At sea with the UKOA

Investigating the effects of rising ocean acidity

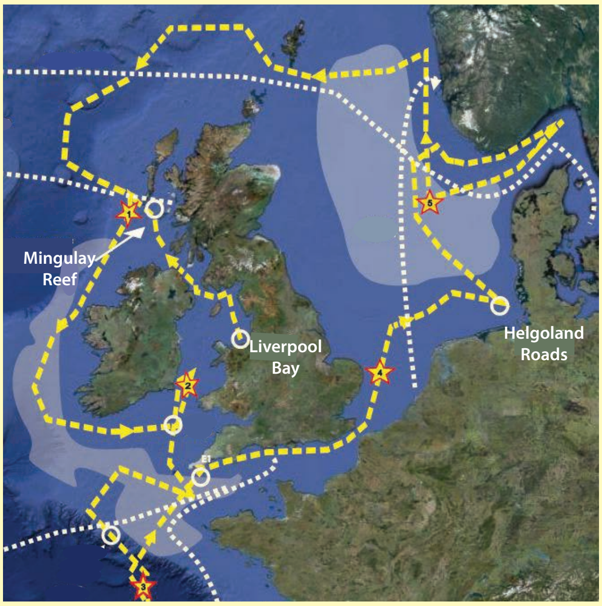
Over the past few years, the UK Ocean Acidification Research Programme (UKOA) has been carrying out a range of experiments, observations and modelling studies within seven consortia projects, aimed at reducing uncertainties in predictions of changes in carbonate chemistry and their effects on marine biogeochemistry, ecosystems and other components of the Earth System, and understanding the responses to ocean acidification by marine organisms, biodiversity and ecosystems (see http://www.oceanacidification.org.uk/). Over the past 10 years of ocean acidification research, the focus has been on experimentation and laboratory studies, but there has been a growing need to monitor and understand the natural carbonate chemistry across different oceanic regions, and the current state and functioning of marine organisms and their ecosystems. The UKOA addressed this need by providing the opportunity to carry out four research cruises, three as part of the UKOA Sea Surface Consortium, and one as part of the UKOA Benthic Consortium. Between them, these cruises encompassed regions of vulnerability (Arctic waters and the Southern Ocean), of coastal importance (the European shelf seas), and of biological vulnerability (cold-water coral reefs). The following four articles describe the work carried out on each of the research cruises, as well as the excitements and challenges, and some preliminary findings The cruises made use of the full suite of research vessels within the NERC fleet – the RRS *Discovery*, the RRS *James Cook* and the RRS *James Clark Ross*. **Helen Findlay**

European Shelf Seas Discovery *cruise*

Laura Wicks, Heriot-Watt University

In June 2011, the RRS *Discovery* steamed away from Liverpool to spend a month circumnavigating the British Isles. The 23 scientists on board, from eight UK institutes, were there with a variety of aims, but all had one specific goal: to understand how ocean acidification will affect European seas. Specifically, we aimed to investigate the impacts of changing seawater chemistry on marine organisms and ecosystems, biogeochemical cycling in the sea, and how the sea interacts with the atmosphere to influence climate.

Each day before the sun rose, sleepy scientists made their way on deck to greet the CTD (a conductivity–temperature–depth meter) attached to a large water sampler. This instrument collected water from a variety of depths at 70 sites around the UK, from up near the Shetlands down to the Bay of Biscay. Once back on the ship, the biology and chemistry of this seawater was examined to investigate everything from the concentrations of different dissolved gases, to the carbonate chemistry, nutrient concentrations and microscopic life. Results so far have found large variability in the carbonate chemistry of surface waters around the UK, with a pH range of around 0.3 units, which also happens to be the projected future 100-year decrease in mean pH.



Stars = sites where bioassay experiments were undertaken. White dashed lines = tracks along which the Continuous Plankton Recorder is deployed, mostly using regular ferry routes. Circles = sites of existing time-series. Grey areas = sites of frequent coccolithophore blooms (another area addressed during the cruise).*

*A bioassay is an experiment to measure the effect of a substance on living organisms; in this case the substance was CO_2, in various concentrations.

To predict what the future may hold for these waters, we conducted bioassay experiments at five of the sites visited (indicated by stars on the map). We dispensed the seawater from a variety of depths into more than seventy 5-litre transparent polycarbonate bottles, and then raised the seawater CO_2 (so lowering the seawater pH), to be representative of the state of the future ocean. These bottles were maintained in a purpose-built laboratory on the ship for four days, during which biological and chemical measurements were taken. Results so far have been interesting but complex, with some microbial species appearing tolerant to increasing acidification and others seeming more vulnerable.

