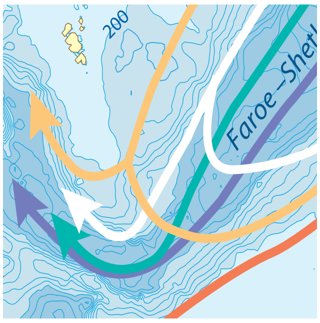
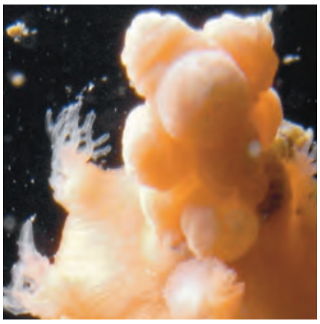
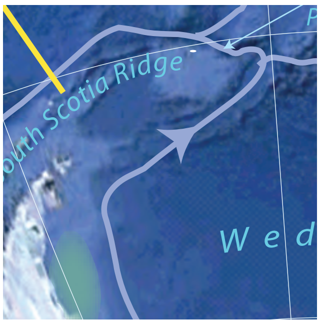






CONTENTS

Most of the maps and diagrams were drawn by The ArtWorks

The cover was designed by Ann Aldred Associates

Cover photograph

Message from the Editor

In this first issue of Ocean Challenge *in 2012, two of the feature articles, by Bee Berx and Loïc Jullion, address the circulation of dense water masses at high latitudes; both also highlight the importance of long time-series. The third feature article, by Simon Haslett, describes compelling evidence for the impact of tsunamis around the British Isles, in recent, historic and prehistoric times. An article by Dennis Burton and Peter Statham charts the development of the UK's Marine Chemistry Discussion Group, which evolved as the science itself evolved. After the lively correspondence provoked by the article about the Chagos Archipelago, we would like to continue with topics that provoke debate, and in this issue we have the first of a series entitled 'A point of view', in this case about the vexed question of fisheries quotas (p.7). We look forward to publishing responses, whether in support or putting arguments to the contrary.*

The Challenger 2012 Conference is fast approaching (see opposite) – photographers please note the subject for the President's Photographic Competition, and details of how to enter.

Angela Colling

Marine Chemistry: A tribute to Professor Dennis Burton

Professor Dennis Burton passed away at the end of last year leaving a significant legacy in terms of his contributions to marine chemistry and also through his friendship with, and mentoring of, many colleagues and students in the field. At the Challenger Society Conference there will be a special session providing a forum for those with interests in marine chemistry, geochemistry and biogeochemistry to present and discuss developments in these subject areas. Bringing people together to talk about their interesting ideas in a positive and friendly environment was a route Dennis was always keen to pursue in advancing the field.

Abstracts for talks and posters on a wide variety of marine chemical, geochemical and biogeochemical topics are most welcome. These can include, but are not restricted to, applications of isotopes to marine processes, palaeo-proxies informing our understanding of past climate, the distribution of trace elements and isotopes, sediment geochemistry, atmospheric inputs to the sea and estuarine chemistry.

The session will be chaired by Peter Statham, University of Southampton, and Daniela Schmidt, University of Bristol

Celebration of a distinguished career in physical oceanography

To celebrate the career of Professor Harry Bryden, a meeting entitled 'Trans-Atlantic Oceanography' was held at the National Oceanography Centre, Southampton, on 30 April and 1 May. Harry retired officially from the University of Southampton in September 2011, but remains active in research and scientific matters more generally – including his role as President of the Challenger Society. A report of the meeting will appear in the next issue.

NATUR CYMRU
Nature of Wales

The article 'They are slugs Jim, but not as we know them' (pp.8–9) first appeared in a recent edition of the quarterly magazine *Natur Cymru – Nature of Wales.* This accessible publication often includes articles about marine organisms and the marine environment – see www.naturcymru.org.uk. Annual subscriptions cost £16.00, or £15 by direct debit. For further details see the website or call 01248-387-373.

The President's Photographic Competition

The President's Prize for the best Photograph on a designated theme was introduced in 1994 (President, Professor Brian McCartney). This year's theme will be 'Marine Science in Stormy Weather'.

Photos will be displayed on a screen in the poster hall. All entries should be received by Tuesday morning, 4 September. The photograph judged by the President to best convey 'Marine Science in Stormy Weather' will be awarded the prize at the conference dinner. Entry to the competition constitutes agreement for the Challenger Society to use the photos (with attribution) in publicity material (but they will not otherwise be distributed). A short description of the photo, including vessel name if relevant and month and year would be appreciated but is not a requirement and will not be displayed with the photo at the conference (photos are judged anonymously). All entries must be taken by the person submitting the photo and must not be overly post-processed (e.g. colours should be natural and objects should not be added or removed). Black and white images are acceptable.

To enter, email your photo to challenger2012@uea.ac.uk.

Challenger Conference for Marine Science 2012

The Challenger Society for Marine Science

Norwich
3–6 September 2012

University of East Anglia

Wave Hub – a marine energy test-bed

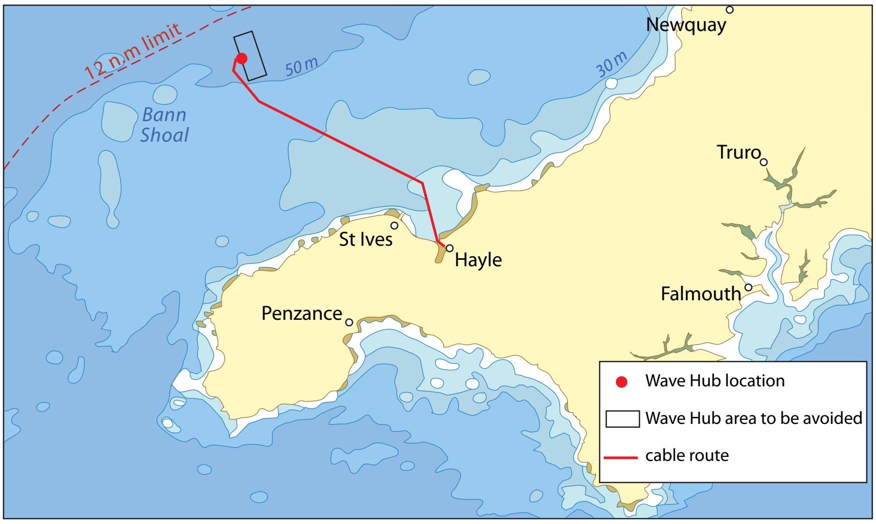
helping industry make the big leap forward

Jason Clark

Wave Hub is a facility for the large-scale testing of technologies that generate electricity from the power of the waves. Wave energy is still very much in its infancy and Wave Hub is desiged to help the industry make the leap from protoype-testing to commercial-scale power generation. The Wave Hub project leases space to developers of wave energy devices, and exists to support the development of marine renewable energy around the world.

Wave Hub is a 12-tonne electrical hub on the sea-bed, 16 km off the north coast of Cornwall where the prevailing Atlantic swell typically delivers 15–25 kW m^{-1} (kW per metre of wave front). It is linked to the UK's electricity grid network via a 25 km, 1300 tonne sub-sea cable which connects with a substation on shore. The Hub was installed during the summer and autumn of 2010 (*see below*) and was fully powered up for the first time in November 2010. We expect to see activity onsite later this year.

The project holds a 25-year lease from the Crown Estate for an area of 8 km^2 of sea and sea-bed, and has the necessary consents and permits for up to 20 MW of wave energy generation; this can be upgraded for up to 50 MW of generating capacity in the future. It offers a clearly defined and fully monitored site for marine energy production, and is the largest facility of its type in the world.



The Wave Hub site is located off the north coast of Cornwall in ~ 55 km of water, within the UK's territorial sea. Various factors contributed to the choice of site, including wave climate, grid connectivity, bathymetry and navigational safety.

Four separate berths are available for lease, each with a capacity of 4–5 MW. Two of these berths have so far been reserved, one by US- and UK-based Ocean Power Technologies for its PowerBuoy device (*opposite*), and one by Ocean Power Ltd of Cork in Ireland with its OE Buoy (*overleaf*).

Project history

Wave Hub was first conceived in 2003 when the South West Regional Development Agency considered which emerging renewable energy technologies would present the best opportunities for economic growth in South West England.

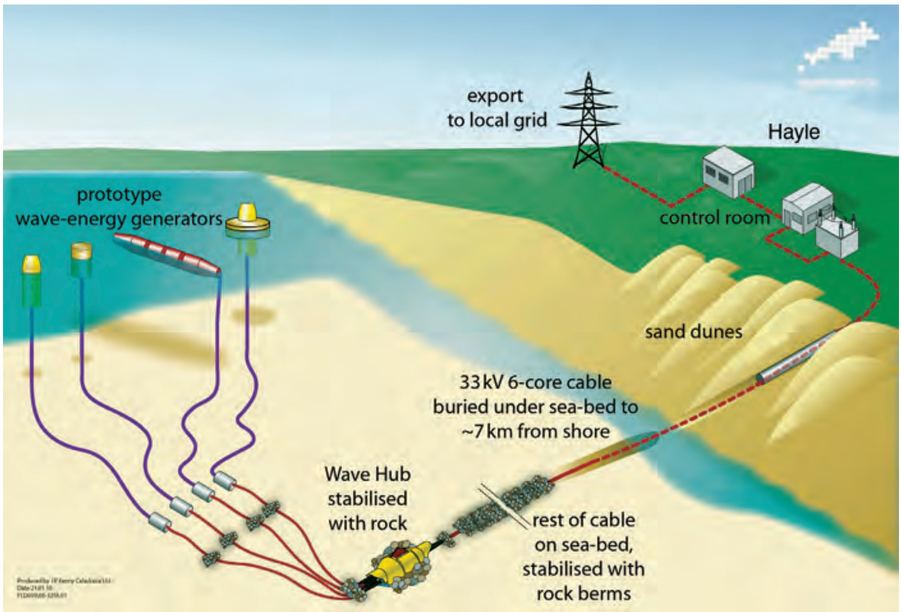
A panel of industry experts was brought together by RegenSW, the renewable energy agency for South West England. Its recommendation was that the natural resources, existing skills and research capabilities in the South West were a good base for developing the emerging marine energy industry in the region.

The north coast of Cornwall receives powerful Atlantic swells. This ideal wave climate, and available capacity in the electrical grid near the coast, made the concept of a grid-connected site for the demonstration of wave energy devices a most attractive proposition, one that promises to be a valuable UK contribution to the marine renewables industry.

A scoping study to determine the viability of the concept led to a technical feasibility study that looked at options for site location, engineering considerations, legal and permitting issues, and the business case for Wave Hub. The project received the necessary consents from the UK government in the autumn of 2007.

Wave Hub is publicly owned by the UK Department for Business Innovation and Skills (BIS) which has set up a stand-alone operating company, Wave Hub Limited, based in Hayle, Cornwall, to manage the day-to-day operation of the testing facility on its behalf.

***Wave Hub being lowered onto the sea-bed in September 2010 by contractors CTC Marine on the cable-laying vessel* Nordica.**



Schematic diagram of the Wave Hub facility and its associated infrastructure
The Hub is connected to the shore by a 25 km, 1300 tonne cable, 16 cm in diameter. The cable was made in one continuous length and includes six copper cores and 48 fibre-optic cables wrapped in two layers of armoured steel wire and an outer polymer sheath. The cable is buried under the sea-bed for the first 5 km offshore and thereafter under 91 000 tonnes of rock with 177 concrete 'mattresses' laid at intervals on top. The end of the cable was floated ashore using more than 400 buoys.

Investigations are underway to determine whether the site could be suitable for testing other forms of marine energy technology, including floating offshore wind turbines (*see Stop Press overleaf*). But Wave Hub is about much more than offering 'plug and play' hardware to the marine renewables industry.

Wave Hub and PRIMaRE

In South West England significant investment has gone into developing marine renewables research capacity, with the creation five years ago of the Peninsula Research Instutute for Marine Renewable Energy (PRIMaRE). PRIMaRE is a collaboration between Plymouth University and the University of Exeter and has brought together a team of international researchers and world class facilities to accelerate the development of technology and address the most critical challenges facing the marine renewable energy industry. Wave Hub has a close working relationship with PRIMaRE, and the institute's scientists are using the Wave Hub site to gather data to address these fundamental questions.

The site represents an ideal opportunity to carry out detailed research in a number of key areas, including environmental and biodiversity impacts. Several years of baseline environmental data from the Wave Hub site will allow the impacts of different types of device to be measured over an extended period of time, and this will enable methods to be developed for predicting the impacts of larger scale marine energy projects.

PRIMaRE conducts research in six main areas (see also www.primare.org):

Characterising marine energy resources

Wave and tidal resource characterisation enables the detailed assessment of the economic viability of potential sites. For example, PRIMaRE is using wave buoys, computational simulation and land-based radar to quantify the wave energy available at the Wave Hub site.

Ocean Power Technologies was the first company to sign up to Wave Hub and intends to deploy a version of its PowerBuoy device, shown here before and after launching.

Support for marine renewable energy systems There are considerable engineering challenges associated with marine renewable energy. PRIMaRE's research is assisting the development of mooring systems, umbilical connections and the installation and maintenance infrastructure.

Impacts on the environment and biodiversity PRIMaRE researchers are working to understand, quantify and reduce the environmental and biodiversity impacts of marine renewable energy extraction – key considerations in gaining consent for marine energy projects. For example, baseline studies at the Wave Hub site will provide detailed impact assessment data for developers.

Safety PRIMaRE is developing cost-effective and reliable systems to reduce the risk of collision and to manage the interaction between wave energy devices and sea-users. For example, a fully-operational simulation of the Wave Hub site is being used to investigate the response of navigators under various weather conditions and the results of this work will inform the design of automated monitoring systems.

Electrical systems The variability of the energy resource is a key consideration in the design of marine electrical generation systems, and output from marine energy converters has to be carefully conditioned before it can be exported. PRIMaRE is investigating the challenges associated with grid compliance, power quality and system protection, including fault prediction and fault tolerant operation. Solutions are also being sought to problems unique to marine renewable energy: connections between devices and export cables, the siting of switchgear afloat or on the seabed, and power transmission losses.

South West Marine Energy Park

Wave Hub and PRIMaRE are key components of the South West Marine Energy Park, which was launched by UK Climate Change Minister Greg Barker in January. The park stretches from Cornwall and the Isles of Scilly to Bristol, and its aim is to speed up the progress of marine power development. It will create a collaborative partnership in the region between national and local government, Local Enterprise Partnerships, the Universities of Plymouth and Exeter and industry.

At the launch of the Park the Minister said:

'This is a real milestone for the marine industry and for the South West region in securing its place in renewables history as the first official marine energy park .... Marine power has huge potential in the UK, not just in contributing to a greener electricity supply and cutting emissions,

Ocean Energy Ltd from Ireland is planning to bring a full-scale version of its Ocean Energy Buoy to Wave Hub this year having tested this quarter-sized protoype for three years in Galway Bay.

but in supporting thousands of jobs in a sector worth a possible £15 billion to the economy to 2050. ... The UK is already a world leader in wave and tidal power, so we should capitalise on this leadership to make marine power a real contender in the future energy market.'

The Park also includes a nearshore 'nursery' test facility in Falmouth Bay: FabTest has been developed in partnership with industry and is operated by Falmouth Harbour Commissioners with the University of Exeter. FabTest, which is not grid-connected, has a lease from the Crown Estate. It will enable wave energy generation device developers to conduct sea trials of their devices in moderate seas, close to port facilities, and is a stepping stone to the deployment of devices at Wave Hub. A full prospectus detailing the assets and expertise that make up the South West Marine Energy Park can be downloaded from the Wave Hub website www.wavehub.co.uk.

The new Marine Science Building
Plymouth University will be offering its unique tank testing facilities later this year. The first client will be British–Italian wave energy developer 40South Energy Ltd.

Meanwhile in Plymouth, a £19 million Marine Science Building is scheduled to open later this year on the Plymouth University campus. It includes new hydrodynamic testing facilities that will be unique in the UK. It will test scale models of wave and tidal devices, both individually and in arrays, in multidirectional waves and variable currents, and will model shallow and deep-water conditions. The main wave tank measures 35 m by 15 m and is 2 m deep. As well as the new hydrodynamic test facility, the Marine Science Building will also house an extensive Ship Simulator, allowing the interaction of 12 independent vessels in a virtual environment

Jason Clark is press officer at Wave Hub.
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Stop Press: Wind Power too?

It is estimated that the UK has over a third of Europe's potential offshore wind resource – enough to power the country nearly three times over. If floating wind turbines were found to be practical, this would open up new areas off the coast of the UK to capturing wind power.

