UK Ocean Acidification
Research Programme

ANNUAL SCIENCE MEETING

St Andrews 22-24 July 2013

NATURAL ENVIRONMENT RESEARCH COUNCIL

DEPARTMENT OF ENERGY & CLIMATE CHANGE

Living With Environmental Change

defra
Department for Environment Food and Rural Affairs

Photo: JC073 "Changing Oceans" ROV still

WELCOME to the 3rd Annual Science Meeting of the UK Ocean Acidification (UKOA) research programme, hosted by the University of St Andrews. The UKOA Science Plan (inviting consortium-based proposals for programme support) was published in 2009: since then, there has been more than a 5-fold increase in the published literature on ocean acidification. These new papers, around a thousand, have dramatically increased our awareness of many previously-unsuspected marine consequences, and societal implications, of a high CO_2 world. UKOA has itself already made a significant contribution to that increase in knowledge. The presentations and discussions at this meeting will undoubtedly provide further important insights into the impacts – and complexity – of the far-reaching changes in global ocean chemistry that are now underway, occurring at an unprecedented rate.

More than 120 researchers have been directly involved in UKOA, in 26 laboratories across the UK. However, from its start, UKOA has benefitted from close connections with the EU European Project on Ocean Acidification (EPOCA) and the German BIOACID programme. Subsequently, productive collaborations have been developed with the EU Mediterranean Sea Acidification in a Changing Climate (MedSeA) project; with US researchers in the NOAA OA Program and the Ocean Carbon & Biogeochemistry (OCB) project; and with very many other scientists around the world. Whilst the focus of this meeting is necessarily on UKOA research, there is strong international participation – culminating in a joint session with the 2nd workshop of the Global Ocean Acidification Observing Network.

This linkage between national and international research effort is mutually advantageous. It stimulates ideas, and enhances the efficient and complementary use of limited human and financial resources. It also promotes effective communications, not only between researchers, but with policy-makers and other stakeholders. Thus ocean acidification research is not just an intellectual exercise: it is science with a purpose, delivering societally-benefical information and understanding of the "other CO_2 problem", thereby helping to safeguard environmental sustainability and human well-being.

The UKOA research programme is co-funded by the Natural Environment Research Council (NERC), the Department for Environment, Food and Rural Affairs (Defra), and the Department of Energy and Climate Change (DECC). Further information at: www.oceanacidification.org.uk

***Members of UKOA Programme Executive Board**: Mike Webb (NERC, Chair), Caron Montgomery (Defra), David Warrilow (DECC) and Harry Elderfield (Univ of Cambridge)*

***Science Coordinator:** Phil Williamson (NERC/UEA); **Knowledge Exchange Coordinator:** Carol Turley (PML); **Programme Administrator**: Jodie Clarke (NERC)*

***Members of UKOA Programme Advisory Board:** Harry Elderfield (Cambridge, Chair), Eric Achterberg (Southampton), Jean-Pierre Gattuso (CNRS - UPMC Villefranche), Paul Halloran (Exeter), Angela Hatton (SAMS), Mike Heath (Strathclyde), John Raven (Dundee), Ulf Riebesell (IFM-GEOMAR), Steve Widdicombe (PML) and Andrew Yool (NOC Southampton)*

Additional UKOA-wide management support from Debbie Hembury (Defra), Ken Wright (DECC), UKOA consortium lead PIs, Kelly-Marie Davidson and Julia Crocker (PML), and Kelvin Boot. Also for this ASM, David Paterson, Emma Defew and Nikki Khanna (St Andrews).

UK Ocean Acidification Research Programme

UKOA Annual Science Meeting: 22-24 July 2013

University of St Andrews, North Haugh (main campus), St Andrews KY16 9TF

Meeting sessions to be held in Medical & Biological Sciences building; accommodation in Agnes Blackadder Hall