Laura sorting Lophelia *samples on the deck of* Discovery *(see overleaf)*

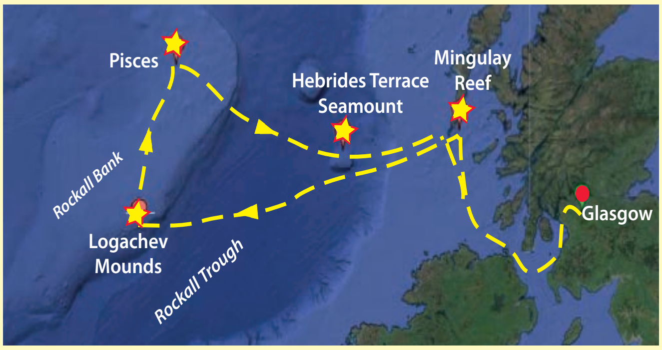
But not all the scientists were on board to look at the water column; I was there with colleagues from Heriot-Watt University, Edinburgh, to examine how cold-water corals off Scotland would cope with the changing chemistry of the oceans. We collected the enigmatic species *Lophelia pertusa* from the Mingulay Reef Complex in the Hebrides, to use in short- and long-term ocean acidification experiments. Cold-water corals are among the most three-dimensionally complex deep-sea habitats known and are associated with high local biodiversity. However, their remoteness and the relatively short history of ecological research in these habitats mean that to-date we have little information on how these ecosystems will fare in the face of predicted future climate change. Our results so far show that corals exposed to increased CO_2 conditions had significantly lower respiration rates but were able to maintain their calcification rate. This suggests they may actually be using their energy stores to survive, which would have detrimental long-term effects. The long-term experiment we are conducting is now drawing to a close at the Heriot-Watt aquarium, where cold-water corals collected by the *Discovery* have spent the last year being grown in a variety of CO_2 levels and temperatures. This experiment aimed to determine whether these important reef-building animals can possibly acclimate to a future changing ocean.

Changing Oceans Expedition: cold-water coral

Helen Findlay, Plymouth Marine Laboratory

The Changing Oceans research cruise onboard the RRS *James Cook* in May–June 2012, was a dedicated cold-water coral research expedition, and followed on from the trip on-board the *Discovery*, used to gather corals for experiments (*see above*). The cruise personnel was made up of 21 scientists, five ROV pilots and technicians, six technical crew and 22 ship's crew. While our main aims were to carry out reef surveys and investigate coral responses to CO_2 in onboard experiments, it was also critical that we characterised the present carbonate system in the seawater surrounding these deep-water reefs, particularly pH and saturation states of aragonite and calcite (two of the dominant forms of calcium carbonate minerals), in order to understand the conditions these reefs are exposed to.

We set off from Glasgow in a grey misty cloud, but arrived nearly 12 hours later to a brilliant sunrise and clear skies at our first station: the Mingulay Reef complex, off the Outer Hebrides. We spent about six days at this location. During the day, the Remote Operated Vehicle (ROV) would be sent to the reef to survey and collect samples. The samples, mainly corals and sponges, were placed into makeshift aquariums in the main hanger of the ship. In each of these tanks, the temperature and CO_2 concentrations were manipulated so that we could investigate how ocean acidification and warming were affecting a whole suite of parameters associated with the corals.



Track of the Changing Oceans cruise. Stars = sites where bioassay experiments were undertaken.

These investigations addressed physiological impacts, such as effects on respiration and calcification, DNA, RNA and proteins, feeding, metabolism and trophic structure, as well as release of gases such as DMSP (dimethyl sulfoniopropionate, the major precursor of the climatically important gas dimethyl sulphide, DMS).

Skeleton of the cold-water coral Lophelia.

After Mingulay, we steamed out to Rockall Bank. Our first stop was the Logachev Mounds, large carbonate mounds with extensive living reef structures, on the south-east flank of the Rockall Bank. Out in the open sea, conditions became much rougher, and while we were able to deploy the ROV most of the time, there were a few days when the weather prevented over-side operations. During this time, we used the Moving Vehicle Profiler (MVP) to survey the nearby area for water column structure, particles and plankton.

We were operating on a 24-hour schedule, with the main ROV operations being carried out during the day. During the night we would carry out additional CTD casts and water-sampling to investigate the short-term variability and hydrodynamic influence on the carbonate and nutrient biogeochemistry near the reefs. We conducted box-coring surveys to examine the coral habitat and local biodiversity, and gravity coring surveys to examine fossil coral carbonates. We also completed surveys of the sediment–water interface along transects of different habitats associated with the cold-water corals, using Cefas' SPI Camera equipment.

