass is a constantly evolving area, and efforts such as Seagrass Ocean Rescue, a 2-acre restoration pilot in Dale Bay, Pembrokeshire (Figure 5), led by Swansea University and WWF, have helped pave the way for future restoration work in the UK. There are aspects of the UK coastal environment that mean that we have had to develop harvesting, processing and planting methods that may differ from those used in projects overseas.

An example of this developing methodology is BoSSLine (Bags of Seagrass Seeds Lines), created by a team at Swansea University. This method involves planting seeds and sediment using hessian bags attached to strings anchored to the sea bed (Figure 7). Using BoSS 'lines' is proving a successful strategy in early UK trials. The method has not only reduced some of the difficulties of safely planting seagrass by hand but also eliminated the ongoing battle with European green shore crabs, which consume seagrass seeds: this method is not perfect, and there's a lot to learn as restoration efforts take off around the UK, but it certainly represents an encouraging start for the UK's seagrass restoration journey. Restoration does not always have to begin from scratch, population reinforcement projects (adding plants to existing meadows) are also a way of accelerating natural recovery in locations where there is confidence that seagrasses are able to survive.

Following the replanting pilot in Dale Bay, there are hopes to plant seagrass in scarred meadows in North Wales and the Solent. Project Seagrass is also working in areas where seagrass is being damaged by anchor chains: at low tide, a slack anchor chain will be moved around on the sea bed by tidal currents, creating a circular scar (Figure 6).

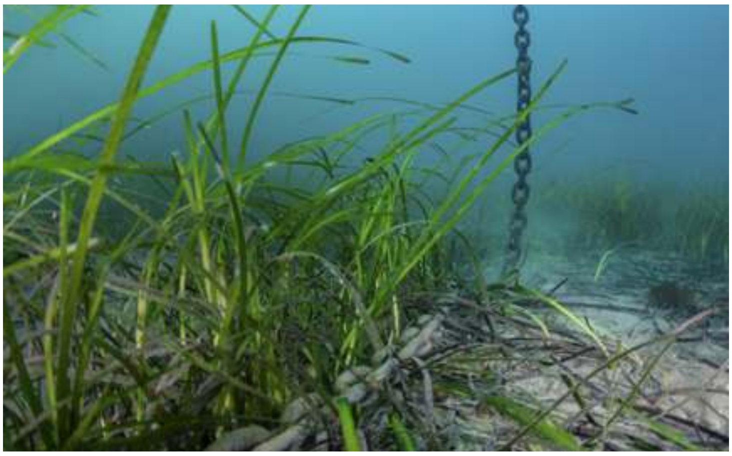


Figure 6 *Anchor and mooring chains have been linked to the fragmentation of seagrass meadows in areas where there is a lot of sailing and fishing activity. The continual movement of heavy chains can damage the surrounding area of seagrass, resulting in a scarred patch of bare sand. (Photo: © Lewis Michael Jefferies)*

We are therefore encouraging the use of Advanced Mooring Systems (AMS) which work by lifting the anchor chain up and away from the sea floor, thus reducing the damaging effects of repeated moorings. As a bridge is being built between local communities and those of us working in conservation, there are opportunities to improve anchoring regulations and install marker buoys to warn water users of the seagrass below (Figure 7).

It's important that any efforts to conserve and protect seagrass work with coastal communities and not against them. Conservation work should set out to strengthen the relationship between communities and seagrass meadows and protect the provision of seagrass services. Successful seagrass science is about working collaboratively and it's an exciting time as projects such as the LIFE Recreation ReMEDIES project on the south coast of England begin their work, and various community-led projects set about their own restoration activities. There are also plans in the pipeline to improve the condition of 'at-risk' seagrass meadows around the coast of the UK.