The Energy Technologies Institute (ETI) – a UK-based company formed from global industries and the UK Government – is investigating whether it could use Wave Hub to accommodate floating offshore wind turbines. The feasibility study is expected to be completed before the summer. The main project, valued at over £25 million, will involve the design, construction and installation of a floating system to demonstrate that it can generate high levels of electricity, and be maintained without using specially designed vessels, as well as to verify the predicted technical and economic performance.

• A point of view •

The art and sciences of setting TACs

Why conscientious fisheries research and modelling is not enough

Sophie des Clers

Total allowable catches (TACs) for Europe's shared fisheries resources are set annually at the December meeting of the Council of European fisheries ministers. Last year the Marine Conservation Society, a UK-based environmental NGO, was 'appalled' at the TACs set for 2012. 'This is a clear case of the European Fisheries ministers once again deciding to ignore scientific advice in favour of short term economic gain,' the MCS declared.

Marine commercial fisheries seem to be in the spotlight with negative stories of over-exploitation, mismanagement, waste and greed, but the black light does not shine equally on the main protagonists. In the complex triangular relationship between government fisheries managers, scientists and commercial fishermen, it would seem fisheries scientists escape any bad publicity. Yet, if scientific advice is so often ignored, shouldn't we do something to remedy the situation?

The estimation of a sustainable TAC is as much a craft as a science. You take the fundamentals of single-species population dynamics and apply them to a group of like-minded beasties (a 'stock') and never stop counting. You fit age-structured models to research and landings data by country, fleet, gear, area and so on, in order to estimate what is there (the standing stock), how much new biomass is coming in (recruitment) and how much can be caught sustainably next year – the TAC.

Several complications conspire to humiliate fisheries stock-assessment scientists. A first category would be external factors that cannot easily be predicted. Looking at cod in the North Sea for example, environmental variability in particular is relentless and influences all life history parameters – birth, growth, migration, reproductive capacity, natural mortality, even catch-ability and everything else in the ecosystem that comes between fish and fishing gear. Market forces are another complicating factor; for example, vessels might stop catching abundant fish because prices are too low or costs have suddenly increased. These factors of variability in natural systems and commercial production limit the scope for predictions longer than year-on-year, and make scientists rely heavily on data collection programmes, such as that required by the European Data Collection Regulation (DCR).

A second source of complication comes from the simplifying assumptions that have to be made, the type of models used and what processes are included or left out. For North Sea cod, two subpopulations have been identified genetically, one in the south and one in the north, but they are nevertheless assessed as one 'stock' for the North Sea, Skagerrak and eastern Channel* together. This is standard and valid procedure for modellers, but it means that coastal fishermen, who possibly make up 80% of the catchers but take less than 5% of the cod caught in terms of tonnage, are lost in the picture based on data from the larger vessels operating offshore in the fishery. For North Sea cod, UK coastal fishermen are convinced that scientists, their models, data and assessments are wrong; they have a very valid point.

A final if not terminal complication lies in the interaction of management measures with the quality of data that can be collected. What biologists want to estimate is fishing mortality, which corresponds to all fish caught, whether or not they are the target catch. Currently only the quantities of fish landed are precisely counted. For North Sea cod, which is found with a variety of other demersal species, discarding has meant that scientists still don't have an operational model for multi-species fisheries. In the Norwegian part of the North Sea, where discarding has been gradually banned, the biggest trawlers get clean catches, no juveniles, no excess quota, no vulnerable species and everything that is caught together with cod is known. For the same cod caught in the EU part of the North Sea, discard rates have been as high as 40–70% of the catch weight in recent years.†

*ICES Sub-area IV, the northern section of Division IIIa and Division VIId, respectively.

† ICES (2011) *Report of the Workshop on the Analysis of the Benchmark of Cod in Subarea IV (North Sea), Division VIId (Eastern Channel) and Division IIIa (Skagerrak) (WKCOD 2011), 7–9 February 2011*, Copenhagen, Denmark. ICES CM 2011/ACOM:51. 94pp.

Rather than introduce a gradual discard ban and move towards more intelligent fishing, the top-down European Fisheries Policy has been to ignore fishermen's local knowledge and introduce fishing days quotas for individual vessels. Little science is used to convert fishing mortality into combinations of landing, catch and fishing effort quotas; it is a fish accountancy exercise. The system whereby scientific advice is prepared for the Council, first by biologists and then by economists, without collaboration between them** ultimately makes little sense to either the fishing industry or fisheries managers. It is no surprise then that fisheries ministers do not rubberstamp scientific advice. Fisheries scientists are partly responsible.

All is not doom and gloom – the current reform of the CFP is proposing to ban fisheries discards, although if this happens it will be much more to the credit of a British chef than to scientists. More management responsibility is gradually being devolved, allowing the innovative Scottish Conservation Credits Scheme (SCCS) to emerge in 2008 as an open cooperation between managers, scientists and the fishing industry. The SCCS rewards vessels reporting, voluntarily moving and staying away from grounds with juvenile cod. But there is a long way to go. As scientists, we need to mobilise and respect fishermen's local knowledge and work across disciplines. We also need to explain the science of fisheries management advice in simple terms. In 2004, Clive Cookson wrote in *Ocean Challenge* that the future of marine scientists 'depends on communicating and engaging with the public'. Scientists who count, model and recommend TACs and quotas need to remember this – as do we all.

Sophie des Clers is an independent fisheries management consultant and honorary senior research fellow, Department of Geography, University College London.

**See Wilson, D. (2009) *The Paradoxes of Transparency. Science and the ecosystem approach to fisheries management in Europe.* Amsterdam University Press (ISBN: 978-90-8964-060-4).

They're slugs, Jim – but not as we know them…

Why Skomer is about so much more than seabirds

Phil Newman

The Skomer Marine Nature Reserve (MNR) – Wales' only statutory marine reserve – recently celebrated its 20th anniversary. The small team of diving marine biologists employed by the Countryside Council for Wales (CCW) to manage the reserve carries out a wide range of work. Much of the work has parallels with National Nature Reserve management on land and involves implementing and enforcing bye-laws and codes of conduct, raising public awareness of marine conservation, maintaining visitor facilities such as the exhibition centre in Martin's Haven and the visitor moorings in North Haven. Weekend boat patrols are carried out through the summer months to ensure visitors are aware of the MNR and the sensitivity of some of its areas. The weekend work also allows staff to maintain more than twenty years of recording recreational and commercial use of the MNR.

As well as recording people and their activities there is also a comprehensive programme of monitoring and surveillance. A wide range of marine organisms, from higher vertebrates like Atlantic grey seals to the microscopic invertebrates of the plankton, come under the MNR spotlight. Many are fragile colonial organisms that are more often associated with the warmer waters of the south-west of Britain or even the Mediterranean. The same Gulf Stream waters that benefit the local agricultural industry keep the waters off the Pembrokeshire coast warm enough to support them this far north. Examples include the pink sea fan (*Eunicella verrucosa*), which is a Biodiversity Action Plan species and one of the UK's few protected sea-bed species, and the Ross coral (*Pentapora foliacea*) (*right*). Both are colonial organisms made up of hundreds if not thousands of individual polyps. The sea fans at Skomer are known to be slow-growing with growth rates in larger colonies (up to 70 cm wide) of less than 5 mm per year. The Ross coral colonies (not true corals, but sea-mats or bryozoans) can grow up to 1 m wide and provide a complex structure used as a refuge by other small and juvenile organisms. Ross coral colonies are, however, very fragile and easily damaged, whether it be by a boat's anchor, a lobster pot or even a diver's fin, and therefore no-anchoring codes of conduct as well as a prohibition on mobile fishing gears are in place in the MNR to minimise impacts.

Volunteer divers

Other species studied by the MNR team include seaweeds, sponges, cup corals, red sea fingers (*Alcyonium glomeratum*) and yellow trumpet anemones (*Parazoanthus axinellae*). Some species require more intensive effort to assess their populations effectively and for these we make use of teams of volunteer divers. There are four such intensive projects:

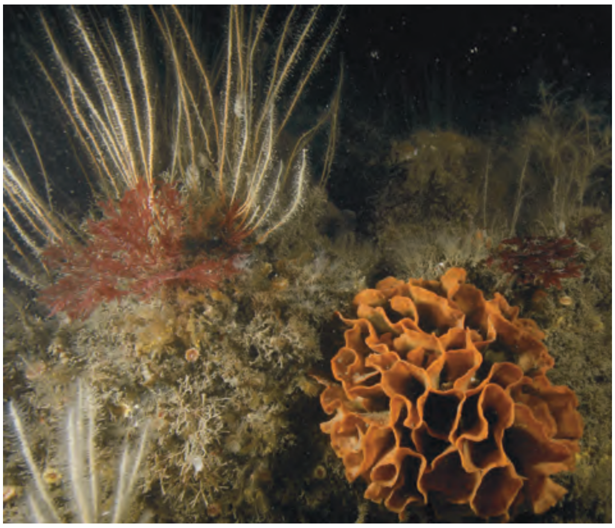
- Territorial fish populations (especially the wrasse species).
- Sea urchins and starfish. Urchins are the main 'grazing' organisms in the MNR, feeding almost indiscriminately on anything growing on rock surfaces.
- Eel grass (*Zostera marina*) – a true flowering plant not a seaweed.
- King scallops (*Pecten maximus*) – protected from any form of fishing within the MNR.

Each of these four projects is carried out on a rolling four-yearly programme (one project each year). They are open to divers regardless of their marine biological skills, as long as they have reached a specified level of progression in their sport.

In order to better understand the fluctuations in the populations of the species monitored, MNR staff also carry out environmental data recording. This includes seawater quality measurements, including temperature, salinity, pH and even water clarity, together with weather data provided by an automatic weather station – one of a network maintained by CCW as part of their Climate Change Network.

Marine abundance

The richness of the the seas around Skomer and the Marloes Peninsula is evident through the statistics generated by the MNR team. About 200 Atlantic



Some of the delicate organisms that thrive in the waters around Skomer: ***Upper*** *The pink sea fan* Eunicella verrucosa. ***Lower*** *The Ross coral* Pentapora foliacea *and the feathery antenna hydroid,* Nemertesia antennina grey seal pups are born here each year, there are around 100 species of sponge, over 250 species of seaweed, and in 2010 alone 55 species of sea slugs or nudibranchs (bare-gills) were counted. The total species list for sea slugs at Skomer now stands at 72 including nationally rare and scarce species. This is two-thirds of the total for the whole of the UK, which is all the more remarkable when you consider that the area of sea-bed in the MNR represents less than 0.01% of UK territorial waters. Because of the importance of sea slugs at Skomer we survey for them every four years, involving as many of our volunteer divers as we can muster.

Sea slugs are a good example of the way that the MNR team's species monitoring projects can give an insight into the general 'health' of the MNR as these animals depend on a wide range of other sea-bed species, not only for food, but also as a substrate for laying eggs. In fact, it is the presence of particular prey species that triggers metamorphosis from the swimming larval stage into the crawling adult. Hence the assumption that if many species of sea slugs are present then all their supporting fauna and flora are available too.

Some sea slugs can be several centimetres in length, whereas others may be smaller than a grain of rice. Quite often the only clue to a sea slug's presence is its eggs. Usually laid in ribbons or rosettes, the shape of the egg mass can help identify the species that laid them (*see below*).

Feeding habits

The type of marine life the sea slug is feeding on can also be an important identifying feature as many are very specific in their tastes. One example is the sea fan sea slug *Tritonia nilsodhneri*, which feeds on the pink sea fan and is superbly camouflaged (*below right*).

The flambuoyant sea slug **Flabellina pedata** *– the tips of its cerata are armed with stinging cells of the hydroids it has fed on*

Many sea slugs feed on hydroids, usually concentrating on one particular species. Hydroids use stinging cells to capture prey and one group of sea slugs, the Aeolidacea (from Aeolis the Greek wind god, perhaps from the 'windswept and interesting' appearance of sea slugs in this group), put these stinging cells to good use by being able to pass them intact through their digestive system and store them in the tips of cerata* on their backs. Stored in this way the stinging cells provide an effective deterrent to predators, with the bright colours of the cerata providing fair warning. *Flabellina pedata* (*above*) is a good example of this group and their colouration.

Another group, the Doridacea (Doris was a mythical Greek sea nymph), is quite different in appearance and can be distinguished by the rosette of branched gills surrounding the anus. The sea lemon (*Archidoris pseudoargus*), which can sometimes be found in rock pools, has this typical body form as does *Acanthodoris pilosa*.

Other sea slugs feed on specific anemones, sponges, sea squirts and sea mats, but a few have more unusual diets, such as *Favorinus blianus* that feeds on the eggs of other nudibranchs and *Facelina annulicornis*, that eats other Aeolid sea slugs. Other sea slug diets include fish eggs and barnacles, and there is even a species that specialises in the free-floating ocean wanderers, goose barnacles (which live attached to floating debris) and the 'by-the-wind sailor' *Velella velella*, an organism related to, but less ferocious than, the Portuguese man-o-war.

*Sea slugs' cerata are fluid-filled tubes which contains a duct of the digestive gland.

Below *Nudibranch eggs, most likely those of the sea lemon,* **Archidoris pseudoargus**, *one of the Dorid group of nudibranchs.*
Right **Tritonia nilsodherneri** *(circled) on a pink sea fan.*

Marine twitchers

Although related to the land slugs their marine counterparts have proved rather more endearing to those fortunate to be able to see them in their natural setting. Indeed, many divers are now in danger of turning into marine 'twitchers', eagerly peering at tiny camouflaged shapes on hydroids, bryozoans and sponges and reaching for their identification books as soon as they get back to the beach.

From a marine conservation perspective this is infinitely preferable to the old, and thankfully largely outdated, image of the diver with goody bag and crab hook, interested in nothing more from the underwater environment than a free meal!

Further reading/information

Skomer Marine Nature Reserve Nudibranch Diversity Survey 2010, CCW Regional Report CCW/WW/10/11.

Skomer Marine Nature Reserve Project Status Report 2010, CCW Regional Report CCW/WW/10/8.

Phil Newman is Skomer Marine Nature Reserve Officer for the CCW and has worked at the MNR for 20 years. He is also a director of NATUR, the Welsh Institute of Countryside and Conservation Management.

This article first appeared in edition 41 of the quarterly magazine Natur Cymru – Nature of Wales*, and is reproduced by kind permission of the Editor and the author. For more information about* Natur Cymru *see page 2.*

The World's Largest No-take Marine Reserve

Meeting of the Linnean Society and the Chagos Conservation Trust

Catherine Head

You may have heard it said that the Chagos Archipelago is the gem of the Indian Ocean with the cleanest waters and some of the most pristine marine ecosystems in the world. Last November, a meeting at the Linnean Society of London showcased exactly why we can make these bold claims and indeed why this archipelago is now the world's largest no-take marine reserve.

In 1999 the Linnean Society of London published the volume *Ecology of the Chagos Archipelago,* a synopsis of data obtained during the 1990s. This time round, the Linnean Society and the Chagos Conservation Trust, with the support of the Pew Environment Group, chose to present some of the highlights of ecological research findings, uncovered by international scientists over the last decade, through a one-day meeting.

Charles Sheppard, organiser of the event, kicked-off the meeting with an overview of the ecological research carried out over the years, including his recent work on the fast recovery of much of Chagos' coral reef ecosystem following an intense period of ocean warming and subsequent coral bleaching in 1998. The archipelago's resilience to the impacts of ocean warming, which have detrimentally affected other coral reefs globally, is thought to be due to the exceptionally good condition of its marine environment.

Some of the most jaw-dropping findings presented at the meeting were those of Nick Graham, of James Cook University, Australia, who reported that the Chagos Archipelago has orders of magnitude more fish biomass in its coastal waters than anywhere else in the Indian Ocean, and higher fish biomass than even its isolated Pacific island counterparts such as the Northern Line Islands. Perhaps this alters our understanding of the true baseline for coral reefs? Ongoing genetic connectivity work presented by Matt Craig of the University of Puerto Rico, showed the importance of Chagos as a stepping-stone for many species across the Indian Ocean. Bernhard Reigl, Deputy Director of the National Coral Reef Institute, USA, talked about his work on the importance of the lagoon system to the survival of Chagos' coral reefs as climate change continues to alter the temperature, currents, and chemistry of our oceans.

Climate change was an ever-present topic, and Miriam Pfeiffer of Aachen University, Germany, spoke about her work into climate interpretation using Chagos coral. She concluded that Chagos was a key site for monitoring climate because of its global mean temperature (being a combination of land and sea-surface temperature). Colin Clubbe, of the Royal Botanic Gardens, Kew, related his discovery of a previously unknown mangrove swamp that has yet to be documented, along with rare original *Pisonia* woodlands that still exist on some of the islands and give an invaluable insight into the archipelago's natural habitat prior to human settlement.