See map for venue locations. Separate schedule for GOA-ON workshop 24-26 July

	UKOA ASM: Monday 22 July	
From 10.00	**Registration.** Presentation load-up[1]; set up posters. Coffee & tea.	
10.30	Welcome: *David Paterson*	10 min
	Longterm perspective #1 *Chair: Caron Montgomery*	
10.40	Modelling carbonate chemistry and future OA impacts in regional seas:	
	• North west European shelf *Yuri Artioli*	20 min
	• Arctic Ocean *Andy Yool*	20 min
	• Summary report on recent modelling workshops - on carbonate processes, macrofaunal processes and microbial process *Jerry Blackford*	15 min
11.35	Discussion	10 min
11.45	Global modelling of OA processes and their biogeochemical impacts:	
	• Project progress, including update on the Ocean Acidification Viewer and report on the workshop 'Why do coccolithophores calcify?' *Andy Ridgwell*	20 min
	• What controls the biological pump in the ocean? Implications of OA-sensitive ballasting vs. temperature *Lauren Gregoire*	15 min
12.20	Discussion	10 min
12.30-13.30	**LUNCH**	
	Longterm perspective #2 *Chair: Paul Halloran*	
13.30	Not-that-abrupt past changes in ocean carbonate chemistry – and their biological consequences.	
	• Introduction. *Paul Pearson*	10 min
	• Surface pH changes at the Paleocene-Eocene Thermal Maximum (PETM) *Marcus Gutjhar*	20 min
	• Plankton evolution, OA and extreme temperatures at the PETM. *Tracy Aze*	20 min
	• Coccolithophores and OA – past and present. *Sam Gibbs*	20 min
14.40	Discussion	10 min

[1] Files should be labelled with presenter's surname and date, with presentations for consortium sessions preferably in a single folder. All content (axis labels, tables etc) must be clearly legible, and final slide of each presentation should summarise conclusions and implications. Short, poster-related presentations should be limited to 2-3 slides, including author name(s) on title slide.

14.50-15.30	**Tea & coffee**	
15.30	**Short poster presentations** *Chair: Phil Williamson*	
	Yuri Artioli - *In silico* experiments for testing sensitivity to ocean acidification *Jerry Blackford* – Modelling benthic sensitivities to high CO_2 *Andrew Yool* – Climate change and OA impacts on lower trophic levels and the export of organic carbon to the deep ocean *Jamie Wilson* – The biological pump in warm climates *Kate Salmon* – Environmental controls on seasonal changes in planktonic foraminiferal abundance, shell mass and trace element geochemistry *Maria Williams* – Environmental forcing on pelagic carbonate production *Alison Webb* – Dimethylsulphide dynamics under the effects of OA: a mesocosm comparison *Mariana Ribas-Ribas* – Carbonate chemistry intercomparison in NW European Sea *Laura Pettit* – Benthic foraminifera along shallow water CO_2 gradients *Martin Stemp* – Autonomous surface vehicles as data-gathering platforms for OA studies	10 x 5 min = 50 min
16.20-17.00	**FIRST POSTER SESSION (A).** All UKOA ASM posters displayed; authors in attendance for those named above and others in Group A. See separate list for full titles, authors and abstracts.	40 min

19.00	ST ANDREWS UNIVERSITY 600th ANNIVERSARY RECEPTION Agnes Blackadder Hall	
19.30	**DINNER** Agnes Blackadder Hall	

UKOA ASM: Tuesday 23 July

	OA impacts in the upper ocean *Chair: Ulf Riebesell*	
09.00	Activities, outputs and outcomes from the UKOA sea surface consortium:	
	• Overall progress *Toby Tyrrell*	15 min
	• Carbonate chemistry in European seas (D366) *Dorothee Bakker*	15 min
	• Initial results from the Arctic (JR 271) *Ray Leakey*	15 min
	• Initial results from the Southern Ocean, including pteropod studies (JR 274) *Geraint Tarling*	15 min
	• Bioassays and biological responses *Toby Tyrrell*	15 min
	• Coccolithophorid distributions and bioassay responses *Jeremy Young*	15 min
	• Outreach activities *Athena Drakou*	15 min
10.45	Discussion	15 min
11.00-11.20	**Coffee & tea**	
11.20	**Short poster presentations** *Chair: Phil Williamson*	
	Chris Williamson – The carbonate environment of *Corallina* macroalgae *Jasmin Godbold* – Distinguishing between the effects of exposure duration and seasonality in OA experiments	9 x 5 min = 45 min

Ben Harvey – Meta-analysis reveals complex marine biological responses to the interactive effects of ocean acidification and warming

Gemma Cripps – Could maternal influences be masking the negative reproductive effects of OA in copepods?