Figure 7 ***Left*** *A volunteer deploying bags of seagrass seeds as part of the Seagrass Ocean Rescue restoration pilot in Dale Bay, Pembrokeshire.* ***Right*** *A seagrass marker buoy installed in Dale Bay. (Photos: Left: © Joseph Gray/WWF UK; Right © daleseagrass.org)*

Project Seagrass At Project Seagrass, it is our mission to lead societal change to enable the recognition, recovery and resilience of seagrass ecosystems globally. Our vision is a world in which seagrass meadows are thriving, abundant and well managed for people and the planet. Project Seagrass was founded in 2013, and as an independent marine NGO we have grown and matured with support from both Cardiff University and Swansea University, universities with whom we have worked both collaboratively and in partnership, with the aim of turning cutting-edge research into effective conservation action and education schemes. As a dedicated team of seagrass scientists, we work to protect seagrass, and through protecting seagrass, we support marine conservation more broadly.

Figure 8 *Project Seagrass volunteers snorkel for seeds in a seagrass meadow off Porthdinllaen, North Wales (Figure 5) as part of the Seagrass Ocean Rescue restoration initiative with WWF and Sky Zero. (Photo: © WWF UK)*

Today, in 2021, we are working with WWF on a groundbreaking 'Seeds of Hope' project to restore the UK's lost seagrass meadows. We started small, with the pilot project in Dale Bay, but we have bigger plans. We are currently looking to re-establish 2500 hectares of seagrass meadows across the UK by 2030. Until Seagrass Ocean Rescue was launched in early 2019, there had been no successful large-scale seagrass restoration projects in the UK. However now, as more and more stakeholders begin to look towards nature-based solutions, and there is an opportunity to work collaboratively with the Government to improve nature, it's important that decisions are made not only to restore seagrass in the British Isles but also to better protect those healthy meadows that we already have. As the UK Government seeks to drive private sector investment in nature, our hope is to see more initiatives dedicated to marine habitat conservation and not just restoration. As the old adage goes, prevention is better than cure.

Figure 9 *Seagrass Spotter was the product of a collaboration between Project Seagrass, Swansea University, Cardiff University and Seagrass Watch. The app allows people all around the world to become 'citizen scientists', contributing to marine conservation by using their mobile phone.*

Citizen science and community-led conservation Project Seagrass are advocates for citizen science, and from our perspective it's a largely untapped resource for the scientific community. Using tools such as 'Seagrass Spotter' (Figure 9), a free app, we have gained access to data that were previously unavailable. Using SeagrassSpotter.org, ocean enthusiasts around the world can become citizen scientists who contribute to marine conservation with just a few taps of their phone. Our vision is that through citizen science we can build a comprehensive picture of seagrass distributions around the world, and that when we combine these data with remote sensing observations, we will be better able to understand the causes of seagrass loss.

Community-led projects such as Seawilding in Loch Craignish are pioneering, on-the-ground, citizen science. Project Seagrass hopes to support and help facilitate more projects like this in the future.

Project Seagrass's contributions to United Nations programmes

Project Seagrass's ambition for the next ten years is to bring seagrass forward in the marine conservation agenda and ensure its protection for future generations. We have therefore officially partnered with two strategic United Nations 'Decades' in the race to mitigate the lasting effects of climate change and biodiversity loss.

In collaboration with the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP) has launched the 'United Nations Decade on Ecosystem Restoration'. The explicit aim of this Decade is preventing, halting and reversing the degradation of ecosystems worldwide in the period 2021–2030. Project Seagrass has partnered with this Decade to further restore seagrass ecosystems in the UK, setting out to re-establish a large area of seagrass with WWF UK and a number of other strategic project partners over the next ten years.

The second Decade, also running from 2021 to 2030, is the 'United Nations Decade of Ocean Science for Sustainable Development'. The Intergovernmental Oceanographic Commission (IOC) of UNESCO has been tasked by the UN General

Figure 10 *Project Seagrass has partnered with the United Nations Decade on Ecosystem Restoration*

Assembly to work with all interested stakeholders to design a decade of ocean science that will help us to 'deliver the ocean we need, for the future we want'.