Since the establishment of the Chagos no-take marine reserve in 2010 the Chagos Science Advisory Group has been set up to facilitate and direct international scientific research in the archipelago. David Billet of the National Oceanography Centre, Southampton, introduced the group, which consists of scientists with a variety of research interests from institutes across the UK, and described its goal. Many presenters called for more regular and reliable access to the archipelago for scientific research. The establishment of the group appears to be a positive step towards this goal, and towards monitoring of the marine reserve. One of the major challenges now is how to effectively monitor an isolated 544 000 km^2 predominantly open-ocean marine reserve. Alistair Gammell of Pew Trusts gave his take on how the marine reserve could be monitored and enforced as a whole using the patrol vessel *Pacific Marlin*, and perhaps also using information from the US military base on Diego Garcia if they are willing to share it. Matt Gollock, of the Zoological Society of London (ZSL), discussed how scientists at ZSL and the University of Western Australia are working together to address the challenge of monitoring pelagic fish populations in Chagos by trialling the use of specially designed drop-cameras and other novel methods.

The conference closed with a stimulating series of five-minute talks on exciting ideas for future conservation science research for the marine reserve. Proposals ranged from deep-sea exploration, to the development of biomarkers for bleaching susceptibility, to the assessment of the diversity of the small reef animals which are rarely seen, and much, much more. One of the lasting impressions of this session is that despite the high quality scientific exploration of Chagos, to date we have barely scratched the surface of what this archipelago has to offer!

The fascinating insight into the ecology of the Chagos Archipelago provided by this meeting illustrated the archipelago's exceptionally good environmental condition; its potential as a baseline for global scientific research, of which there are very few such places around the world; and Chagos' ecological importance in the Indian Ocean. Let's hope that the establishment of the Chagos Archipelago marine reserve will enable more exciting scientific exploration in the future, and most importantly conserve this unique archipelago for the benefit of the Indian Ocean fauna and its people.

Middle and South Brother Islands, two of the eight islands on the Great Chagos Bank

Photo by courtesy of Chris Davies

Catherine Head is a Ph.D student at the University of Oxford/Zoological Society of London.

Chagos corals – the debate continues

The article 'Protecting the Chagos Archipelago – a last chance for the Indian Ocean reefs?', by Charles Sheppard, which appeared in the last issue of *Ocean Challenge* (Vol.18, Summer 2011) stimulated some correspondence. This article went online before publication, with the result that the same issue also contained a critical piece by Richard Dunne and Magnus Johnson ('Return to Chagos: conservation and humanity can go hand-in-hand') as well as a 'letter to the editor' from David Snoxell; we also received a letter from Allen Vincatassin, President of the Provisional Government of Diego Garcia and Chagos Islands. Charles Sheppard's response to his critics appears below. *Ed*

Good science demands that the best scientific evidence available should prevail, and to this end I make the following responses to Richard Dunne and Magnus Johnson, and to David Snoxell.

Dunne and Johnson question the biogeographic importance of Chagos. This has been summarised in 18 statements provided by a dozen scientists; these are available on request, as are other papers referred to later. One basis for Dunne and Johnson's argument is: '… the fishes of the Chagos have been shown to be most similar to the Maldives but have only 7% of the species in common with the wider western Indian Ocean'. The percentage is actually 92% and for the Maldives it is 83%, i.e. *less* for the Maldives than for the western Indian Ocean (*Fishbase* data accessed October 2011). Dunne and Johnson's scientific remarks on coral cover are similarly misleading and incorrect, as shown by a 2011 paper by Ateweberhan *et al.* in *Coral Reefs* which documents Indian Ocean coral cover over several decades. Finally, a scientific review of many of these points, by 40 authors who have been engaged with Chagos research, has recently been published in *Aquatic Conservation: Marine and Freshwater Ecosystems*.

Dunne and Johnson urge resumption of commercial fishing, saying that a fishing ban 'will take away the one source of information that has been available'. This old fisheries plea has little merit in Chagos: a review published last year in *Marine Pollution Bulletin* showed that past monitoring was so poor that little information would be lost if it no longer occurred. Special pleading to continue fishing has long been made by parts of the fishing industry, even 'scientific fishing' for research, reminiscent of 'scientific whaling'. (The Indian Ocean Tuna Commission has admitted to serious shortcomings and problems.) At the same time, Dunne and Johnson condemn recreational fishing in Diego Garcia by people in the services and civilian contractors from Asia as 'plunder', but that fishery totals about 50 tonnes per year, mostly less, and mostly of tuna in deep water, so their criticism is incompatible with their support for resuming commercial catches up to hundreds of times greater from the rest of Chagos. It is worth noting that the previous commercial fisheries did nothing for, and paid nothing to, any Chagossians, but there is no criticism by Dunne and Johnson of this despite their main stated concern being support for Chagossians. Finally, they say 'We would like to be able to report that there is to be a scientific programme in the British Indian Ocean Territory to monitor the effect of the new 'no take' area on the fish stocks, but unfortunately there is none.' This is also incorrect: quantitative reef fish biomass monitoring started in 2010, benthic monitoring long before that, and pelagic fish monitoring is being developed for starting in 2012. A Springer volume in the coral reefs series, *Coral Reefs of the British Overseas Territories* (series editor, Bernhard Riegl), due to be published in 2012, will amplify much of this further.

Mr Snoxell says that 'scientific experts' claim that that some of my statements are 'highly questionable'. All science is questionable – this is the scientific method – but Mr Snoxell does not say what statements are questioned, nor by whom. He also states that I 'argue against any return of Chagossians to their homeland'. I don't, and Mr Snoxell knows that years ago I supported what we call the 'Aldabra solution' which involves establishing a modest group of Chagossians, supported externally, who could act as wardens in various ways described elsewhere. I am, however, opposed to proposals for much larger and expensive resettlement plans resulting in townships, because nowhere in the world have these not led to marine degradation. Much recent work shows the Chagos reef condition to be spectacularly better than most other areas, and in my *Ocean Challenge* article I argued that the Indian Ocean needs this for several reasons, including for scientific research of reef condition in 'pristine' conditions, and the region does not need another degraded site or one at risk of degradation. As the Chagos Environment Network stated during the Foreign and Commonwealth consultation on whether Chagos should become a fully protected MPA: 'Given the unique and vulnerable ecology of the archipelago, if there were ever to be a decision made in favour of resettlement, it should be accepted that any resettlement will likely have impacts on the environment which would increase should such resettlement be large-scale or poorly planned ...'

It would be sensible if proponents of Chagossian resettlement set out what they plan in that Territory. There are no infrastructure or communications, and preliminary costing shows that hundreds of millions of pounds would be needed to provide them. Elsewhere, Dunne recently suggested construction of a research station, supported by an 'eco-village' of Chagossians. I would welcome a research station more than anyone, which is why this idea was floated years ago, but with many potential users in existing institutions already strapped for funds, the economics of this are very precarious. Given the economic climate, the existing model of research expeditions has continued for years. This has allowed me to to facilitate visits by over 50 scientists to date, involving over 100 scientists in Chagos research since visits resumed in 1996. Whether a research station could offer much in the way of employment is uncosted and unclear at best.

In contrast to the critical contributions, the letter by Allen Vincatassin shows a much more realistic approach to the MPA. Vincatassin is the leader of the largest of several Chagossian groups in the UK (and was demonstrably elected to his position). This leading Chagossian, who has done more than most to help other Chagossians, supports the MPA, with caveats. Vincatassin asks the critical question: '… how many people would return and where would they want to return?' This point is mostly ignored. As Mr Vincatassin also says: 'it's up to the *Chagossian* people to say what they want to happen' (his emphasis).

Fisheries economics and the Mauritian claim to sovereignty are two drivers of MPA opposition. Short-term fisheries interests were expressed at a workshop on Chagos and tuna held in 2010 at the Zoological Society of London. The tuna industry told us they capture perhaps a third of tuna biomass each year. However, we know from other oceans that under-reporting is massive, which is why tuna are in a precarious state. Some opponents have argued that they support an MPA, but not one that prohibits fishing; one has even said that they want it to be 'a full-take MPA' rather than a no-take MPA, an obvious oxymoron. The Mauritian government objects on sovereignty grounds as they claim the archipelago. One government representative (cited in Wikileaks) is reported to have said that there is no need for MPAs in the Indian Ocean anyway because this was 'the only ocean in the world where the fish die of old age'. This is not supported by a 2011 paper in the *Proceedings of the National Academy of Sciences* showing that in a dozen countries surveyed (not including Chagos), reef-fish densities are now mostly at lamentably low levels, and that Mauritius is in worst condition of all.

The latter chimes with a conversation I had with a Mauritian government official who replied to my question of why they wanted Chagos so much with the honest words: 'We have fished out our own reefs, now we want yours.' Mauritian sovereignty over Chagos could be alarming in terms of potential impacts on Chagos' reefs.

There is indeed a human rights issue, but misrepresentation of scientific information to help those goals is a flawed endeavour. It is easy for anyone to say that they are pro conservation, but the practical follow-up is more difficult. Active engagement and participation in conservation work by Chagossians is done by several groups with clearly stated neutrality on the political question of resettlement. These groups, who work within the government's framework, are members of the Chagos Environment Network. If those criticising the MPA, or those who wish to overturn it (including the tuna fishing industry, tourism industry, and some politicians) genuinely do have Chagossian interests as their motive, they could perhaps demonstrate their sincerity by funding similar work. Their funding would, I suspect, be greatly welcomed.

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The origin and evolution of the UK's Marine Chemistry Discussion Group

Dennis Burton and Peter Statham

Legend would later have it that the idea of forming the Marine Chemistry Discussion Group (MCDG) arose when a small gathering of marine chemists were talking whilst drinking beer in a London pub. Back in those days, however, the licensing laws meant that the pubs were closed in the late afternoon and it was in fact in the sedate ambience of the lounge in one of the hotels on Russell Square that the talking took place, one afternoon in November, 42 years ago. Those present had been attending a scientific meeting and the talk was mostly shop. By the time the gathering broke up there was a general feeling that it would be useful if marine chemists in the UK met occasionally as an informal discussion group to share ideas and information.

The outcome was a meeting in the rooms of the Linnean Society at Burlington House on 22 January 1970, attended by eighteen marine chemists. Thirteen laboratories were represented, with six of them in academic institutions (Bangor, East Anglia, Liverpool, Newcastle, Southampton and Swansea). The other institutions represented were the National Institute of Oceanography (NIO), the Plymouth Laboratory of the Marine Biological Association (MBA) of the United Kingdom, the fisheries laboratories at Aberdeen, Lowestoft and Burnham on Crouch, and the Fawley laboratory of the Central Electricity Generating Board. These details give a fair indication of the small size of the marine chemical community at that time, and the extent to which it was widely scattered amongst the various institutions engaged in marine scientific research.

It was agreed that the Marine Chemistry Discussion Group should be formed 'with the object of providing a forum for the exchange of ideas and information'. Peter Liss and Dennis Burton were elected joint secretaries, acting also as treasurers. The group was concerned to keep its activities as informal as possible. The mailing list for notice of activities constituted the membership. The subscription was 10 shillings (50p) per annum. It was envisaged that the future meetings would be held along with the January meetings of the Challenger Society in London but to maintain impetus the first scientific meeting would be in the coming June. Two things seem remarkable looking back from these days of over-management – the ease with which the MCDG could launch itself in this autonomous manner, and the simplicity of the Group's organisation.

The idea of forming a specialist group was not novel. In retrospect, however, the formation of the Group can be seen as timely. Marine chemistry in the UK had by 1970 lagged behind the other main branches of marine science. In the non-academic institutions in the UK, much effort in the field was devoted to providing essential analytical services for other fields more relevant to commercial and other national interests.

Marine chemistry had, however, developed new directions in the 1950s and 1960s, with the growth of marine geochemistry. Much of the impetus towards the view of the ocean as a major reservoir in global geochemical cycles came from scientists in the USA, including Wallace Broecker, Edward Goldberg and Karl Turekian. James Lovelock's controversial Gaia Hypothesis would soon provide another stimulus, particularly to studies of trace gas exchanges at the air–sea interface. Considerable advances were made in this period by marine chemists in the UK, for example work relating to questions about the definition of salinity, time-series measurements of nutrients, and greatly improved methods for their determination. There was, however, a slow response to the developments in the USA, and it was not until the early 1970s that a marine geochemist was recruited by the NIO. Around this time also, concerns about marine pollution were giving marine chemical studies a higher priority than hitherto.

The decade of the 1970s saw a considerable expansion of activity in marine chemistry in the UK. The formation of the MCDG coincided with the early stages of the expansion and may be seen as one of its consequences. In its unofficial role, the Group helped not only to keep members aware of developments across the field but also to foster a sense of community which was of value for the large-scale collaborative projects which lay in the future.

The first scientific meeting of the MCDG duly took place on 17 June 1970 at the Hydrographic Department of the Ministry of Defence, in Taunton. By then, the Group had 28 members, of whom 18 came to the meeting. Talks were given on work in progress in nine laboratories, and were interspersed with discussion. A final session was devoted to a sharing of experience in the analysis of nitrate in seawater. It seems that even so routine an analysis as that of nitrate could still raise questions about the finer points of methods using reductor columns.

Later in 1970, Ricardo Pytkowicz, visiting Britain from Oregon State University, gave a lecture, organised by the Group at the Linnean Society, entitled 'The CO_2 system in the oceans'. The full-day meetings in January 1971 and 1972 were devoted respectively to trace metals in seawater and to organic chemistry in the marine environment. Work on metals had expanded but the major advances achieved with the introduction of clean procedures for sampling and analysis still lay some years ahead. For the 1972 meeting there was a change of venue to Imperial College. The scope of the subject was widening and among the presentations was one devoted to organic material in the ocean surface microlayer. On an administrative note, the Group's finances in 1971 make interesting reading. Expenditure amounted to £16.02 and there was a healthy balance of income over expenditure of £11.33. The annual subscription had been raised to 75p and would rise again to £1.00 in 1973; those were inflationary times.

The role of suspended particulate mater ial (SPM) in the oceans was another area receiving more attention and the meeting in January 1973, attended by almost a hundred, was devoted to this theme. The range of topics presented and discussed was impressive for the time. They included *in situ* measurements, surface charge, and an SPM budget for the North Sea. Attending the meeting were J.M. Leonard and V.J. Linnenborn, two scientists from the USA who at the time were attached to the United States Embassy in London. They wrote up the meeting for an American readership and their report gave much pleasure to the Group. They began: 'In this Age of Organisation [in 1973!] it is refreshing to see a thriving enterprise that eschews formal organisation. No constitution, no by-laws, no president … The only officials are two secretaries chosen by some superb but murky process.'

On the previous evening a dinner was held at Imperial College to mark the occasion of Leslie Cooper's retirement from his post at the laboratory of the MBA at Plymouth. From the time of its inception he had, as a senior figure in the field, greatly encouraged the MCDG in its efforts. The Group was honoured to welcome Edward Goldberg who, prior to the dinner, gave a lecture in which he incorporated appreciative comments on Cooper's important contributions to the field.

The second meeting in 1973 was held at the University of Liverpool in December, when twelve presentations on aspects of the geochemistry of marine sediments formed the basis for discussion. The early years of the MCDG coincided with a rapidly

Group photograph taken at the 1997 PICO meeting at Southampton. At the right-hand end of the front row, Dennis Burton and Peter Statham sit either side of Peter Williams; to Dennis's left are Peter Liss, Rachel Mills and Martyn Tranter.

growing interest in estuaries and in May 1974 the first joint meeting of the MCDG and another scientific body was held in collaboration with the Estuarine and Brackish Water Sciences Association. Papers on estuarine chemistry were presented at the Scientific Societies Lecture Theatre in London, occupying a full day. Two of them were given by scientists from overseas, E.K. Duursma and A.J. deGroot. A second full day was devoted to discussion sessions held at Imperial College. With this meeting the MCDG may be said to have come of age.

The period from 1974 to 1980 saw the peak of the Group's activity in terms of the number of meetings, averaging two a year, with some being two-day events. All of them were held outside London. A number of members, then as later, gave freely of their time and effort, acting as secretaries or local organisers. The Group retained its informal character and had no permanent office. Archived material becomes thinner for later years, but evidently there was less activity in the 1980s, the number of meetings falling below one a year. The meetings continued nonetheless to range widely, covering open ocean and continental shelf environments, and were well attended. Thoughts on the Global Ocean Flux Study (GOFS) proposal figured in two meetings in 1986.