Suzanne Jennions – Assessing the structural integrity of marine calcifiers under changing environmental conditions

Eric Armstrong – The effects of OA on shell mineralogy of the scaled giant clam *Tridacna squamosa*

Emma Cross – OA impacts on the shell characteristics of articulated brachiopods

Tessa Page – Effects of lowered pH on the exoskeleton composition of porcelain crabs

Jonathon Stillman – Interactive effects of pH and temperature variability on metabolism and cardiac function in an intertidal porcelain crab

Clara Manno – Swimming behaviour response of pteropods to the synergic impact of OA and freshening

12.10-12.45	**SECOND POSTER SESSION (B)**. All UKOA ASM posters displayed; authors in attendance for those named above and others in Group B. See separate list for full titles, authors and abstracts.	35 min
12.45-13.30	**LUNCH**	
	OA impacts on benthic ecosystems *Chair: Angela Hatton*	
13.30	Outputs and outcomes from the UKOA benthic consortium:	
	• Introduction *Steve Widdicombe*	5 min
	• Benthic OA impacts at the physiological level *Piero Calosi*	25 min
	• From individuals to ecosystems and biogeochemistry *David Paterson*	25 min
	• Scaling-up benthic community function, for inclusion in food-web models *Silvana Birchenough*	25 min
	• “Changing Ocean” 2012 expedition – and OA impacts on cold-water corals and maerl *Murray Roberts*	25 min
15.15	Discussion	15 min
15.30	Summary report on workshop on OA impacts on macroalgae, seagrasses and microphyto-benthos *Chris Williamson*	10 min
15.40-16.00	**Tea & coffee**	
	Knowledge Exchange, programme synthesis and forward look *Chair: Mike Webb*	
16..00	UKOA KE, including involvement in activities by UN bodies *Carol Turley & Kelvin Boot*	20 min
16.20	Public perception of OA and its impacts *Stuart Capstick*	10 min
16.30-17.45	**BREAKOUT GROUPS** (n = 5). Discussion leaders/facilitators: Kelvin Boot (green group), Carol Turley (blue), Philip Stamp (red), John Baxter (yellow) and Helen Findlay (silver) • Identification of ‘top 5’ OA research advances since 2010, and ‘top 5’ research issues requiring further attention.	75 min
19.30	**UKOA CONFERENCE DINNER** Lower College Hall: location 44 (K2) on St Andrews town map	

UKOA ASM: Wednesday 24 July

09.00	Short reports from breakout groups; discussion. *Chair: Phil Williamson*	30 min
09.30	**OA impacts on commercial species** *Chair: John Raven*	
	Outputs and outcomes from the UKOA consortium on commercial species and socio-economic impacts: • Overview presentation *Kevin Flynn* (including results from experimental studies at Exeter and Swansea; sensitivity analysis for end-to-end model of North Sea; and socio-economic impact assessment. Co-authors include *Rod Wilson, Ceri Lewis & Rob Ellis; Ed Pope; David Morris; and Nichola Beaumont*)	60 min
10.30	Discussion	10 min
10.40-11.00	**Coffee & tea**	
	OA observations and synthesis *Chair: Libby Jewett*	
11.00	OA observations and analyses for UK waters and the North Atlantic, and their contributions to global synthesis studies: • Overall progress *Andrew Watson* • Cefas observations and analyses *David Pearce & Naomi Greenwood* • Marine Scotland observations and analyses *Pamela Walsham* • North Atlantic and SOCAT synthesis *Ute Schuster & Dorothee Bakker*	10 min 20 min 15 min 20 min
12.05	Discussion	10 min
12.15	UKOA data management: status report *Rob Thomas*	10 min
12.25	Concluding remarks: *Mike Webb & Caron Montgomery*	10 min
12.35-13.30	**LUNCH** ***End of display of UKOA ASM posters; set-up of GOA-ON posters***	