Agenda 2030 and the United Nations Sustainable Development Goals (SDGs) At Project Seagrass we also want to maximise our contribution towards the United Nations' Agenda 2030 and its Sustainable Development Goals (SDGs). Seagrass conservation and restoration efforts support a number of the SDGs: there are obviously clear links to Goal 13 (Climate Action) and Goal 14 (Life Below Water), but working to protect and restore seagrass ecosystems indirectly supports a number of other SDGs. As seagrass meadows provide such a wide range of environmental and socio-economic benefits, from mitigating the effects of climate change to putting food on the table, they are just as critical for life above water as they are for life below.

Conclusion

Seagrass is slowly gaining the recognition it has long deserved as an ecosystem that underpins livelihoods for coastal communities. The effects of climate change, coastal urbanisation and largely unmonitored fishing practices are currently being felt on a cataclysmic level beneath the waves, and as we move forward it is vital that we set out clear pathways to protect and enhance existing and restored ecosystems so that we may continue to benefit from the ecosystem services they provide.

Protecting what we have is far easier than restoring what we have lost, but restoring seagrass meadows is not enough when they are being lost at such a fast rate. As a more comprehensive picture of global and specifically the UK's seagrass is developed, it will become easier to work out what needs to be done to return these areas of habitat to their former glory. It's important to remember that collaboration is key, and that real success derives from engaging coastal communities in the restoration process. If our journey as an organisation has taught us anything, it is that achieving our mission begins with how we build our team and how we work together and with others. As a dedicated interdisciplinary team we are passionate about securing a future for seagrass. We believe – indeed, experience has taught us – that only by bringing together a diverse range of identities, experiences and perspectives can we respond to truly global challenges.

Further Reading

Butcher, R.W. (1934) *Zostera.* Report on the present condition of eel grass on the coasts of England, based on a survey during August to October, 1933. *ICES J. Mar. Sci.* **9**, 49–65. doi: 10.1093/icesjms/9.1.49

Bekkby, T., N. Papadopoulou and 12 others (2020) Habitat features and their influence on the restoration potential of marine habitats in Europe. *Front. Mar. Sci*., 7 April 2020. doi: 10.3389/fmars.2020.00184

de los Santos, C.B., D. Krause-Jensen and 25 others (2019) Recent trend reversal for declining European seagrass meadows. *Nat. Commun*. **10**, 3356. Published online 2019, Jul 26. doi: 10.1038/s41467-019-11340-4

Duarte, C.M., S. Agusti and 13 others (2020) Rebuilding marine life *Nature* **580**, 39–51. doi: 10.1038/s41586-020-2146-7

Fourqurean, J.W., C.M. Duarte and 9 others (2012) Seagrass ecosystems as a globally significant carbon stock. *Nature Geoscience* **5**, 505–9. doi: 10.1038/NGEO1477

Green, A.E, R.K.F. Unsworth, M.A. Chadwick and P.J.S. Jones (2021) Historical analysis exposes catastrophic seagrass loss for the United Kingdom. *Frontiers in Plant Sci.* doi:10.3389/fpls.2021.629962

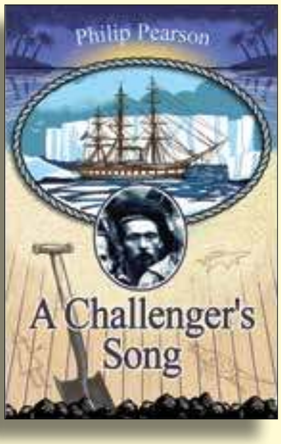
Marine Unprotected Areas Summary Report by the Marine Conservation Society (2020) https://media.mcsuk.org/documents/marine-unprotected-areas-summary-report.pdf

Out of the Blue: The value of seagrasses to the environment and to people. Report by GRID-Arendal and UNEP-WCMC. https://www.unep.org/resources/report/out-blue-value-seagrasses-environment-and-people

Ricart, A.M., M. Ward and 9 others (2021) Coast-wide evidence of low pH amelioration by seagrass ecosystems. *Global Change Biology* **27** (11), 2580–91. doi: 10.1111/gcb.15594