There were subsequent meetings in 1988 and 1991, but after these events MCDG activities fell into a lacuna, with only very limited activities occurring. This decrease in activity was commented upon during a Challenger Society meeting in 1994 in talks between Tim Jickells, Martin Preston, Peter Statham and Simon Wakefield. A clear wish was expressed to revitalise the spirit of the past MCDG meetings, and the idea of the Progress in Chemical Oceanography (PICO) meetings was born. The decision was to have the PICO meetings between the biennial Challenger meetings; as Challenger meetings themselves had marine chemistry sessions, this provided an annual opportunity for the marine chemistry community across the UK to come together and discuss progress in the field. At this time, PICO was regarded as being under the wing of the MCDG and Challenger Society, and a series of biennial meetings followed from 1995, held respectively at UEA, Southampton (to mark the retirement of Dennis Burton), Plymouth, Bangor and UEA again.

At this point it was felt that there was a need to re-energise and update the spirit of the Group's activities, and after consultation with marine chemists by Peter Statham it was decided in 2005 to re-name MCDG/PICO to reflect the interdisciplinary nature of modern marine chemistry. Over the previous 30 years the study of the chemistry of marine systems had evolved at a rapid pace, and an important part of this evolution was the ever-growing awareness of the need for marine chemists to interact and collaborate with biologists, physical oceanographers and marine geologists to gain an improved and more holistic understanding of marine systems. This was reflected in the choice of the new name – the Marine Biogeochemistry Forum (MBF), and in this spirit a series of meetings entitled 'Advances in Marine Biogeochemistry' (AMBIO) was initiated. The first of these meetings was held at the Southampton Oceanography Centre (SOC) in September 2005, and was followed by a landmark event in AMBIO II, with the first international Irish–UK meeting being held in Galway, Eire (coordinated by Rachel Cave). The most recent meetings have followed the good example set earlier with joint meetings, involving, in these cases, the Geological Society (2009) and the Satellite Special Interest Group of Challenger (2011).

Thus, despite many twists and turns over the past 40 years the spirit of the MCDG is still alive and well in its MBF format, and is supported by the patronage of the Challenger Society, as well as many companies over these years, to whom we are most grateful; it is presently in the capable hands of the incumbent secretary, Gary Fones at the University of Portsmouth. We have good reason to look forward to the future, and feel sure there will be much innovative work reported and discussed under the auspices of the MBF, the most recent incarnation of the MCDG.

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Information on the early years of the MCDG and more recent meetings are held in the Challenger archive at the NOCS library.

Announcement

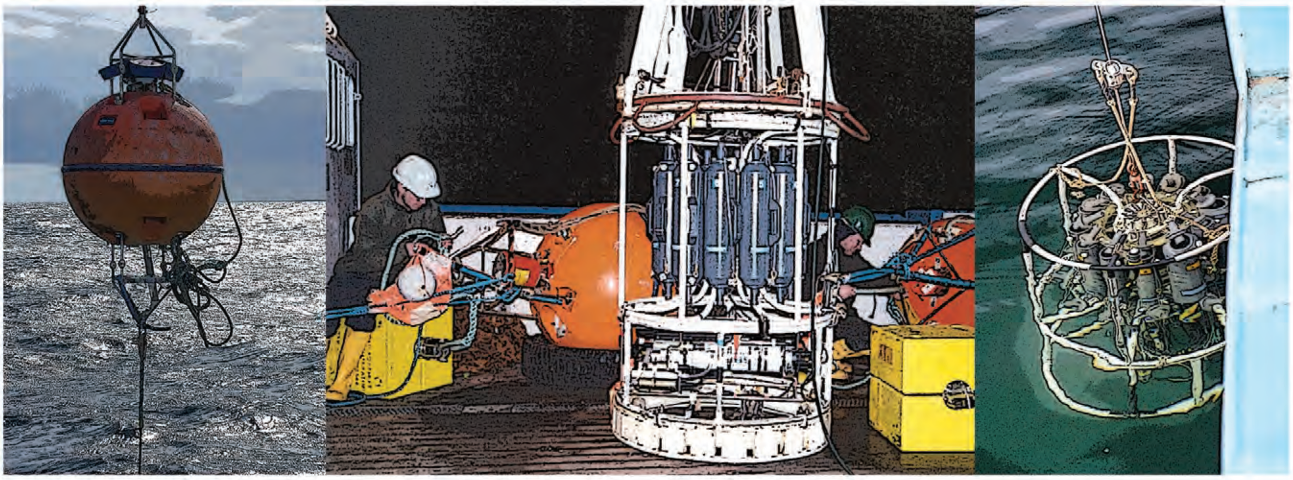
The International Union for History and Philosophy of Science (IUHPS), Division of History of Science and Technology will be holding its 24th International Congress in Manchester, UK, on 22–28 July 2013, under the theme 'Knowledge at Work'. The IUHPS Commission of the History of Oceanography has been asked to participate with its own Symposium under this theme, broadly interpreted (the title of the symposium will be defined according to the submissions).

Presentations will include:

- Patronage of tidal science – the foundation and early years of the Liverpool Tidal Institute *Anna Carlsson-Hyslop*
- Oceanographic expeditions – ICES hydrographical investigations before World War I *Jens Smed*
- At Sea with Science, at work with water bottles and fishing nets. The importance of instruments for the development of oceanography, ca. 1870-1910 *Vera Schwach*
- Oceanographic instruments – Walfrid Ekmann's repeating current meter and its use at Deep-sea 1930 *Artur Svansson*
- On the understanding of plankton blooms in the North Sea – from single net catches to 3D dynamical computer simulations *Walter Lenz and Andreas Moll*
- The Danish Deep Sea Expedition of the *Galathea II* 1950-1952 *Hauke Bietz*
- Marine science and Croatian naturalists – contributions through the history of 430 years of Adriatic marine science *Jacov Dulcic*

Anyone interested in participating is invited to send the title of their proposed talk to the organisers *as soon as possible*: Walter Lenz from Hamburg Germany (walter.lenz@zmaw.de) & Vera Schwach from Oslo, Norway (vera.schwach@nifu.no).

The hydrography and circulation of the Faroe–Shetland Channel



A century of research

Bee Berx

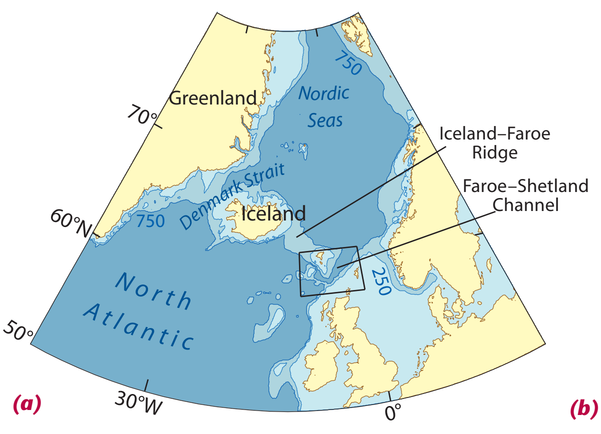
The Faroe–Shetland Channel has been a region of scientific interest since the late 19th century, and research there continues to date. What is the oceanographic significance of this area? And what have we discovered so far? The following article provides a short overview of the oceanographic importance of the Faroe–Shetland Channel, and of the general circulation within it, as currently understood. This is followed by a summary of results so far, and an outline of work to come.

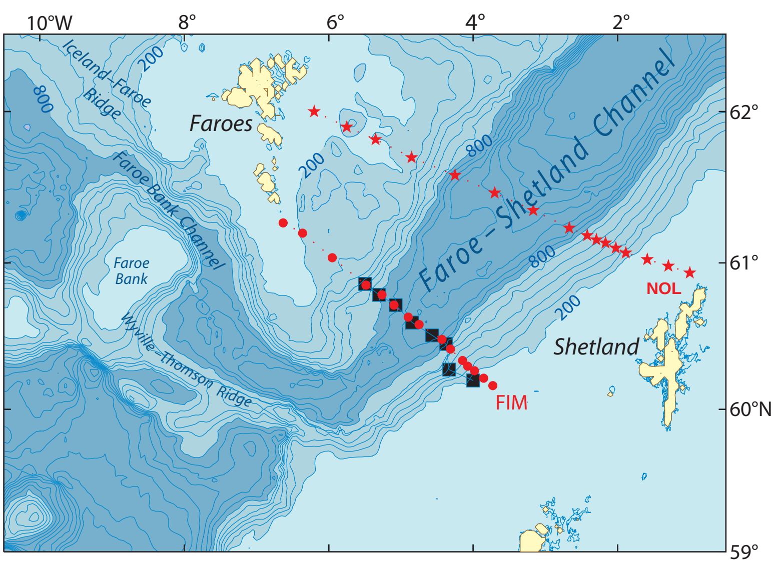
The northward flow of warm Atlantic water helps maintain the mild climate experienced by the British Isles and north-west Europe, in comparison with equivalent latitudes on the eastern coast of North America. But Atlantic water flowing into the Nordic Seas between Greenland and Scotland (Figures 1 and 2) is not only of significance for our pleasant weather, it is also an important component of the global ocean circulation.

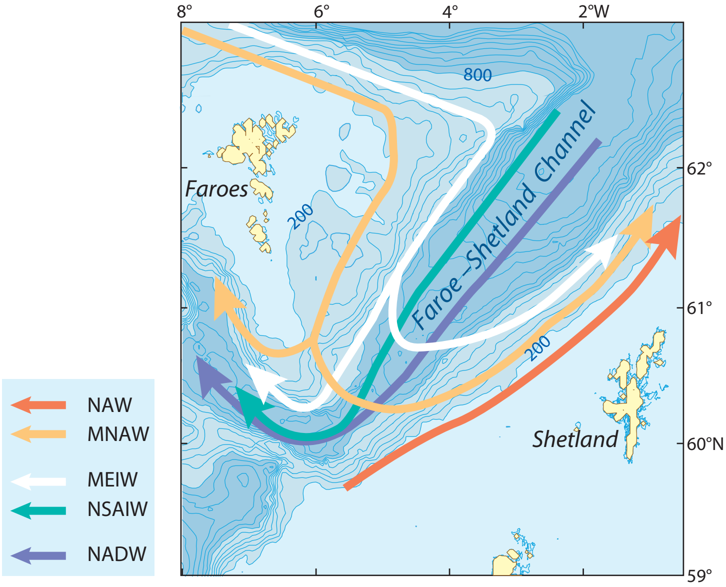
There are three main ways in which water from the North Atlantic enters the Nordic Seas (i.e. the Norwegian and Greenland Seas): there is an inflow of Atlantic water through the Faroe–Shetland Channel, discussed in this article; the Faroe Current crosses the Iceland–Faroe Ridge; and the North Iceland Irminger Current flows polewards in the eastern Denmark Strait. Within the Greenland Sea cooling of these relatively high-salinity Atlantic waters causes them to become sufficiently dense to sink, filling the deepest parts of the Greenland and Norwegian Seas.

The Faroe-Shetland Channel is a critical link between the North Atlantic and the Nordic Seas

Figure 1 ***(a)*** *The setting of the Faroe–Shetland Channel, between the North Atlantic and the Nordic Seas. (Area in box enlarged in (b)).* ***(b)*** *Bathymetry of the Faroe–Shetland Channel, showing the positions of the Fair Isle–Munken Line (FIM) (red dots), the Nolso–Flugga Line (NOL) (red stars) and the ADCP monitoring locations (black squares). Contour values are in metres.*







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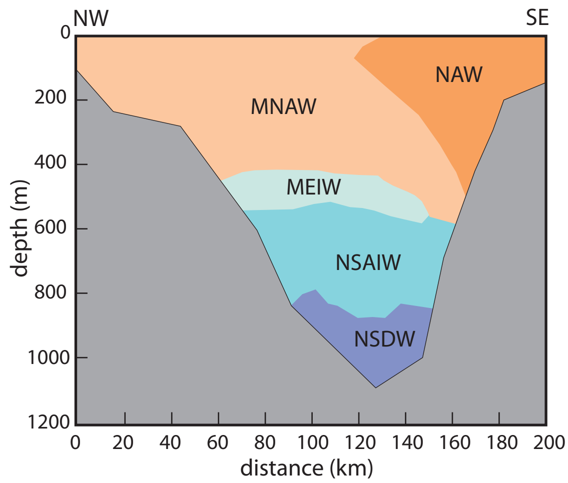

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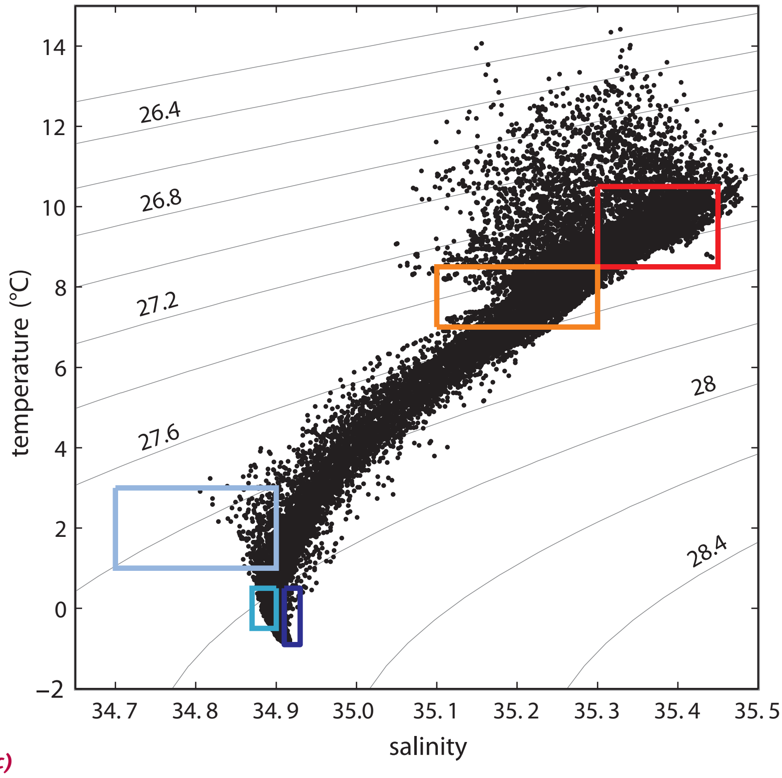


(c)

***Figure 2** **(a)** Schematic representation of the paths of the main water masses flowing through the Faroe–Shetland Channel: NAW: North Atlantic Water; MNAW: Modified North Atlantic Water; MEIW: Modified East Icelandic Water; NSAIW: Norwegian Sea Intermediate Water; NADW, North Atlantic Deep Water. **(b)** Highly schematic section across the Faroe–Shetland Channel showing the generalised distribution of water masses. (a) and (b) are based on CTD data collected between 1994 and 2005. **(c)** Temperature–salinity diagram for water in the Faroe–Shetland Channel, indicating the T–S ranges of the main water masses and mixtures between them, based on observations collected between 1994 and 2008.*

((a) and (b) by courtesy of Sarah Hughes)

Formation of deep water in turn draws more Atlantic water northwards into the Nordic Seas across the Greenland–Scotland Ridge. This thermohaline circulation, combined with wind and mixing, drives the Meridional Overturning Circulation or 'great ocean conveyor belt', which is of global significance in the Earth's climate system. Between Greenland and Scotland, these deep cold water masses flow southwards, channelled through the three gaps mentioned above: the Denmark Strait, the Iceland-Faroe Ridge, and the Faroe-Shetland Channel (Figure 1).

As climate change has increasingly gained our attention, so scientific interest in ocean circulation has grown, particularly in regions where key processes affecting the conveyor occur. Nevertheless, whilst scenarios of the impact of global circulation changes have received much publicity, relatively little attention is paid to the continuous monitoring 'behind the scenes'. This effort not only contributes to our present knowledge on the drivers and variability of ocean circulation, but also provides early warnings of changes in the ocean's circulation.

Research in the 19th and 20th century

As mentioned earlier, scientific interest in the oceanography between Greenland and Scotland, and particularly in the Faroe–Shetland Channel, is not new. In the late 19th century scientists from around Europe were organising expeditions to the Faroe–Shetland Channel; not only for purely oceanographic reasons, but also to study the organisms of this biologically productive region, from its plankton, to fish and large mammals.

Monitoring of the properties of oceanic water masses began in the early 20th century, with Dr H.N. Dickson of the then Scottish Fisheries Board undertaking the first regular surveys in the region. Since then, many more researchers from a truly international field (including Scottish, Faroese, Norwegians and Russians) have come to the Faroe–Shetland Channel to make observations of temperature, salinity and transport. From the early days, efforts have been focussed on two hydrographic sections across the Channel: one from South Faroe to South Shetland (the Fair Isle–Munken Line, FIM), and one from North Faroe to North Shetland (the Nolso–Flugga Line, NOL) (see Figure 1). Observations in the Faroe–Shetland Channel have been made on an almost annual basis since 1903, with the exception of the war years and several years in the early 1980s, making this one of the longest oceanographic time-series worldwide.