Joint session of UKOA ASM and GOA-ON workshop: Wednesday 24 July

13.30	**Ocean acidification research in a wider context** Chair: Carol Turley	
	1. From national to international, from science to policy *Phil Williamson*	15 min
	2. Awareness and action on ocean acidification *Jane Lubchenco*	15 min
	3. Environmental protection in the North Atlantic *Darius Campbell, Executive Secretary, OSPAR Commission*	15 min
	4. Framework for ocean observing and ship-based time series – aiding the design of a global OA observing network *Maciej Telszewski*	15 min
	5. Update on the OA International Coordination Center *Lina Hansson*	10 min
	6. Promoting technological advances: the X-Prize *Paul Bunje*	5 min
	Discussion	15 min
15.00-15.20	**Tea & coffee**	20 min

15.20	**The development of a global ocean acidification observing network** Chair: Bronte Tilbrook	
	1. Why we need a global OA network *Wendy Watson-Wright, Executive Secretary IOC/UNESCO*	15 min
	2. Where we are now: outcomes from the 1st GOA-ON workshop, Seattle 2012 *Jan Newton*	25 min
	3. An introduction to the global OA observing asset map *Cathy Cosca*	5 min
	Discussion: where we want to be	15 min
16.20-16.30	**Break**	10 min
16.30	**Global observing of ocean acidification and ecological response** Chair: Arthur Chen	
	1. Observing OA in regional seas: a modeller's perspective *Jerry Blackford*	15 min
	2. OA processes and impacts in US coastal waters *Richard Feely*	15 min
	3. Observing OA in upwelling regions off South America *Rodrigo Torres & Nelson Lagos*	15 min
	4. Observing OA and its impacts in the Pacific-Arctic *Jeremy Mathis*	15 min
	5. Observing OA and its impacts in the Southern Ocean *Pedro Monteiro*	15 min
	Discussion	15 min
18.00	Session ends	
19.30	**DINNER** Agnes Blackadder Hall	

Photo: Toby Tyrrell/UKOA Sea Surface Consortium

UKOA ASM Poster Abstracts

Note:

- Poster abstracts listed alphabetically according to presenting author (underlined)
- Poster boards are numbered, and allocated to the two poster sessions with authors in attendance, Session A (16.20-17.00, 22 July) and Session B (12.10-12.45, 23 July).
- All UKOA ASM posters are expected to be on display until lunchtime on 24 July. Those marked * will also be displayed at the GOA-ON Workshop, with different numbers.

1 B

S.-A. Watson, Eric Armstrong[1], P. Calosi[2] & J. Stillman[3]

[1] *University of California, Berkeley, USA*
[2] *University of Plymouth*
[3] *San Francisco State University,* USA

The effects of OA and global warming on shell mineralogy of the scaled giant clam *Tridacna squamosa*

Increased temperatures and decreased oceanic pH are products of anthropogenically induced climate change and have been shown in many marine taxa to affect rates of calcification and alter mineral structure of carbonate exoskeletons. The potentially synergistic effects of these stressors are likely to be particularly severe for tropical molluscs like giant clams (genus *Tridacna*) which may currently live at or near their respective thermal maxima, and which produce the largest exoskeleton of all extant bivalves. In this study, we investigated the effects of increased temperature and lowered pH on the mineral composition and organic content of shells of the scaled giant clam, *Tridacna squamosa*. Juvenile *T. squamosa* were reared under one of four treatment conditions in a 2x2 temperature (28.5°C modern and 31.5°C projected future) cross CO_2 (395 ppm and 950 ppm future) experimental design. Clams were exposed to experimental conditions for 60 days before samples of both new and old growth shell were collected. Shell mineralogy ([Ca2+], [K+], [Mg2+], [Mn2+], [Sr2+], [Na+], [P3-], [Si4+], and [As3+]) and organic content (C:H:N ratios) were examined using inductively coupled plasma mass spectrometry (ICP-MS) and elemental analysis (EA) respectively and results from both new and old growth were compared across all treatments.

2 A

Yuri Artioli, L Polimene, F Hopkins & J Blackford

Plymouth Marine Laboratory

In silico experiments for testing ecosystem sensitivity to ocean acidification

Laboratory and mesocosm experiments aiming to determine the biological impacts of OA show high variability in the magnitude and sometimes even in the sign of the response. This makes it difficult to parameterise OA-related processes in a modelling framework in order to assess the impact of OA at ecosystem level. Nevertheless, models can still be very useful to explore the potential ecosystem sensitivity to OA: used as preliminary *in silico* experiments, they can provide a first test of experimental hypotheses and at the same time highlight the potential feedbacks of a single process at ecosystem level, helping to design further *in vivo* experiments or *in situ* observations. Similarly models can be a useful tool to help in the interpretation of *in situ* or laboratory studies when these are not fully constrained by observation, providing plausible quantitative information to support the explanation of the data. Here we show a couple of examples of such use of models and we call for new hypotheses to test in our modelling framework.