Waltham, N.J., M. Elliott and 16 others (2020) UN Decade on Ecosystem Restoration 2021–2030: What chance for success in restoring coastal ecosystems? *Front. Mar. Sci*. 20 February 2020. doi: 10.3389/fmars.2020.00071

Eve Uncles is a graduate of Swansea University and is now the Project Support Officer at Project Seagrass. She has dedicated the last three years to supporting the restoration efforts and research conducted by Seagrass Ocean Rescue both as a volunteer (SCUBA diving) and full time officer. In 2021, she used her skills as a commercial drone pilot to map seagrass, and is training to become a commercial skipper. eve@projectseagrass.org



A Challenger's Song

by Philip Pearson

Charlie Collins was the last surviving member of the crew who served during the *Challenger* Expedition (1872–76). In this book, by his great-grandson, readers of *Ocean Challenge* who enjoyed 'A song for the *Challenger*'s crew' (Vol. 23, No. 2) can learn more about Charlie's life and his time onboard the *Challenger.* Stories passed down through Charlie's family are combined with accounts by others who sailed on *Challenger* to provide a vivid picture of the difficulties of undertaking science at sea in the 1870s, and of Charlie's tough but interesting life.

Austin Macauley Publishers ISBN: 978-1-913898-11-3
Available as paperback (£10.99) and as an ebook (£3.60).
(Austin Macauley paperbacks are 35% off at time of going to press)

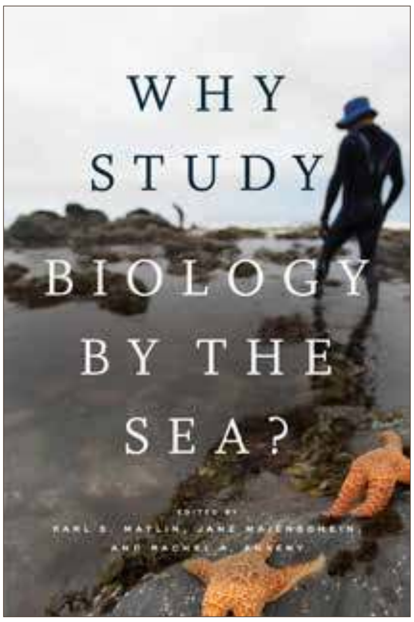
To order online, go to https://www.austinmacauley.com/book/challengers-song

Book reviews

Why marine biological stations matter to us all

Why study biology by the sea? edited by K.S. Maitlin, J. Maienschein and R.A. Ankeny (2020) Part of a 4-book series *Convening Science: Discovery at the Marine Biological Laboratory.* University of Chicago Press, 355pp. £36 (paperback, ISBN: 978-0-226-67293-9), £81.26 (hard cover, ISBN: 978-0-226-67276-2), £34 97 (e-book 978-0-226-67293-9).

The intriguing title may give you the idea that this is a textbook of marine biology. It is not. It is a historical celebration of what we can learn about biology from studying marine animals and especially of the indispensable role played in that context by marine research stations. To achieve this, the book homes in on four marine stations in different parts of the world: the Marine Biological Laboratory at Woods Hole in Massachusetts, the Stazione Zoologica Anton Dohrn at Napoli, the first modern marine station in China associated with Amoy University, and the Misaki Marine Biological Station in Japan.



The book reviews the history of these institutions and how they came about, which is quite different for each one. But the main emphasis is on key activities that have taken place in these and other marine stations which have contributed to general biological knowledge. To achieve that aim the book has two parts. The first four chapters, Part 1 of the book subtitled 'Marine Places', introduces the four stations, and the second part, subtitled 'Marine Practice', has eight chapters, each dealing with a different area of biological knowledge obtained from marine organisms.