Water masses and circulation

Water column structure across the channel (Figure 2(b)) reveals the presence of five main water masses. Each of these water masses can generally be identified using temperature-salinity diagrams (Figure 2(c)) and is characterised by a specific range of chemical/biological properties. In the Faroe–Shetland Channel, the water above ~400 m is made up of either North Atlantic Water (NAW) or Modified North Atlantic Water (MNAW). NAW flows as a slope current along the Shetland Shelf Edge, whilst MNAW flows into the Channel from the north of the Faroe Islands and recirculates in the Channel (Figure 2(a)). These two surface water masses are the saltiest and warmest (Figure 2(c); Figure 3(a),(b)), and together they are responsible for the northward transfer of heat and salt from the Atlantic to the Nordic Seas through the Faroe–Shetland Channel.

At intermediate depths (typically around 400–800 m depth), Modified East Icelandic Water (MEIW) and Norwegian Sea Arctic Intermediate Water (NSAIW) can be found. The deepest water mass is Norwegian Sea Deep Water (NSDW) which makes up most of the southward overflow, directed through the Faroe Bank Channel and across the Wyville Thomson Ridge. This overflow, together with overflows in the Denmark Strait, will become part of North Atlantic Deep Water (NADW).

From 1994 to the present, a collaborative effort between Faroese, Scottish and Norwegian scientists has led to the establishment of an array of acoustic Doppler current profilers (ADCPs) to monitor the strength of the inflow of Atlantic Water into the Nordic Seas (Figure 1(b)). The mean along-channel current velocities are summarised in Figure 3(d). The strongest currents are those associated with the highly saline, warm-water core of the northward flowing slope current, transporting NAW. On the Faroese (northwest) side, southerly currents (blue in Figure 3) transport MNAW, while on the other side of the Channel, MNAW flows northwards again (pink and paler red in FIgure 3(d)). As indicated above, these Atlantic waters have flowed northwards over the Iceland–Faroe Ridge and then around the north of the Faroe Islands, before recirculating in the Faroe–Shetland Channel (Figure 2(a)). In the deeper layers, dense overflow water can also be observed travelling south; these waters will contribute to the Faroe Bank Channel and Wyville Thomson Ridge overflows with transports of 1.9 Sv and 0.9 Sv, respectively (1 sverdup (Sv) = $10^6\,m^3s^{-1}$).

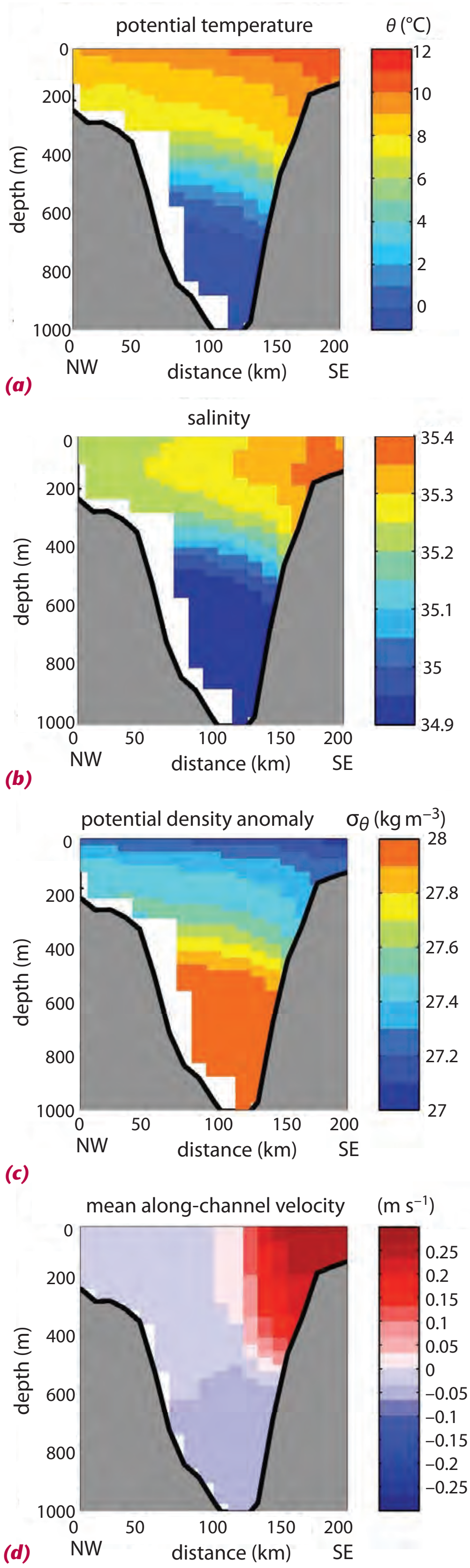


Figure 3 *Distributions of **(a)** mean potential temperature (θ, °C), **(b)** mean salinity, **(c)** mean potential density anomaly (σ_θ, kg m^{-3}), all from ship-based CTD surveys made between 1994 and 2008. **(d)** Mean along-channel velocity (m s^{-1}) from five ADCP moorings on the Fair Isle–Munken line (see Figure 1) in the Faroe–Shetland Channel between 1994 and 2008.*

Deployment of modern instrumentation meant that details of the hydrography in the Faroe–Shetland Channel became clearer between 1994 and 2008

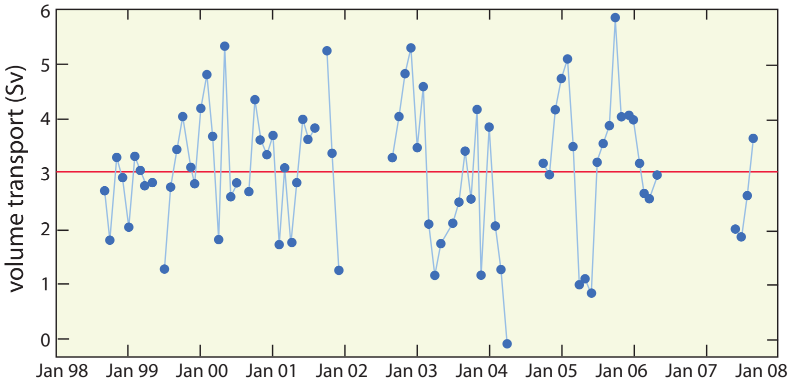
Variability in the Faroe–Shetland Channel

Research based on the above-mentioned long-term observations (1994–present day) has highlighted the region as a highly variable, energetic environment. A time-series of the volume flux of Atlantic water through the Faroe–Shetland Channel (Figure 4) shows the seasonal and interannual variability to be high. Sherwin and colleagues found wind stress to be an important influence on the seasonal patterns of the Atlantic inflow, and eddy kinetic energy levels in the Channel to be relatively high because of the passage of mesoscale eddies. In addition, Hatun and colleagues have had some success with simulating the observed seasonal and longer-term variability in the Faroe–Shetland Channel using a numerical model. They found good correlation for the prediction of raw and annual mean temperatures, but were less successful in simulating the salinities. Predicting the volume transport through the Faroe–Shetland Channel remains difficult, and the observational time-series is being compared to various numerical ocean models to verify their predictions.

Analysis of the water-mass properties in the Faroe–Shetland Channel has also revealed important changes. In the surface layers, both North Atlantic Water and Modified North Atlantic Water have increased in temperature and become more saline over the past two decades. Temperatures have been increasing by approximately 0.5 °C per decade, and salinities by approximately 0.07 per decade. It is thought that this is in part due to the weakening and westwards retraction of the subpolar gyre in the Irminger and Labrador Seas, opening a pathway for an increased contribution of subtropical waters to the water masses in the Faroe–Shetland Channel. Analysis of the characteristics of the deeper layers, by Turrell and colleagues, has shown that bottom waters in the Faroe–Shetland Channel have been freshening by about 0.01 per decade, due to both an influx of fresh Arctic waters into the Nordic Seas (i.e. changes in the properties of water masses), and a decrease in the formation of deep water in the Greenland and Iceland Seas (i.e. changes in the ratios of different source water masses). Within the deepest parts of the Nordic Seas, bottom waters have been getting warmer. Furthermore, the variability of water mass properties in the Faroe–Shetland Channel is not limited to the extremities of the water column, as changes of the order of 0.02 per decade have been found in the salinity of the intermediate water masses too.

The volume of Atlantic Water flowing through the Channel is highly variable on both seasonal and interannual time-scales

Figure 4 *Monthly averaged volume flux of Atlantic Water through the Faroe–Shetland Channel (in sverdrups), as determined at the FIM monitoring site by integrating the velocity observations over the surface 500 m. (1 sverdrup = 10^6 m^3 s^{-1})*



Project THOR

Observations of volume, heat and salt transport in the Faroe–Shetland Channel were first made within numerous international projects, and have continued to be part of such projects. Currently, the research effort is part-funded under the EU Framework 7 Project THOR (ThermoHaline Overturning – at Risk?) which started in December 2008.

This European project is focussing on monitoring and forecasting the North Atlantic thermohaline circulation on decadal time-scales, and on assessing its stability and the risk of a breakdown in a changing climate. The project involves the collaboration of more than 20 institutes from across nine countries, and will conclude in 2013. The research activities are centred on five core themes: quantifying and modelling variability of the thermohaline circulation using palaeoclimate observations and simulations; an assessment of uncertainty in forecasting; observations of the North Atlantic thermohaline circulation; predicting the meridional overturning circulation; and improving the technology for near real-time observations and data assimilation in coupled ocean–atmosphere models.

Three more ADCPs have been deployed in the Faroe–Shetland Channel with the aim of improving our understanding of the variability of the Atlantic inflow. The existing monitoring array (cf. Figure 1(b)) crosses the Faroe–Shetland Channel in a region of high eddy energy, which has made it hard to interpret the existing observations as they include a component of variability from the eddies. Within THOR, researchers will use the additional ADCPs in two different deployment configurations to identify the most suitable location for the monitoring array. In a first phase of the fieldwork the additional ADCPs have been deployed along the Fair Isle–Munken section. Data from these are currently being worked up to see whether adding instrumentation at the existing section improves estimates of Atlantic water transport. In a second fieldwork phase (currently underway), these instruments will be deployed on a new section further to the south-west where analysis of altimeter data has shown eddy energy to be lower.

In addition, observations of surface temperature and salinity are now also being made from ferries such as the *Norröna*, which regularly crosses the Faroe–Shetland Channel on its way from Denmark to the Faroe Islands and Iceland. As this dataset starts to build up it will be helpful in further interpreting the observed variability. In general within THOR, scientists from both modelling and observational backgrounds are working together to improve their understanding of the decadal variability of the North Atlantic thermohaline circulation, and of how the thermohaline circulation might be affected by global climate change. In conclusion, research in the Faroe–Shetland Channel over the past centuries has provided great insight into the details of the circulation between the northern Atlantic and the Nordic Seas, as well as its importance in global ocean circulation. However, the answers to several questions remain outstanding, and perhaps the most important one is: How will anthropogenic climate change influence the northward transport of Atlantic water to the Nordic Seas?

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This research is only made possible through the hard work and dedication of the officers, crew and scientists who have braved the rough waters of the Faroe–Shetland Channel over the past decades. Since 1994, those aboard the FRV *Scotia* and RV *Magnus Heinason*, in particular, have provided the essential support to sustain the Scottish–Faroese-Norwegian monitoring efforts in the region.

The photo above is by courtesy of George Slesser; the images in the title graphic are by courtesy of Marine Scotland

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A newly discovered contribution to North Atlantic Deep Water

The Denmark Strait overflow water is the largest dense water plume from the Nordic seas to feed the lower limb of the Atlantic Meridional Overturning Circulation. Its primary source is commonly thought to be the East Greenland Current but the recently discovered North Icelandic Jet – a deep-reaching current that flows along the continental slope of Iceland – has called this view into question. The Jet advects overflow water into the Denmark Strait and constitutes a pathway that is distinct from the East Greenland Current. The jet supplies about half of the total overflow transport, and may be the primary source of the densest overflow water. For more see: Kjetil Våge, K., R.S. Pickart, M.A. Spall, H. Valdimarsson, S. Jónsson, D.J. Torres, S. Østerhus and T. Eldevik (2011) Significant role of the North Icelandic Jet in the formation of Denmark Strait overflow water, *Nature Geoscience* **4**, 723–7 doi:10.1038/ngeo1234

FROM THE ATMOSPHERE TO THE ABYSS IN THE SOUTHERN OCEAN

How the wind could be influencing the abyssal circulation

Loïc Jullion

Recent observations of the warming of the abyssal layer of the world's ocean raise the question of what controls the variability of Antarctic Bottom Water (AABW), the water mass filling the deepest parts of much of the oceanic basins. With co-workers at the National Oceanography Centre Southampton and the British Antarctic Survey, I have been trying to understand the relationship between atmospheric forcing, the local oceanic circulation and the properties of the Antarctic Bottom Water exported out of the Weddell Sea, the main formation region of this water mass. We found that an increase in the wind speed over the northern Weddell Sea result in the trapping of the coldest, most dense water in the Weddell Sea, creating, only a few months later, an apparent warming of the bottom water downstream. Could this be an indication of the influence of humanity on the circulation and properties of the abyssal ocean – an effect that could increase in the future?

AABW spreads northwards forming the lower-most part of the lower branch of the Meridional Overturning Circulation, the global thermohaline circulation that carries heat across the world (like the atmospheric circulation) thus playing a critical role in the regulation of our climate. Because of the lack of *in situ* observations (especially repeated and sustained observations) in the Southern Ocean, due to the long distances, rough sea state, technical challenges and high costs inherent in polar oceanography, the lower branch of the Meridional Overturning Circulation has received little attention compared with its upper limb, for which a large amount of *in situ* data are available, notably from the Argo programme.*

Off Antarctica, the combination of freezing temperatures and increased salinity resulting from interactions between ice-shelves and the ocean, and sea-ice formation, causes surface waters to become so dense that they sink along the continental slope down to the sea-bed. All the dense water plumes sinking down to the bottom mix together to form the densest water mass that will fill the deepest parts of the ocean.

*The Argo programme, which began in 2000, provides information about the upper ocean from around 3000 profiling floats. Together these provide a near global coverage; the mean distance between floats is ~ 300 km.

The processes that lead to bottom-water formation only occur in winter and in specific regions of the Southern Ocean where the local topography and sea-ice production cause the density of surface water to increase significantly. Weddell Sea Deep Water, formed in the Weddell Sea in the Atlantic sector of the Southern Ocean, is believed to be the main contributor to AABW. Bottom-water formation occurs mainly in the southern Weddell Sea and along the Antarctic Peninsula where the waters carried by the cyclonic Weddell Gyre interact with the large ice shelves (Figure 1).

The Weddell Sea is bounded by the Antarctic coast to the south and the west and by a chain of ridges to the north and the east. The South Scotia Ridge, linking the tip of the Antarctic Peninsula to the Mid-Atlantic Ridge, blocks the northward flow of newly formed AABW which is only able to overflow the ridge through passages deep enough to reach the level at which AABW is found. The Orkney Passage is the deepest gap in the South Scotia Ridge (about 3600 m at the sill) and is the most direct northward export route into the Scotia Sea (Figure 1). AABW too dense to overflow the South Scotia Ridge can flow around the Scotia Arc (the South Sandwich Islands) and may enter the Scotia Sea via the Georgia Passage (route not shown in Figure 1).