*3 B

Dorothee CE Bakker[1], S Hankin[2], A Olsen[3,4], B. Pfeil[3,4], K Smith[5], S Alin[2], C Cosca[2], B Hales[6], S Harasawa[7], A Kozyr[8], Y Nojiri[7], K O'Brien[5], U Schuster[1], M Telszewski[9], B Tilbrook[10], C Wada[7] and all other SOCAT contributors

[1] *University of East Anglia*
[2] *NOAA PMEL, USA*
[3] *University of Bergen, Norway*
[4] *Bjerknes Centre for Climate Research, Bergen, Norway*
[5] *University of Washington, USA*
[6] *Oregon State University, USA*
[7] *National Institute for Environmental Studies, Tsukuba, Japan*
[8] *CDIAC, Oak Ridge, USA*
[9] *IOCCP/Institute of Oceanology of Polish Academy of Sciences*
[10] *CSIRO, Hobart, Australia*

An update to the Surface Ocean CO_2 Atlas (SOCAT version 2)

The Surface Ocean CO_2 Atlas (SOCAT) is a major synthesis effort by the international marine carbon research community. It aims to improve access to surface water fugacity of carbon dioxide (fCO_2, similar to partial pressure) by regular releases of quality controlled and fully documented synthesis and gridded fCO_2 products. SOCAT version 2 has been made public in June 2013. Version 2 extends the SOCAT version 1 data set by 4 years until 2011, while providing many additional data for the years 2006 and 2007. It has 10.1 million surface water fCO_2 data from 2660 cruises between 1968 and 2011 for the global oceans and coastal seas. The procedures for creating version 2 are similar to those for version 1. The SOCAT website (www.socat.info) provides access to the individual cruise data files, as well as synthesis and gridded data products. Interactive online tools allow users to visually explore and interpret the data. Scientific users can also access the data as downloadable files or via Ocean Data View. Version 2 enables global carbon scientists to carry out process, budget and modelling studies.

4 A

Nick Stephen, Jerry Blackford & Yuri Artioli

Plymouth Marine Laboratory

Modelling benthic ecosystem sensitivities to high CO_2

Based on future simulations (A1B) with and without biological feedbacks on ecosystem function, we show that the organic matter flux to the benthic system will change in a complex, spatially and temporally heterogeneous manner. As a result we can forecast a range of changes to benthic function and biomass which would be at least significant for whole system function. Separately, using published data on benthic community sensitivity to high CO_2, we simulate the benthic system evolution at a number of proscribed and fixed future pCO_2 values and show that further impacts on benthic functionality are possible. We currently lack a full synthesis of benthic let alone ecosystem impacts of the system to OA, increased temperature and hypoxia. This preliminary work indicates that the system is potentially sensitive to high CO_2.

5 B

Gemma Cripps, Kevin Flynn, Penelope Lindeque & Robin Shields

University of Swansea

Could maternal influences be masking the negative reproductive effects of ocean acidification in copepods?

In relation to their ecological significance, little has been reported on OA effects in copepods. In published studies, there are large interspecific sub-lethal differences in their sensitivity to realistic OA scenarios. One of the most used sub-lethal parameters is fecundity success (egg production and hatching), due to the relative ease of conducting such experiments and the implications it could have on populations and trophic link interactions. We exposed mature *Acartia tonsa* to 5 different CO_2 levels at different reproductive phases, whilst monitoring the influence on offspring production. Egg production and hatching success declined with increasing levels of hypercapnia in experiments with combined parental reproductive exposure. Sole maternal (post fertilised) exposure demonstrated an increased resilience to high CO_2 in offspring production and hatching compared to no prior parental exposure, combined parental exposure and sole paternal exposure. Thus maternal influence can mask the true fecundity effects of hypercapnia when using post copulated females, which could account for the variation in species response shown in previous studies.