The biological topics used to exemplify the role of marine stations begin with animal behaviour, particularly the use of laboratory studies beside the sea on tropisms (responses to environmental stimuli) in marine animals. This is followed by a chapter on the 'Scientific Fishery', which goes beyond fisheries to exemplify the importance of knowledge of different floral and faunal parts of the ecosystem which contribute to the fishery, particularly seen in a series of Mediterranean studies at Napoli. Another chapter emphasises the importance of research and education going together in marine studies. Not surprisingly, the classic role of studies on squids in research on neuroscience is covered. Microscopic studies on cells of freshly obtained marine animals is highlighted. A really topical chapter covers corals and the various changes in reefs over the last three decades. Studies on marine molluscs and echinoderms are used to exemplify work on fertilisation and cell cleavage in sexual reproduction. The final topic reviewed is vascular biology where hagfish were chosen to study developments in tissues which might one day inform human medical practice.

This book came about as a consequence of an Annual History of Biology Seminar in 2016 at Woods Hole entitled 'Why Marine Studies?' The 14 authors (who include the three editors) were drawn principally from the USA, but there were also one each from Japan, Italy, China, Australia and the UK. Each chapter has its own reference list, and many of the lists are usefully extensive, so that this is something like a symposium volume. A final epilogue stresses how there is so much to learn about biology from the oceans, which represent 70% of the Earth's surface but whose biology is so less well known than that of land.

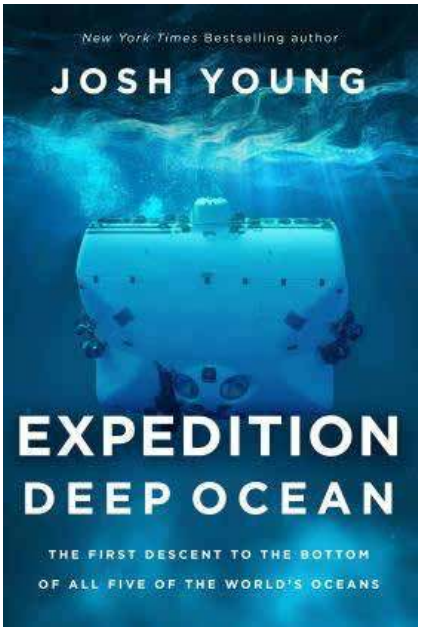
The book is predominantly historical but shows clearly why biology as a whole can learn from studies on marine animals beside and in the sea, and why marine biological stations have an important role to play here. But some projection to the future is made, which is pertinent at a time when we are so concerned with climate change. The reviewer is a seaweed specialist and so was a little disappointed to see that throughout much of the book biology was considered synonymous with zoology when our concern with the climate should also include the important role of marine plants in the cycling and storage of carbon. But the book is mainly a historical review and the focus on animals is probably a true reflection of past attitudes.

This is not a UK-centred book, and important institutions elsewhere in the world are used to successfully establish the significant role of marine stations. It is important to learn from this, and protect our remaining British marine biological research stations – several have closed during the reviewer's professional lifetime. This lesson of the book is important to us all but the volume will be of particular interest to those interested in the history of biology and of marine zoology.

Martin Wilkinson
Heriot-Watt University

Diving deep

Expedition Deep Ocean: The first descent to the bottom of all five of the world's oceans by Josh Young (2020) Pegasus Books, 384pp. £27.95 (hardcover, ISBN: 978-1-643-13676-9). (See the Pegasus website for how to buy the book, and the various different formats available.)



Multi-millionaire Victor Vescovo had a glittering career in high finance, was a successful intelligence officer in the US navy, and had completed the so-called 'Explorers' Grand Slam' (climbing the tallest mountain on each continent – including Everest in 2010 – and skiing to the North and South Poles). So what next? The answer, as narrated in this book, was to dive to the deepest point in each of the five oceans. The only problem was that in 2012 there was no vehicle that could carry a person to such extreme depths. So Vescovo (who already owned and piloted his own jet aircraft and helicopter) decided to build one – at no small cost – and pilot it himself. When the completed system (submersible, support ship with multibeam echo-sounder and ancillary boats, and three autonomous ocean-bottom landers) was put up for sale in 2019, the price was $48.7 million which, for comparison, was more than NOAA's annual 'exploration and research' budget.