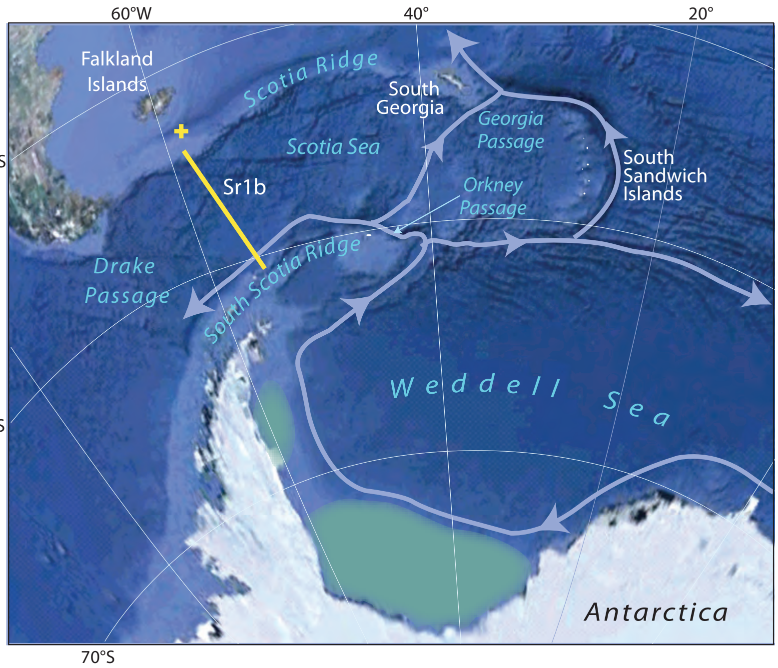


***Figure 1** The Weddell Gyre and the main export routes of Weddell Sea Deep Water/AABW, whose main areas of formation over the shelves are shown in pale green. Flows are shown schematically in relation to the bottom topography. The Sr1b section (see overleaf) is shown in yellow (cf. Figure 2(b)).*

(Bottom topography by courtesy of Google)

A puzzle about warming deep water

Over the last two decades, an increasing body of evidence seems to indicate that the deepest layer of the world's ocean is warming. Comparisons between hydrographic sections occupied several years apart show that the deep ocean is warming at a rate of about 0.01 °C per decade. This observed deep-ocean warming could have a significant impact on the global meridional heat budget and on sea-level rise. If the bottom water becomes warmer, it will expand and push the overlying water upward. A study published in 2010 (see Further Reading) found a statistically significant warming in most of the ocean basins, with the greatest warming found in the southern-most basins. The authors calculated the contribution to sea-level rise associated with the abyssal warming to be 0.053 (± 0.017) mm yr^{-1}. (For comparison, the contribution to sea-level rise resulting from the ice loss in Antarctica is estimated to be between 0.27 mm yr^{-1} and 0.83 mm yr^{-1}.)

Such a decadal warming trend has not been observed close to regions of AABW formation like the Weddell Sea, and this raises some interesting questions. First of all, what is the reason for this warming, and why is it less clear near the formation region than downstream? If it is being caused by changes in the formation processes, then surely we should be able to observe the warming signal close to the formation region. Could it be that this long-term warming trend is masked by some higher frequency variability?

Recently, a study suggested that this lack of warming near the AABW formation region could be explained by a change in the local circulation rather than by a change in the formation process. Mike Meredith and colleagues proposed that the interannual changes they observed in the Scotia Sea, just downstream of the Weddell Sea outflow *en route* to the Atlantic Ocean, could be linked to a change in the strength of the Weddell Gyre: a stronger (weaker) Weddell Gyre would lead to less dense (denser) water being exported over the South Scotia Ridge, resulting in a change in AABW properties in the Scotia Sea. The rationale for this proposal is shown in Figure 2.

Changes in the strength of cyclonic winds affect the intensity of the Weddell Gyre and the density of the WSDW contributing to AABW

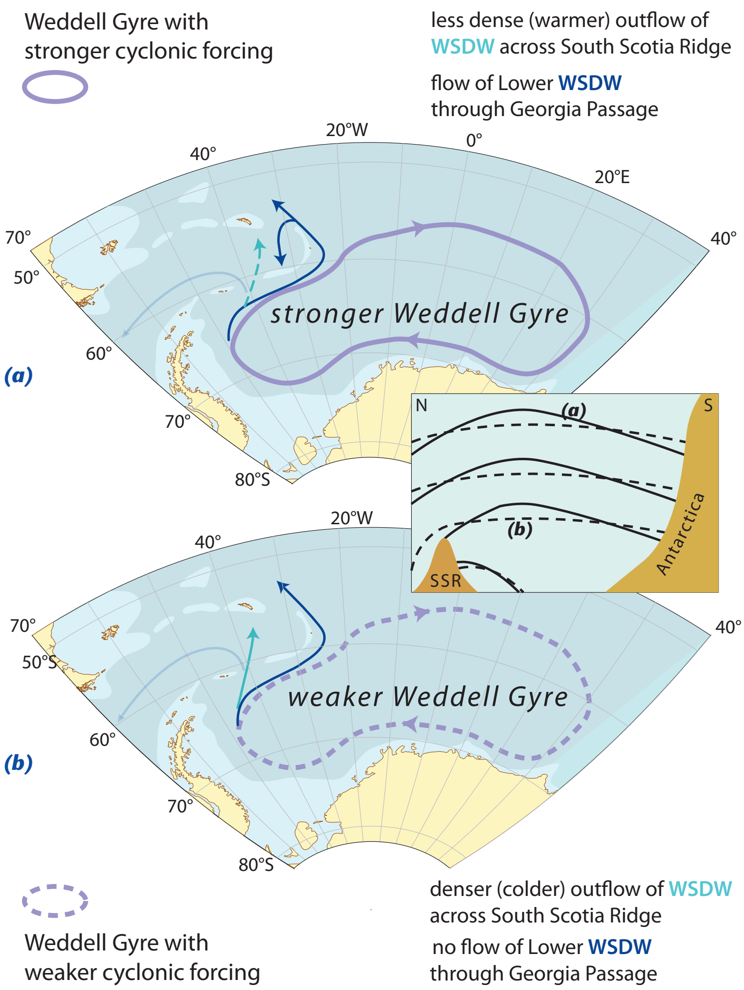


***Figure 2 Inset** The steepening or slumping of isopycnal surfaces in the Weddell Sea, in response to gyre spin-up/down, affects the density of the Weddell Sea Deep Water (WSDW) being exported across the South Scotia Ridge (SSR) to the Scotia Sea.*
***(a)** A stronger Weddell Gyre leads to less dense (warmer) WSDW crossing the SSR via the Orkney Passage, and Lower WSDW entering the Scotia Sea through the Georgia Passage at the north-eastern edge of the Sea. **(b)** A weaker Weddell Gyre leads to more denser (colder) WSDW crossing the SSR, and the absence of an inflow of Lower WSDW through the Georgia Passage.*

From Meredith et al. *(2008). Inset adapted from Coles* et al. *(1996).*

A unique dataset from the Drake Passage

In this later study, we tried to test the 'Weddell Gyre strength' hypothesis with an extensive dataset. To get a better idea of the variability of the properties of bottom water as it exits the Weddell Sea, we looked at 16 repeats of the Sr1b section across the Drake Passage (Figure 1). The Sr1b section was first occupied in 1993 under the auspices of the World Ocean Circulation Experiment. Since then, through cooperation between the British Antarctic Survey and the National Oceanography Centre in Southampton, this section has been occupied almost every year (with the exception of 1995 and 1998), making it the most frequently occupied full-depth hydrographic section in the Southern Ocean. Each spring/early summer, during the initial logistic trip of the RRS *James Clark Ross* between the Falkland Islands and the Rothera base on the Antarctic Peninsula, a few days are dedicated to science, with about 30 stations being occupied along the section, including full hydrographic profiles (temperature, salinity, dissolved oxygen concentration and pressure) and direct velocity measurements.

We used the Sr1b dataset to create time-series of AABW properties in the Drake Passage (Figure 3, upper) and we then investigated the mechanisms responsible for the variability found in the time-series. We found that the interannual variability in AABW properties in the Drake Passage was high compared with the decadal trend observed in the Atlantic Ocean, with interannual fluctuations of up to 0.1 °C in temperature and 0.02 in salinity. The pronounced interannual variability of AABW properties at some distance from its source illustrates the difficulty in reliably determining interdecadal variations in bottom-water properties in regions close to areas of water-mass formation from temporally scarce hydrographic measurements. Moreover, it is very difficult to detect a decadal trend in our data, which is not surprising giving the short length of this dataset. No doubt repeated measurements along Sr1b, if maintained over a sufficient period of time, will prove very useful for monitoring decadal changes in the Southern Ocean water masses.

Periods of warmer, more saline and less dense AABW in the Drake Passage are preceded by positive SAM phases, which are characterised by strong westerlies

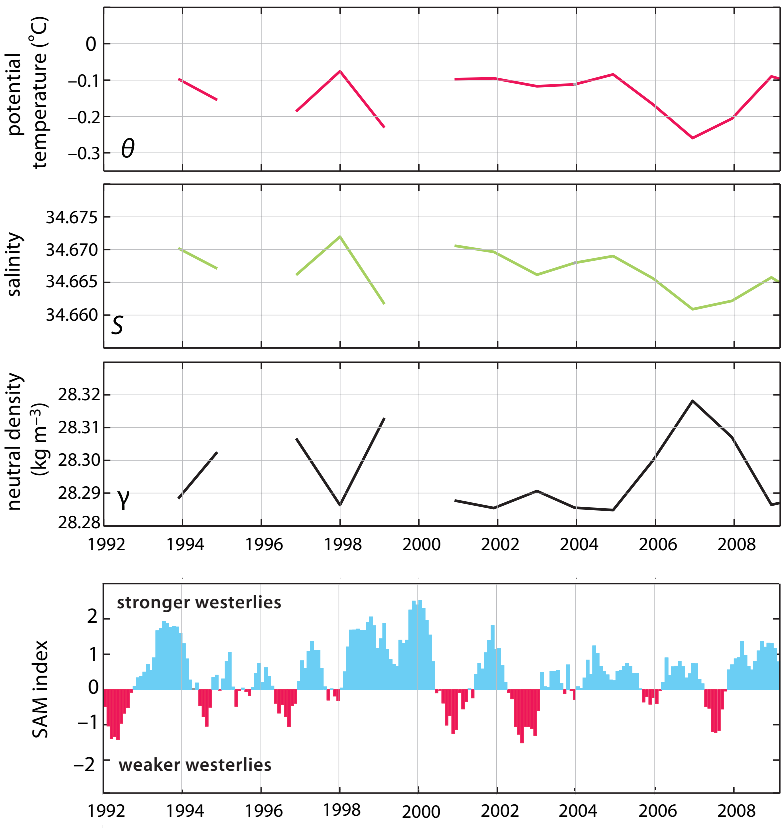


Figure 3 (Upper) *Time-series of potential temperature, salinity and neutral density* of AABW flowing through section Sr1b between 1992 and 2009.* ***(Lower)*** *The 1-year low-pass filtered time-series for the Southern Annular Mode (SAM) index over the same period.*

(From Jullion et al. *2010)*

Testing the 'Gyre Strength' hypothesis

In order to understand what drives this variability and, in particular, in order to test the 'Weddell Gyre strength' hypothesis (cf. Figure 2), we correlated our Sr1b time-series with climate reanalysis data.† We are particularly interested in the relationship with the wind, as the wind (especially the cyclonic forcing over the Weddell Sea/Scotia Sea area) is the primary driver of the circulation in the Weddell Sea. We performed correlations between our time-series and monthly wind anomalies over the Southern Ocean, introducing lags in the correlations, as we do not expect an instantaneous adjustment of the abyssal ocean to a change in the wind.

Figure 4 (opposite) shows the correlation between the zonal wind anomaly and the AABW potential temperature at Sr1b with a 5-month lag. The clear pattern of correlation found over the northern Weddell Sea and the eastern Scotia Sea (significant at the 95% level of confidence; darkest reds on the map) suggests a strong link between changes in the zonal wind in the region and the variability of the properties of AABW in the Drake Passage. Of course, although changes in the winds and changes in the properties of AABW co-vary with a lag of 5 months, this does not necessarily imply causality. However, this result is consistent with our working hypothesis of an influence of changes in the wind and in the Weddell Gyre strength in controlling the density class of AABW exported to the north of the South Scotia Ridge.

*Neutral density γ is similar to σ_θ, but is slightly adjusted to take account of the non-linearity of the equation of state of seawater at high pressures.

†A climate reanalysis is a model simulation of past climate that includes data assimilation of historical observations. It produces homogeneous data (relating to wind, humidity, pressure etc.) from spatially and temporally inhomogeneous observations, in a physically coherent framework.

The circumpolar pattern of the correlation signal reflects the strong degree of coherence of the zonal wind over the Southern Ocean, and the zonally oriented high negative then high positive correlations (red then blue) over the Southern Ocean/subtropical region, reminiscent of a Southern Annular Mode (SAM) pattern, clearly suggests that the variability of AABW properties is significantly influenced by large-scale changes in the wind.

The wind averaged over the area contained within the ellipse in Figure 4 is significantly correlated with SAM at short time lags (r = 0.496 at 0-month lag) but is only marginally significant at the 95% level. Correlations with SAM reflect the predominance of this mode in determining local winds. During a positive (negative) SAM phase, stronger (weaker) westerlies between 50°S and 70°S increase (decrease) the wind stress curl (i.e. the torque exerted by the westerly winds over the northern part of the Weddell Gyre) and predictably spin-up (slow down) the cyclonic Weddell Gyre, causing isopycnals to bow upwards (relax), leading to a warmer, saltier and less dense (cooler, fresher and denser) class of AABW being exported to the Scotia Sea (cf. Figure 2).

If those results encouragingly suggest a relationship between the atmospheric forcing and the changes in AABW properties in the Drake Passage as predicted by our working hypothesis, they also raise a fundamental question about the physical mechanism at play. If one takes into account the transit time between the Orkney Passage and the Sr1b section (about 2 months according to current measurements along the northern slope of the South Scotia Ridge), only 2–3 months remain for the Weddell Gyre to adjust to a change in the wind regime. However, theoretical papers about such baroclinic adjustment of gyres to wind changes, indicate that the time-scales involved are usually of the order of several years rather than a few months. The short (5-month) lag found here is therefore inconsistent with the theory and suggests a different mechanism, probably a more local adjustment of the circulation, as opposed to the basin-wide adjustment of the gyre shown in the inset in Figure 2.

Those conclusions led us to investigate what could possibly explain such a short lag between changes in the wind forcing and changes in the AABW properties on the Sr1b section. In a recent

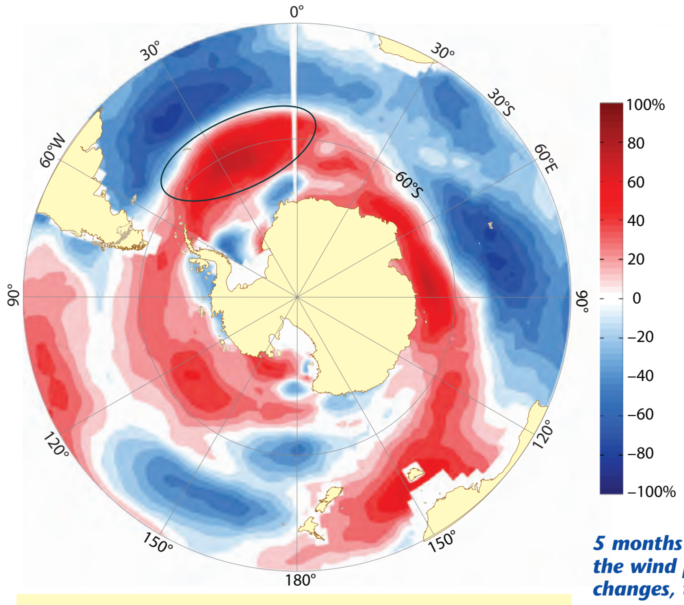


Figure 4 *Spatial correlation at 5 months lag between the zonal wind anomalies (differences from the monthly annual mean) and the potential temperature time-series of the densest AABW in the Drake Passage (cf. Figure 3). Darkest red = highest positive correlation; darkest blue highest negative correlation. The oval outline shows the area where averaged wind stress anomalies were correlated with the SAM.*

5 months after the wind pattern changes, the temperature of deep water in the Drake Passage will also change

paper, Mike Meredith and colleagues compared two temperature time-series situated just north and south of the South Scotia Ridge, directly in the AABW export route, and found that raised outflow temperatures are synchronous with stronger current flows, confirming that warmer AABW is linked to an acceleration of the gyre. These changes occur rapidly in response to changes in wind forcing, also confirming the previous findings.