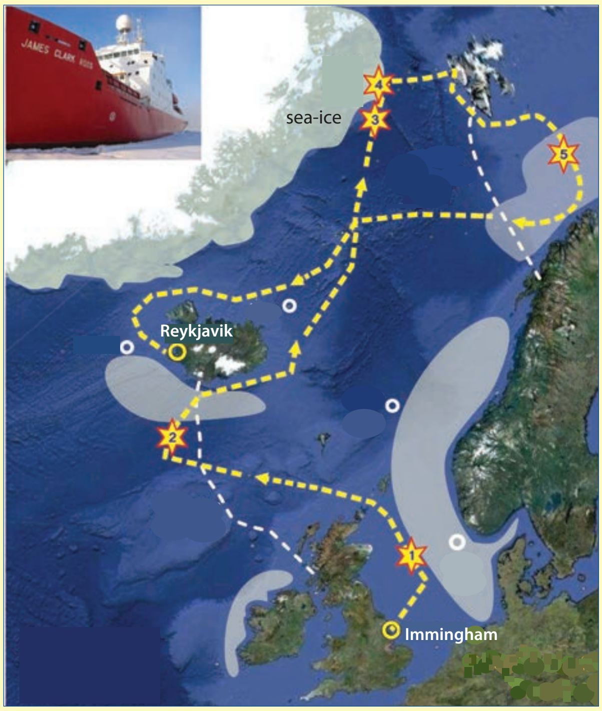
After we left Logachev, we had just a few days on the north-west flank of the Rockall Bank to survey the Pisces site. Here, we passed through a large coccolithophore bloom – a swirling eddy of blues and whites. Interestingly, we got a satellite image of the area sent to us, so we could see the bloom from space, outside our window, and in the samples that we had taken for carbon and alkalinity! After a brief stop at the Hebrides Terrace Seamount, on the eastern side of the Rockall Trough, for a couple of quick ROV dives to survey the area for JNCC (the UK Joint Nature Conservation Committee), we were steaming back towards Scotland. As we once again passed back over the Mingulay Reef complex, the sun was shining, we had amassed a huge dataset on the life and habitat of deep-water corals, and were on track to discover how they might be impacted by ocean acidification in the future.

Plankton, CO_2 and polar bears: ocean acidification in the Arctic

Frances Hopkins, Plymouth Marine Laboratory

As the RRS *James Clark Ross* gently steamed through the lock at Immingham docks on 1 June 2012, passing the vast industrial infrastructure that characterises this part of the North Sea coast, the 33 scientists onboard could only imagine what the next five weeks of science would bring. Most were seasoned research cruise-goers, so setting up the laboratories and settling in to life on a research vessel seemed fairly routine. However, this time there was perhaps a slightly heightened level of excitement as we all knew that this trip had the potential to be pretty special, maybe even exceptional. In the end, our expectations were surpassed.

Our voyage was part of the surface ocean consortium within the UKOA – the part of the programme that assesses how ocean acidification will affect surface ocean biology, biogeochemistry and, ultimately, climate. Onboard were scientists representing Plymouth Marine Laboratory, the National Oceanography Centre (Southampton), Essex University, University College London, the Marine Biological Association, the British Antarctic Survey, and the Scottish Association for Marine Sciences, bringing together a broad range of expertise in order to obtain a comprehensive overview of the response of the Arctic plankton ecosystem.



Stars = sites where bioassay experiments were undertaken. White dashed lines = CPR transects; circles = sites of existing time-series Grey areas = sites of frequent coccolithophore blooms

The Arctic Ocean is particularly vulnerable to acidification as CO_2 is more soluble in colder waters. This, combined with loss of land- and sea-ice and a rapidly changing climate, means that within the next decade areas of the surface Arctic Ocean will be the first to experience the effects of ocean acidification. Our mission was to examine the response of the susceptible Arctic plankton communities to ocean acidification, and would take us on a whistle-stop tour, from the stormy and grey North Atlantic to the tranquil frozen waters of the Greenland Sea, across to the dramatic and mountainous Svalbard Archipelago, then down to the Barents Sea, before traversing back towards Iceland and spending a day surrounded by humpbacks under sunny skies in the Denmark Strait. Highlights of the trip included passing the huge, glacier-encrusted volcanic cone of the Jan Mayen islands, the midnight sun, midsummer in Ny-Ålesund, groups of orcas determinedly cruising past, humpback whales breaching around the ship in the Denmark Strait and of course, close encounters with polar bears.

Frances collecting seawater from one of the bioassay bottles, as part of the experiment to determine rates of production of DMS (cf. p.6)

The ever-changing scenery and wildlife did, of course, help to keep the morale up, even though the work was hard and the days were long. The cruise involved a gruelling routine of both observational and experimental work, with early morning (or should I say the middle of the night) starts and long days of analysis. The polar summer sunlight certainly helped lift the spirits at 2.30 a.m. The observational element of the expedition comprised underway measurements of a set of key seawater characterstics every 20 n.m. or so along the cruise track, including carbonate chemistry, the composition of the microbial plankton community, and nutrients. In addition, twice a day, the full water column was sampled for an extensive range of measurements, including a suite of biological and biogeochemical standing stocks and rates, as well as everything from trace metals to trace gases. This data will be synthesised in a large-scale multivariate statistical approach to determine how Arctic ecosystems respond to natural variations in carbonate chemistry.