Although I was slightly put off by the blurb on its cover, I really enjoyed this book. It should be said that it does not claim to be a book about the science of the deep oceans (the 'hadal zone'), but an account of a feat of exploration. Little detail is given of the science involved, and what there is tends (to my mind) to make overblown claims for what was achieved.

I was disappointed that very little credit is given to the many hundreds of scientific dives made by scientists in Woods Hole Oceanographic Institution's *Alvin*, the French Ifremer's *Nautile*, and other research submersibles. At one point, the author opines that the academic world of scientific diving has 'little cohesion and oftentimes no small amount of competition' (p.277). This is only partly true, and there seems little appreciation of the many valuable inter-institution collaborations, nor of the pressures, drivers and constraints of the academic system – e.g. the needs of grant writing, the restrictions of short-term funding, and the fact that many important scientific questions can be addressed without diving below 6000 m. Where 'academic' submersibles are referenced, it is usually to say that they are incapable of reaching the deepest ocean floor and to imply that therefore the studies they support are of little value. While the latter may be true from the explorer's point of view, it is not from the scientist's. Indeed, scientist readers may be annoyed by the book's relentless focus on reaching the deepest points, with a kind of *Guinness Book of Records* approach. The useful science that was done during the expedition appears to have been mainly biological: documenting new species, addressing the biogeography and potential interconnectedness of species in the hadal zone, and perhaps any biological adaptations to living in that deepest zone. The topography of the dive sites was mapped using a state-of-the-art multibeam echo sounder; but little detail is given.

This book is, however, an excellent description of the whole enterprise of designing, building, testing and operating a submersible (or indeed any major piece of oceanographic equipment). The author, who is a professional writer, not an oceanographer or engineer, was a shipboard participant in the expedition (although we only discover this in the Acknowledgements). I think this leads to the account having a great immediacy. The trials and tribulations of developing and deploying a new piece of oceanographic equipment are faithfully and excitingly presented. We are told, for example, of the many difficulties arising from electrical faults in the various submersible systems, the long hours in lab and workshop to rectify them, the various human reactions to repeated failures and eventual success. Included are realistic accounts of the difficulties and delays caused by weather or the bureaucracy of obtaining (or not) permission to work in territorial waters. There is a clearly described and undeniable pride in the fact that they eventually succeeded in producing a working system – an operable submersible, support ship and launch and recovery system.

The description of the submersible development, up to and including successful dives in the Challenger Deep in the Mariana Trench (the world's deepest point), carries the book excitingly through its first half, where I found it a real page-turner. Thereafter I felt the excitement (and interest) dropped off a little, as the major exploration goal had been achieved. There are, however, interesting accounts of reporting the expedition's success at the American Explorers' Club and the Royal Geographical Society.

The book is obviously written with an American readership in mind: there are several phrases and acronyms whose meaning may not be readily apparent to a British reader, or even accessible by a simple online search. However, these do not detract from enjoyment of the story. On the other hand, I did find the relentless translation of all metric measurements to US equivalents (but not *vice versa*) somewhat irritating. There are also a few inaccuracies. For example, on p.6 we are told that Pacific Rim volcanism is caused by the frictional forces at subduction zones, though this is not the main cause of melting there. There is some confusion over the naming of the decks of the support ship. And at one point Newcastle is stated to be in Scotland! On the positive side, there is an excellent index – very useful, for example, for looking up the background of people introduced in early chapters but then referenced much later. The text is well complemented by a section of 45 colour photographs.