Meredith and colleagues hypothesised that such rapid adjustments could be explained by the fact that changes in the bottom Ekman layer transport will influence the shapes of isopycnals at depth (Figure 5). Any current that extends to the sea-bed results in a well-mixed bottom Ekman layer caused by the frictional drag of the sea-bed, analogous to an Ekman layer at the surface caused by the frictional drag of the wind. In the

Stronger westerlies over the northern Weddell Sea lead to the bottom water available for export into the Scotia Sea being less dense and warmer than average

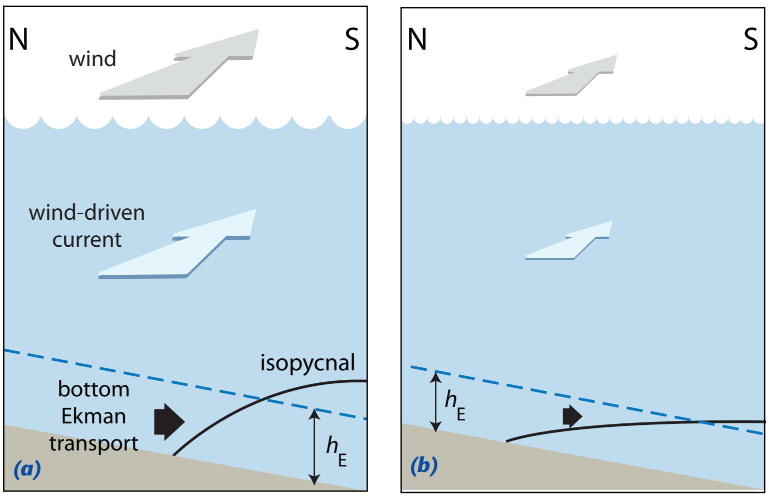


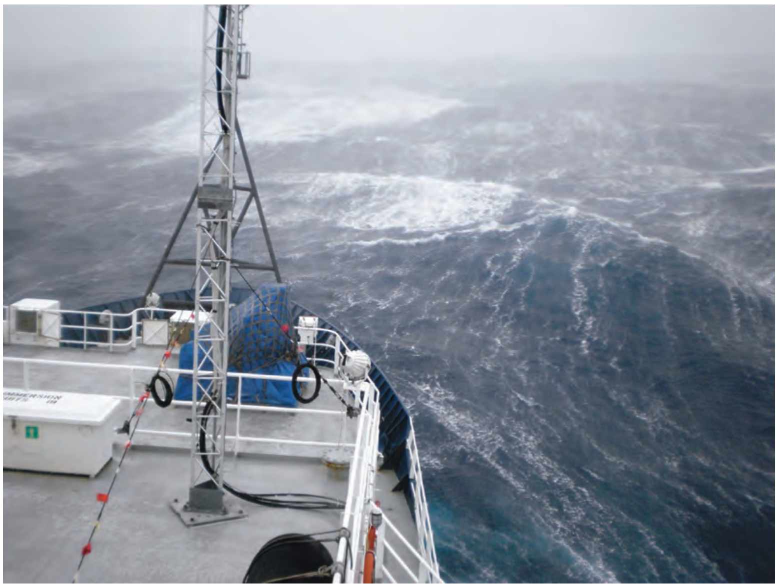
Figure 5 *Schematic diagrams to show how stronger westerlies over the northern Weddell Sea could result in the outflow over the South Scotia Ridge (SSR) being colder/denser. Over a sloping sea-bed,* ***(a)*** *a faster wind-driven current results in stronger flow in the bottom Ekman layer (thickness* h_E*). This causes deep isopycnals to bow upwards, so that their intersection with the sea-bed moves downslope, and the densest water is trapped in the Weddell Sea. By contrast,* ***(b)*** *a weaker wind-driven current results in flatter isopycnals at depth, and the densest water is able to flow out over the SSR.*

Southern Hemisphere, mean flow in the surface Ekman layer is to the left of the wind, and that in the bottom Ekman layer (where everything is reversed) is to the right of the wind (Figure 5). Over a flat bottom, an increase in the wind speed will only cause an increase of the Ekman transport in the bottom layer. However, over a sloping sea-bed, as where the bottom water in the Weddell Sea flows up the southern flank of the South Scotia Ridge, an increase in the wind and hence in the bottom Ekman transport will displace the deep isopycnals, increasing their doming and pushing their intersection with the sea-bed downslope, with the result that the densest AABW is trapped and cannot contribute to the outflow (Figure 5(a); cf. inset, Figure 2). By contrast, when the wind weakens, the isopycnals relax and the densest AABW is able to flow over the South Scotia Ridge and on into the Drake Passage (Figure 5(b)). The dispacement of isopycnals away from their previous equilibrium will be maintained until the wind regime changes again.

It has been estimated that it takes about 54 days for the density structure in the Weddell Gyre to adjust to a change in the wind speed. This is consistent with the lag of a few months indicated by the Sr1b data and suggests that changes in the bottom Ekman layer transport can explain the fast response in the AABW flow to changes in the wind. These results seem to confirm that local rather than basin-wide changes in the circulation are the dominant player here.

Implications for the future

AABW is a water mass that participates in the global oceanic circulation. It is therefore crucial to understand not only what is happening in its formation region but also what is controlling the export of the 'end product' to the rest of the ocean. The mechanism suggested here to explain interannual changes in AABW properties may also underlie the warming trend observed along much of the length of the Atlantic Ocean in recent decades. Since the 1960s, along with interannual variability (Figure 3), the SAM has exhibited a trend towards a more positive state, with stronger westerly winds over the Southern Ocean. The stronger westerlies are at least partly due to the ozone hole, which still persists, having been caused by the widespread use of chlorofluorocarbons up until the 1990s. As described above, stronger winds lead to less dense/warmer AABW being exported from the Weddell Sea, so – assuming that the mechanism outlined is operational over decadal time-scales – this means that anthropogenic changes could be the root cause of the warming that has been observed along nearly the entire length of the abyssal Atlantic.



If the bottom Ekman layer mechanism is indeed the dominant local driver of the variability of AABW properties, this poses a serious challenge to global circulation models, as these models do not have sufficient vertical resolution to correctly resolve the physics of the bottom boundary layer.

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CLUES TO CATASTROPHE

Discovering evidence for tsunamis around Britain's coast

Simon K. Haslett

Analysis of numerous historic documents suggests that Britain may have been affected by tsunamis more regularly than previously thought. In some instances field evidence supports these theories. The mechanisms that may have triggered these tsunamis include earthquakes, submarine slides, extreme weather events, and perhaps even comet impact in the sea. Although this research is controversial, it is important for hazard information purposes to raise and investigate the possibility that tsunamis do occur around the coast of Britain, even if infrequent and normally of low magnitude.

Since 2002 I have undertaken research with a tsunami expert from Australia on the possibility that the shores of Britain have in the past experienced tsunamis – not just one or two, but many over hundreds of years of British history, even influencing our culture and literature. We suspect that tsunamis have affected the coastline right around Britain, but the memory of these events has been lost and is only now being uncovered by a rereading of historic documents and the landscape.

The tsunami expert with whom I am collaborating is Ted Bryant, now retired from the University of Wollongong. Ted published a synthesis of his work in the 2001 Cambridge University Press book *Tsunami: the underrated hazard*. Unfortunately, the reality expressed in the subtitle held sway (outside tsunami-prone areas) until the tragic events of Boxing Day 2004 when a pan-oceanic tsunami generated by the 9.2 magnitude earthquake offshore Sumatra forced people to take tsunamis seriously. Even the United Kingdom government eventually commissioned a report on the UK tsunami threat (see Further Reading). Subsequent tsunamis have been watched by the world, such as those that came ashore in Chile in 2010 and Japan in 2011, both of which had TV audiences awaiting wave arrivals around the Pacific.

But how much of a threat are tsunamis in Britain? Surely they don't occur here? Ted and I first met in 1994 in Scotland, at a field meeting near Stirling, where we were shown sand layers, containing marine fossils, deposited many miles inland and laid down by a mega-tsunami over 7000 years ago. Mesolithic coastal settlements seem to have been obliterated by the event, as archaeologists have now uncovered occupa-

Figure 1 The author with Ted Bryant in the field at Lamorna Cove, Cornwall.

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Fieldwork is an essential part of researching past tsunamis

tion horizons sealed by the tsunami sand. Also, it has been estimated that the wave was around 25 m high in the Shetland Isles, completely washing over the top of some islands. It is known that this tsunami was caused by a submarine slide offshore Norway, now named the Storegga Slide. More recently, in 1755, a large earthquake occurred offshore Portugal, where the combined earthquake and tsunami caused great devastation in Lisbon. Tsunami waves that travelled along the African and European coasts were still around 3 m high when they reached the south-west coast of Britain. So Britain has experienced at least two tsunami events, but have there been others?

The 1607 flood – a tsunami in the Bristol Channel?

Since 1994, Ted and I have collaborated on various projects, but it was a brief visit he made to the UK in 2002 that spawned our British tsunami research (Figure 1). Ted was speaking at a 'Catastrophes' conference at Brunel University and afterwards had a few days free to visit the Severn Estuary, which is where most of my research up to that date had been undertaken. We were to visit an archaeological excavation taking place in the tidal zone of the muddy estuary with the second highest tidal range in the world, but we arrived late and the tide was high and covering the excavation. As the light was good, we went to Redwick, a local church that I knew had a flood marker on it that Ted might be interested to see. The marker on the porch is simply labelled 'The Great Flood 1606', and it records a flood event that many considered was caused by a storm surge. The door was open so we went in and picked up a booklet about the history of the parish. It contained a passage from a 17th century chapbook* describing the event:

*A chapbook was a small book or pamphlet containing poems, ballads, stories, or a religious tract.

For about nine of the morning, the same being most fayrely and brightly spred, many of the inhabitants of these countreys prepared themselves to their affayres then they might see and perceive afar off as it were in the element huge and mighty hilles of water tombling over one another in such sort as if the greatest mountains in the world had overwhelmed the lowe villages or marshy grounds. Sometimes it dazzled many of the spectators that they imagined it had bin some fogge or mist coming with great swiftness towards them and with such a smoke as if mountains were all on fire, and to the view of some it seemed as if myriads of thousands of arrows had been shot forth all at one time.

After reading the extract Ted and I turned to one another astonished and said, almost in unison, 'This isn't a storm, it's a tsunami!' It was one of those rare eureka moments, and has since led us on a journey of discovery around the shores of Britain and beyond.

Both Ted and I are geographers, having studied human and physical geography at university, but after spending most of our careers lecturing in physical geography, it felt a little odd that in this research we had to recall research methods and techniques from historical geography, as much of the evidence would come from historical archives and documents. But Ted and I are first and foremost field geographers, so unlike many desk-based researchers these days we have tried to visit all the sites that are crucial to unpicking the story of British tsunamis. We are now very strong advocates of encouraging students to become integrated geographers rather than becoming ghetto-ised into either the human or physical branches of the discipline.

According to our modern calender, the Great Flood of 1606 occurred on 30 January 1607, and

Figure 2 *Woodcut showing the havoc caused by the Great Flood of 1607. Communities around the Severn Estuary were devastated, and people drowned along with their livestock.*

An inundation of the sea water … by reason whereof many Persons were drown'd and much Cattle and Goods, were lost: the water in the Church was five feet high …

Figure 3 (a) *An historic dark sand layer in a muddy cliff of the Severn Estuary.* **(b)** *An imbricated boulder train (boulders laid down like dominoes) at Dunraven Bay in the Bristol Channel.*
Reproduced with permission from http://www.flickr.com/photos/profsimonhaslett/6915964955/ and 6915964707/

Distinctive sedimentary features indicate the height of the tsunami wave that emplaced them

it has become known as the 1607 Flood (Figure 2). Before our research the event was virtually forgotten, which is very surprising given that around 2000 people appear to have died, making it the worst land-based natural disaster in British history. As well as numerous historical documents there was also physical evidence in the landscape for a tsunami-like event, including the deposition of sand layers in the otherwise muddy Severn Estuary sediments (Figure 3(a)), the stripping out of the estuaries' fringing salt marshes, and the truncation of spurs of agricultural land, all of which had previously been dated to the early 17th century.

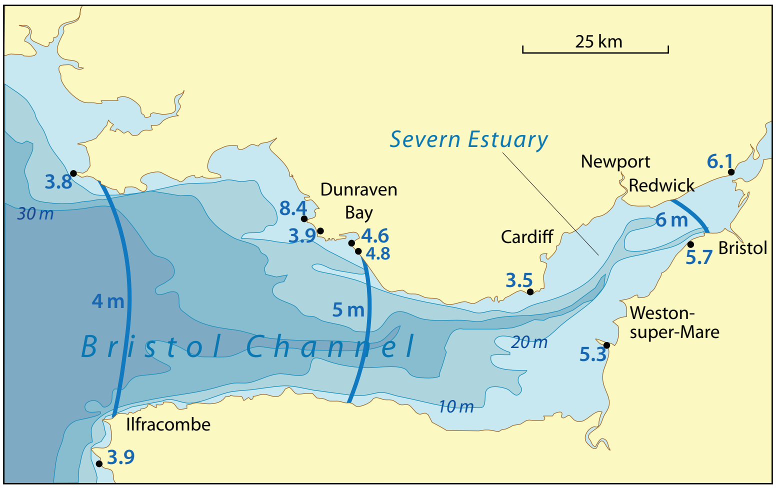
We quickly wrote up and published our tsunami theory for the 1607 flood in 2003 and decided that Ted should make a return visit to the UK in 2004 for a field season collecting data from key sites that we knew from historical documents had been badly affected by the event. Some time during our planning of the field work, the BBC got involved and wanted to make a documentary film about our theory and research. So in September 2004, Ted, I and a BBC film crew embarked on a field trip around the Bristol Channel, from Barnstaple in Devon, up the Severn Estuary to Gloucestershire, and then along the South Wales coast to the Gower Peninsula.

At the time, the BBC Producer was concerned that the general audience wouldn't know what a tsunami was. Little did we know then that, during the final edit of the film, the world would be shocked on 26 December 2004 by a huge tsunami in the Indian Ocean, resulting in a quarter of a million fatalities. 'The Killer Wave of 1607' was eventually broadcast in April 2005, and was watched by over 5 million viewers. It attracted good reviews from critics in the press, but more importantly for us inspired members of the public to learn more about the event, tsunamis, and geography in general.

The data we collected during that trip was all published by 2007 (see Further Reading) and suggested that it was very likely that a tsunami had hit the Bristol Channel in the past. From the analysis of unusual boulder deposits (Figure 3(b)), we were able to suggest the tsunami was about 4 m high at the mouth of the Bristol Channel, but as it passed up the funnel of the Severn Estuary it grew to around 6 m high, exactly where the 17th century historical records indicate the greatest impact had been experienced (Figure 4).

Figure 4 *Tsunami wave height in metres, estimated on the basis of wave heights required to move boulders of different sizes, at various locations in the Bristol Channel and Severn Estuary.*
Based on Bryant and Haslett (2007)

By the time the tsunami wave reached the head of the Severn Estuary it would have been more than 6 m high



Given that 2007 was the 400th anniversary of the event, the story was covered widely in the press, reaching the national television news, with reports in many newspapers and magazines, including *New Scientist, National Geographic* and even *The Economist*. As academic geographers, we were overwhelmed by the attention our research had attracted. But perhaps the most surprising aspect was the effect it had had on the communities now living in the areas devastated by the 1607 flood. Community leaders told us that tourism in their towns and villages had increased, and they held numerous commemorative events, including a service conducted by the Bishop of Bath and Wells, to which we were invited guests, at Redwick Church where our research started back in 2002.

What triggered the 1607 tsunami?

One thing that eluded us was a trigger mechanism for a possible tsunami in 1607. We had suggested that the most likely cause was a submarine slide off the edge of the continental shelf somewhere south-west of Ireland. Roger Musson Head of Seismology at the British Geological Survey, suggested that it wasn't fanciful to consider that the Clare Lineament, a known active fault zone in the same area, could be the culprit – after all, there had been an earthquake on that fault in the 1980s. Because of the uncertainty,

Tsunamis may have affected many locations around the coast of Great Britain

Figure 5 *Sites affected by past tsunamis, mentioned in this article.*

however, a storm surge theory for the flood cannot be refuted, even though there is no other storm-related damage mentioned in the historical accounts.

Professor Michael Disney from Cardiff University published an article in *The Times* newspaper in January 2005 and stated that there was a second-hand report of an earthquake felt on the day of the flood. Apparently this evidence came from an antiquarian book, but we have been unable to find the source; however, if true, this is the 'smoking gun' for our theory. Our research has uncovered two previously unlisted earthquakes in the region in 1607, the first just over two weeks later in February and the second in May, so 1607 appears to have been a seismically active period. These data are important as currently there is a debate about the future of nuclear power facilities alongside the Bristol Channel.

More British tsunamis?

Whilst focussing on the 1607 flood, Ted and I had to ignore other interesting historical records we came across suggesting that tsunamis have occurred more widely around the British coastline. However, in autumn 2007 we undertook a field survey of sites and, once again, were accompanied by a film crew from the BBC to produce a second film entitled 'Britain's Forgotten Floods', and both our paper and the film came out in 2008. The forgotten flood events we analysed fell into four categories, described below.

Dover Straits

The Dover Straits are underlain by a major thrust fault. The area experiences earthquakes regularly, such as the 4.2 magnitude earthquake that occurred in Folkestone in April 2007. When these earthquakes have occurred in the past with a higher magnitude, eye witnesses have described what could be interpreted as tsunamis.