To complement this observational work, we also undertook an intensive experimental regime, involving four five-day ocean acidification experiments. Surface water was collected from five contrasting locations along the cruise track (stars on map), transferred to 4-litre incubation vessels for bioassay experiments, and each vessel was treated with one of three different future CO_2 levels: 550 µatm, 750 µatm, 1000 µatm, along with ambient controls. At 0 h, 48 h, and 96 h a wide range of parameters were measured in order to give an overview of the response of the microbial community and associated processes (including production and cycling of DMS and DMSP) to these future conditions. Laden with reams of data, we arrived in Reykjavik in early July. Now the data analysis begins, and over the next few months we will begin to unravel the response of these vulnerable northern waters to the advancing threat of rising ocean acidity.

Surface ocean acidification in the Southern Ocean

Matthew P. Humphreys, University of Southampton

Over a period of a week at the start of January 2013, 27 scientists arrived in the Falkland Islands, some via Ascension Island, others taking the epic commercial route (London–Madrid–Santiago–Punta Arenas–Falklands). Then began the manic mobilisation of so much equipment on the RRS *James Clark Ross* that veteran crew members were taking photos as mementos of 'the most kit they've ever seen set up for one cruise'. Represented were researchers from the National Oceanography Centre and University of Southampton, Plymouth Marine Laboratory, the British Antarctic Survey, University College London, the Marine Biological Association, the University of Essex, and the Université du Littoral. With one instrument or another bolted down on every surface in every lab, and our five lab containers secured on the aft deck, we set sail from Stanley on a cloudy Wednesday afternoon, to return five weeks later.

As part of the UK Ocean Acidification Research Programme, the main focus of the cruise was to investigate the impact of ocean acidification on surface ocean biology. To this end, we ran four bioassay experiments during the cruise. Each of these involved collecting copious quantities of water from the surface mixed layer, and dividing this up into bottles for incubation for up to eight days. The water chemistry was manipulated so that incubations were carried out under a range of CO_2 levels, from ambient up to a maximum of 2000 µatm (~ 5 times present-day levels); also, with and without the addition of iron. Then, the vast array of analytical machinery we had loaded on to the ship sprang into action to measure a host of biological and biogeochemical parameters during and after the incubations, to assess any responses to the modified carbonate chemistry. Additional similar experiments were run with zooplankton and also using seawater samples collected from greater depths. The interpretation of these results is still at too early a stage to allow us to draw any significant conclusions.

Beginning a CTD cast near the South Shetland Islands

Alongside these bioassays, we carried out morning and evening CTD rosette casts down to 300 m on most days, collected underway samples at a maximum of 2-hour intervals throughout the cruise, and a few full-depth CTD rosette casts, all again for a wide range of biological and biogeochemical measurements. These will allow us to characterise the surface ocean using multivariate statistical analyses and, importantly, they will provide context for the bioassay results.

We were lucky to see many beautiful places and a lot of spectacular wildlife throughout the cruise. To begin, we crossed the Drake Passage, which was a little rough (causing us to miss one day of science), but not bad at all considering how rough that area of sea can be. As we approached the South Shetland Islands their peaks were clouded and misty, but this cleared to give us a magical view of Elephant, Clarence and Cornwallis Islands under a brilliant blue sky. We then zig-zagged through the Scotia Sea, into sea ice often completely covered with chinstrap penguins and fur seals, and up to South Georgia. There, we went alongside at King Edward Point, and spent the day on land visiting the old whaling station at Grytviken and being chased and disgusted by fur and elephant seals respectively. Back at sea, we sailed north-westwards and then south past the South Sandwich Islands, continuing down to about 65°S in the Weddell Sea. Approaching the South Georgia plankton bloom on our way back north we had a brilliant day for wildlife, with a number of humpback whales approaching within a few metres of the ship for several hours, and tens of pilot whales and seals too. We finished with a brief return to King Edward Point and Bird Island to pick up a few extra passengers (and so filling every available berth in an already crowded ship) and a fast crossing back to Stanley.

This cruise was the last of a set of three with similar objectives, with previous related cruises in the Nordic Seas last summer and around the UK the summer before (*see pp.* 5–7). Now, there is a lot of work to be done to finish analysing the few remaining samples; to write up the data from each cruise; and to combine them to achieve a better understanding, on a global scale, of how surface ocean acidification will affect ecosystems and biogeochemistry in the coming decades.

Far left *A fur seal watches RRS* James Clark Ross *off King Edward Point, South Georgia*
Left *Chinstrap penguins on an ice floe in the Scotia Sea*