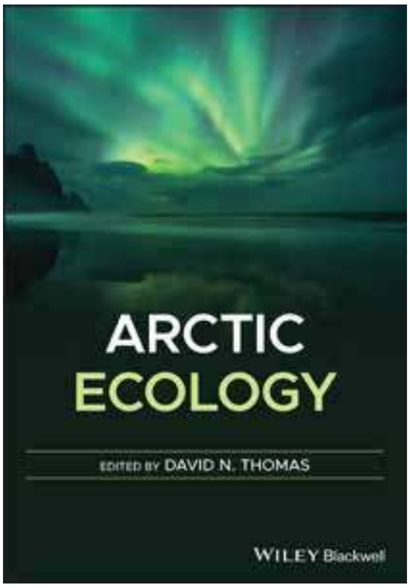
Roger Searle
Durham University

continued

Polar delights

Arctic Ecology edited by David N. Thomas (2021) Wiley Blackwell, 443pp. £45 (hard cover, ISBN: 978-1-118-84654-4), £43.75 (e-book, ISBN: 978-1-118-84655-1).

I'm a sucker for a good book on the polar regions and David Thomas, one of the most prolific writers/editors of polar books, has produced another stunning offering with *Arctic Ecology.* First impressions are always important and the green-tinged image of the northern lights on the cover just shouts out 'Arctic' – and each chapter is extremely readable with good use of images, technical figures, tables and boxes. I love a good figure and *Arctic Ecology* is full of great figures that synthesise some of the key concepts at work; an excellent example is the illustration of the match/mis-match of timing between marine zooplankton life-stages and algal blooms, depending on the timing of sea-ice break-up, in the 'Pelagic Communities' chapter by Daase *et al.*



Arctic Ecology starts off with a lovely chapter which sets the scene, giving a way in for those new to the Arctic. It does an excellent job of preparing the ground for the chapters that come. These technical chapters follow a very nice transition from terrestrial to glacial to riverine then marine – which gives a sense of how each ecological domain is coupled with another. Towards the end of the book there are two chapters that focus on Arctic mammals and birds, which are often the aspect of Arctic ecology with which we have the strongest connection and for which we have the greatest appreciation. Inevitably each chapter is not a full treatise on the subject concerned but provides the important introductory ideas and current research knowledge. I enjoyed the chapters on areas that I'm less familiar with and it's reassuring that a non-specialist can quickly pick up the essence of the topic.

Publication of the book is well timed. In the preface, David sets the scene with record temperatures recorded in the Arctic and the book captures our knowledge of Arctic ecology and its climate vulnerability with a contemporary backdrop of IPCC reports and the critical COP26 event. In this respect, almost all chapters have a section on the impact of climatic change on the ecological domain they have presented. The book also has a chapter dedicated to climate change in the Arctic and concludes with a key chapter, authored by Mark Nuttall, which addresses the social impacts of environmental change in high northern latitudes. It is a very good resource for understanding the pressures facing Arctic ecologic systems in the future.

The hardback version is accompanied by an e-book which makes it very simple and effective to integrate into an undergraduate reading list. I've introduced the e-book into my own teaching for a course on Polar Seas and this is where another of David's books, *Sea Ice* (also published by Wiley Blackwell), makes a very good companion volume. Even within *Arctic Ecology* there are some nice teaching moments; I spotted an ice-growth demonstration in a chapter on the ecology of Arctic sea ice. Individual chapters also make good introductory reading for student dissertations or literature reviews, and wider reading for both marine and non-marine ecology courses; they also provide appropriate Arctic case studies for courses that are perhaps not specialising on polar regions.

Such books with multiple international authorship are not easy to produce. David indicates in his preface that the idea for the book really came together in 2013; so the gestation time was 7+ years. Given such time scales, there is always the potential for the publishing equivalent equivalent of the match/mis-match in timing between zooplankton life stages and algal blooms, in this case involving the cutting edge of research and publication date. In the last couple of years we've seen the Norwegian Nansen Legacy program, the MOSAiC Arctic Expedition and the UK Changing Arctic Ocean Program – these will be generating major papers on Arctic marine ecology which won't appear in *Arctic Ecology.* However, David clearly recognises the rapidity with which knowledge is acquired and how the Arctic is changing so the second edition of this superb book is probably already taking shape in David's mind.

Finlo Cottier
Scottish Association
for Marine Science