There is documentary evidence for a number of tsunamis in the Dover Straits. For example, in May 1382 an earthquake estimated to have had a magnitude of around 5.75 struck, causing churches to collapse, and generating waves that damaged ships in port, causing contemporary writers to describe the event as a 'watershake' or 'waterquake'. This may have occurred in a seismically active period: in December of the previous year, Empress Anne of Bohemia (who was here to marry King Richard II) landed in Dover – no sooner had her party disembarked than 'the water was so troubled and shaken, as the like thing had not to any mans remembrance euer beene heard of: so that the ship in which the appointed queene came ouer, was terrible rent in peeces.' This event is thought by some to have been the inspiration for Chaucer's 'Tempest at hir Hoom-Cominge' in *The Knight's Tale*.

In April 1580, a 5.8 magnitude earthquake occurred with its epicentre in the sea-bed close to Calais – Shakespeare alluded to this earthquake in *Romeo and Juliet*. Giant waves were reported at the time, hundreds of people were killed when ships were sunk by the waves, and the low-lying coastal land around Calais was inundated by the sea. A contemporary French account states 'in the city of Calais such a horrible and terrible earthquake came to pass that a great part of the houses fell, and even the sea overflowed into the city and did ruin and drown a great number of houses, and numerous persons perished, and a great multitude of beasts lost which were at pasture outside this city.' In Dover, part of the chalk cliff collapsed, taking with it part of Dover Castle. It is unlikely that the earthquake was strong enough to rupture the sea-bed to cause a tsunami similar to the Indian Ocean event, but it appears to have been sufficiently powerful to cause an undersea landslide that would have been quite capable of generating a tsunami. (Such an earthquake and tsunami occurred off the coast of Papua New Guinea in 1998, tragically killing around 2500 people.)

Far-travelled tsunamis

The second category of events comprise those tsunamis that travel long distances to reach Britain. Good examples include the undisputed 1755 tsunami generated off south-west Portugal, that was still 3 m high when it reached the shores of south-west Britain and southern Ireland. Ted and I visited sites affected by this tsunami, such as Lamorna Cove in Cornwall where, according to contemporary accounts, large granite boulders were tossed around like pebbles by the tsunami (Figure 6). Also, this group includes the prehistoric tsunami generated by the huge Storegga Slide, mentioned earlier. In total, we identified around ten tsunami events in this category.

Locally generated coastal tsunamis?

Some earthquakes have occurred directly under the British coastline and in some instances these have generated local tsunamis. We have interpreted eye-witness accounts associated with the April 1884 Colchester earthquake (estimated magnitude 4.6–5.5) to be descriptions of a tsunami. Fishermen and sailors on the Colne Estuary in Essex (Figure 7) report their vessels rising and falling by up to 1 m, and one boat found itself sitting in the trough of a long wave, the men not being able to see above the wave crests on either side. Significantly the *Eastern Daily Press* reported the next day that 'the sea is said to have rushed with restless force over the marshes, receding some time afterwards, leaving thick deposits of sand behind, in some instances at incredible distances from the coast'. Coring I did in the estuary uncovered a sand layer in the marshes, which could be the one being described. Taken together, these reports suggest a tsunami was created by the earthquake. The same earthquake also appears to have generated a tsunami on the Thames in central London! Contemporary reports state that 'a wave, estimated to have been about 3 ft high, was seen to cross the river, and to cause a vessel lying at St Paul's Pier to roll heavily without apparent cause'.

Figure 6 *Boulders at Lamorna Cove, Cornwall. Contemporary reports describe how boulders on this shoreline were tossed like pebbles during the 1755 tsunami.*

Reproduced with permission from http://www.flickr.com/photos/profsimonhaslett/6916222117/

The tsunami generated by the 1755 earthquake off Lisbon had dramatic effects on the British coastline

In August 1892, a similar event occurred in Pembrokeshire when a 5.1 magnitude earthquake generated tsunamis in Milford Haven and in the Bristol Channel. Typical reports state that 'two or three waves were seen to run up the shore, the sea both before and after being absolutely still' and 'the water … became suddenly swelled ... the boat seemed as if it passed over three waves, after which the water … became calm as before'. This was before oil refineries were built in Milford Haven, so possible damage might arise should a similar event occur again.

Figure 7 *The Colne Estuary, Essex, where boats rose and fell around 1 m during the 1884 earthquake.*

Reproduced with permission from http://www.flickr.com/photos/profsimonhaslett/6915966701/

The normally quiet Colne Estuary in Essex was the site of a small tsunami in 1884

A tsunami from a comet impact?

The final event is the earliest and most controversial, but is supported by the work of other scientists. In September 1014 vast parts of the British and neighbouring European coasts were inundated by a huge flood. The flood is documented in the *Anglo-Saxon Chronicles* and by William of Malmesbury who stated that 'a tidal wave … grew to an astonishing size such as the memory of man cannot parallel, so as to submerge villages many miles inland and overwhelm and drown their inhabitants'. Mike Baillie from Queens University, Belfast, published a paper in 2007 that linked this flood event with the impact of a comet or comet fragments in the North Atlantic. His theory is supported by the occurrence of ammonium in Greenland ice layers deposited at this time, and by observations made by Chinese astronomers. Also, Steven Ward, a geophysicist at the University of California, Santa Cruz, has modelled a tsunami generated by a comet impact offshore western Ireland, and his results indicate that flooding described in the historic records we surveyed from Cornwall, Cumbria, Hampshire, Sussex, Kent, North Wales and Holland can all be explained by a tsunami generated by such an impact event. Ted and I have cored through marsh sediments in Mount's Bay in Cornwall to reach a sand layer that could have been laid down by the event, but we are yet to fully analyse and publish these field results.

Meteorologically generated tsunamis?

More recently, our research has turned to the study of large destructive waves produced by unusual weather conditions. These meteorological tsunamis, or meteo-tsunamis, may be caused by pressure fluctuations associated with atmospheric gravity waves, sharp changes in atmospheric pressure such as commonly result in thunderstorms and tornadoes, squalls with very strong wind speeds, or resonance effects in bays and lakes.

In June 2011, a tsunami struck South West England between Penzance and Portsmouth, affecting around 200 miles of coastline. In the Yealm Estuary, wave heights were 0.5–0.8 m. Citing our work, the British Geological Survey rightly attributed this event (which was reported on the national news) to a passing thunderstorm. A number of meteo-tsunamis affecting the British coastline have caused fatalities, such as one that came ashore in Kent and Sussex in the summer of 1929 on a sunny July evening when the beaches were full of people. (For more on meteo-tsunamis, see Further Reading.)

Conclusion

These forgotten floods may not all be tsunamis, but the association of many of them with known tsunami causes, such as earthquakes and submarine sediment slides, does support our interpretation. Our research has examined 21 likely tsunami events to hit Britain over the past 1000 years which, if we are correct, makes tsunamis a more common hazard than previously considered. Our research has been propelled by our view that it is important to know if a flood is due to a tsunami or a storm, as storm flooding is more predictable and evasive action can be taken, whereas tsunamis can occur at any time and require educating the public to respond quickly to warning signs. For example, people should not do what a group in Kent did in April 2007 – feeling an earthquake, they rushed out from their houses and on to the beach for safety!

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Book Reviews

To boldly go

Dolphins under my bed by Sandra Clayton (2011) Adlard Coles Nautical, 271pp. £8.99 (flexicover, ISBN 13: 978-1-4081-3288-3).

Turtles in our wake by Sandra Clayton (2012) Adlard Coles Nautical, 225pp. £8.99 (flexicover, ISBN 13: 978-1-4081-5282-9).

In spite of its title, the first of these entertaining books has little to do with our cetacean friends, as they only pop up four times in the whole book. Instead, the storyline is about a middle-aged couple who fend off their aches and pains by sailing into the wide blue yonder. Although this is not an adventure voyage in the usual sense, the author has undertaken what so many of us only sit and dream about. Sandra Clayton and her husband, David, had only done a limited amount of inshore sailing before quitting work, closing up the house and setting course for the Mediterranean in search of a warmer and hopefully healthier life. By her own admission, the author had previously found sailing in home waters both uncomfortable and even unpleasant, only coming round to buying a boat for a new life after insisting on a switch from monohull to multihull.

In my own limited experience of the sailing world, it seems that a multihull is a bit like Marmite: sailors either love it or hate it. Like Sandra Clayton, I find that for live-aboard cruising the multihull wins hands down because it offers a much more stable and spacious home. Day after day at sea heeled over at 45° in a monohull can be very wearing and the space below decks is often narrower and confining. But – and this is a major 'but' – the multihull's extra width in the confines of harbours and estuaries is a distinct challenge, not least because of extra mooring charges (both hulls count towards overall length). After threading *Voyager* past fishing buoys, looming freighters and a mare's nest of mooring ropes, the wind can blow up at just the worst possible moment with the catamaran's twin hulls acting like a horizontal sail, threatening to smash the boat into the jetty.

After an inauspicious start stranded on thick mud in Chichester harbour and jamming their new mainsail in the first few gusty minutes, they faced a round of hazards, not least a minefield of lost shipping containers, while perversely, major nautical threats such as the notoriously stormy Bay of Biscay behaved benignly. The author describes the discomfort and tedium of serving night watches in oilskins with too little sleep on longer crossings, and avoids romanticising their life-changing experience. She even concentrates on mundane essentials such as hunting down launderettes and supermarkets whenever they reach shore. Spanish post offices, for instance, provide a rich vein of humour, although the locals generally prove welcoming and helpful.

Readers looking for a book centred on nautical details such as high-tech winches or squeezing out the last drop of wind from the sails may be disappointed, as this story is pitched as much at the non-sailor and gives as much weight to experiences on shore as it does to life on the water. An important part of the account covers time spent moored up in marinas with a host of irritations such as raucous neighbours, pre-dawn fishing fleet departures and that modern curse of coastal waters everywhere, the utterly pointless, smelly and perpetually noisy jet ski. All in all, this book makes for a cosy fireside read, written in clear unadorned prose and being none the worse for that.

Turtles in our wake is the sequel and picks up the tale where *Dolphins* left off, namely back in the UK on dry land. Our intrepid couple have left *Voyager* safely moored up in Menorca and returned to complete on the sale of their house by Christmas during a localised northern property recession in the late 1990s. As so often in such housing markets, they are plagued by carpet baggers and time wasters and it takes until mid-May and many frustrated pages of this book to close the deal and get back to their boat, free at last to wander wherever the fancy takes them.

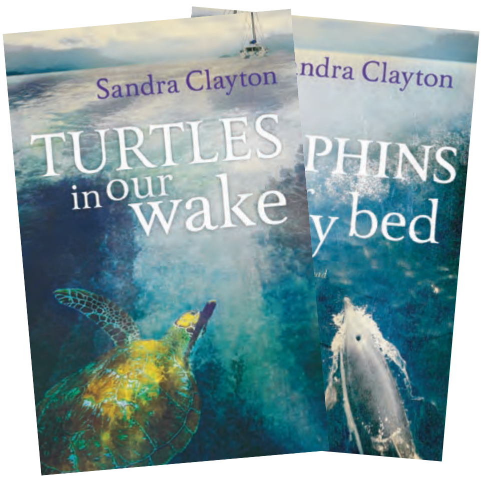
However, boats and babies have one thing in common: they both acquire dirty bottoms that need regular cleaning, and a catamaran is worse because it has two of them. The interior also needed some attention as well as some leaky windows before the couple were eventually able to set off for a cruise around Menorca in mid-June followed by a crossing to Sardinia. This is where the first of many problems begin, with surprisingly stormy weather: I had always thought of the Mediterranean in summer as fairly tranquil but this was not to be the case. I found it equally surprising that this stormy weather was to prove a major problem when moored up, causing the anchor to drag or bump the catamaran against the pontoon or other boats in marinas. It is one thing to do turnabout watches while sailing along, but taking watches in case the anchor drags must be dispiritingly boring.

Their successful escape from northern England's cold air is replaced by the frying pan of full-on Mediterranean sunshine which imakes the boat like an oven at times. Provisioning trips on land sometimes also turn into an ordeal without access to a car, as marinas are not always centrally placed and supermarkets always seem to be at the top of hills. During the extended cruise around Sardinia, *Voyager* often has to remain in harbour while gales blow themselves out, providing many opportunities for exploring the island's historic past.

Another surprise for me was that mooring up in marinas was not as pleasant as it should be. Apart from the expense, facilities like toilets and laundries either do not work properly or have considerable queues even at early hours. Worse still are the noisy, inconsiderate neighbours such as naked divers, late night and loud talkers, jet skis, and sailors with poor or even non-existent mooring techniques that threaten to do considerable damage to *Voyager*. At sea, the bad behaviour continues with owners of large motor cruisers rushing close by, setting up mini-tsunamis that come flooding through open hatches.

The book concludes with the start of their next adventure: an Atlantic crossing to the Caribbean. After the crowded waters of the Mediterranean, their first leg to Madeira goes smoothly. Well, smoothly apart from getting caught up in a giant drift net (or wall of death) and having to go overboard to cut themselves free, as well as ducking around some very lively sail-wrecking squalls. As for those turtles, they do make an appearance early on, but like the dolphins in the first book they simply provide some colour to this very personal sailing story.

Gerry Bearman
Science editor
(retired and currently stranded without a boat in Cornwall)



Gross but gripping …

How to snog a hagfish: disgusting things in the sea by Jonathan Eyers (2012) Adlard Coles, 96pp. £7.99 (paperback, ISBN 13: 978-1-4081-4042-0).

I can't say that the question regarding how I should snog a hagfish has ever occurred to me. However, when the idea was presented, I can't and won't deny that I wasn't a little curious.

In this book, Jonathan Eyers has created a pocket masterpiece. On the surface, every boy's dream and everything to make a girl squirm, *How to snog a hagfish* becomes irresistible from the very first page. Of course, not having grown up a boy, I have never had the inbuilt need to find out the most disgusting facts possible. However, with this book I feel not only armed to tackle such a challenge but also inclined to do so. From the very first page, this book succeeds in quite literally making your skin crawl; several times I felt the need to brush over my hair, just to make sure the tickling sensation I felt was not really a tongue-eating louse waiting to pounce into my open mouth. I also found myself constantly having to explain my facial expression to those in my company – on the train, at school (book under the desk) and even at the dinner table.

Not only does the easy, pick-up and put-down nature of this book enable you to satisfy any cravings you might have for a disgusting fact, but those around you (although they might not know it) will also be just a little bit more knowledgeable after you have shared the fact that a sea star's stomach pops out of its mouth when it fancies a snack.

The use of bold type for enhances the easy access that this book provides; I found that not only did the bold 'highlights' allow me to flick to a page and remember where I left off but also allowed me to share the keys aspects with my friends and family quickly and easily. Another essential part of this book is the pictures – that's of course if your imagination hasn't already filled in all the gaps.

The introduction, entitled 'Beneath the surface' adds another dimension to this book which 'on the surface' seems to solely aim at making the rest of us realise that, in comparison to Johnathan Eyers himself, even the most robust of us have a very low threshold for all things disgusting. However, just as we don't know what lies far beneath in the underwater world, initially we do not see what lies beneath the surface of this book's squirm-inducing exterior. I feel that on reflection after having finished this book, the topics covered are not just 'disgusting' (for Eyers was not exaggerating when he said this) but also rather astonishing. Where authors of fiction have only grazed the surface of what lies 'down there', *How to Snog a Hagfish* dives bravely straight in, swimming amongst the dangers and demystifying what at first seems to us 'alien' but then on closer inspection screams evolution and survival. As you go through this book it is evident that despite all their sickening habits, each and every one of these animals has a reason for doing them. Their life depends upon it.

This book is essentially proof that fact really is stranger than fiction.

Sarah Gray
Year 12
The Portsmouth Grammar School

If this book appeals to you, you might also enjoy *Don't shoot the albatross! Nautical myths and superstitions* by the same author, also published by Adlard Coles (ISBN 13: 978-1-4081-3131-2).

Solution to the Maritime Crossword Challenge

1 W	E	2 S	T			3 H		4 S	W	5 A	L	6 L	O	7 W
E		H		8 D	I	O	D	E		A		E		I
9 A	W	I		R		T		A		10 S	11 T	E	R	N
T		12 P	L	I	M	S	O	L	13 L		R			D
14 H	M	S		F		P			15 A	L	I	A	16 S	
E			17 S	T	O	O	D		K		N		P	
18 R	19 O	P	E			T		20 P	E	R	I	G	E	E
	Z		R		21 I				S		D		R	
22 C	O	M	P	A	N	Y		23 M			24 A	L	M	25 A
	N		E		D		26 E	A	R	27 E	D			T
	28 E	N	N	U	I			N		R		29 A	W	L
30 W			T		31 A	32 L	D	A	B	R	A	N		A
33 A	V	34 A	S	35 T		I		T		O		36 I	B	N
S		R		A		37 S	T	E	E	R		O		T
38 H	O	M	A	R	U	S		E			39 O	N	D	A

The first correct solution was sent in by John Phillips, who received a £40 book voucher.