6 B Emma L Cross[1], LS Peck[1] & EM Harper[2]

[1] British Antarctic Survey
[2] University of Cambridge

Ocean acidification impacts on the shell characteristics of articulated brachiopods

Since the industrial revolution, atmospheric CO_2 has risen from ~280ppm to~390ppm through anthropogenic activities, with a concurrent increase of ~30% in oceanic acidity and a decrease of 0.1 pH units. Due to consequential effects on carbonate chemistry, the most vulnerable species to ocean acidification are likely to be those with high requirements for $CaCO_3$ to produce structural components. Living articulated brachiopods have a worldwide distribution from the poles to the tropics, and from the deep-sea to the intertidal. This phylum is possibly the most $CaCO_3$ dependent on Earth due to >90% of their dry mass residing in their calcareous shell and other support structures. Brachiopods are well represented and highly abundant over long geological periods, resulting in one of the best fossil records of any marine animal group. This PhD project aims to determine how shell microstructure [density and size of shell perforations, (punctae), total shell thickness, primary and secondary layer thickness and crystal morphology] and elemental composition vary between species in the geological and recent past, present and future (by growing specimens under predicted pH conditions) using Scanning Electron Microscopy and Electron Microprobe Analysis.

7 B Jasmin A Godbold, S Rastrick & M Solan

NOC, University of Southampton

Distinguishing between the effects of longterm exposure and seasonality in ocean acidification experiments

Alteration of ocean temperature and chemistry associated with anthropogenic increases in atmospheric CO_2 is affecting a broad range of species and many key ecosystem processes, but it is unclear whether the effects observed in short-term empirical investigations are representative of the likely longterm ecosystem consequences of OA. Recently, emphasis has been placed on extending the length of time experimental systems are exposed to acidified conditions to allow for the establishment of longer-term processes that moderate the susceptibility of species to a changing environment. Here, we present preliminary findings on how the interactive effects of warming and OA affect the growth, behaviour and associated levels of ecosystem functioning (nutrient release) for a functionally important echinoderm (*Amphiura filiformis*) over a period of time (542 days) sufficient to characterise and separate the effects of cyclical natural variation from directional change imposed by long-term climatic forcing.

8 A Naomi Greenwood [1], DJ Pearce [1]
T Hull [1], B Silburn [1], DB Sivyer[1]
DCE Bakker [2], M Ribas-Ribas [3]

[1] Cefas, Lowestoft
[2] University of East Anglia
[3] NOC Southampton

Determining the variability in the carbonate system in UK shelf seas

Routine measurements of the carbonate system have been carried out in UK shelf seas within the UKOA research programme since December 2010. Discrete sampling has been conducted on surveys in the North Sea, Channel and Celtic and Irish Seas by augmenting sampling on existing research cruises and three time series stations have been established at SmartBuoy sites in the southern North Sea. In addition, the Cefas research ship *RV Endeavour* has been instrumented with underway sampling capability for pCO_2. Results collected over two years confirm previous findings of large horizontal and vertical gradients in dissolved inorganic carbon in the seasonally stratified North Sea and the strong riverine signal in total alkalinity in the southern North Sea. Results from summer cruises compare well with measurements made on the UKOA D366 cruise in summer 2011. Large seasonal variations in the carbonate system are observed in the southern North Sea. This is a region exhibiting strong biological activity as determined through high resolution measurements of inorganic nutrients and chlorophyll made by SmartBuoy over the past 12 years. Good agreement has been found between pCO_2 measured directly by the underway system and pCO_2 calculated from total alkalinity and dissolved inorganic carbon in discrete samples.

9 B

Ben P Harvey[1], Dylan Gwynn-Jones[1] & Pippa J Moore[1,2]

[1] *Aberystwyth University*
[2] *Centre for Marine Ecosystems Research, Edith Cowan University, Australia*

Meta-analysis reveals complex marine biological responses to the interactive effects of ocean acidification and warming

OA and warming are considered two of the greatest threats to marine biodiversity, yet the combined effect of these stressors on marine organisms is largely unclear. Using a meta-analytical approach, we assessed the biological responses of marine organisms to the effects of OA and warming in isolation and combination. As expected, biological responses varied across taxonomic groups, life-history stages, and trophic levels, but importantly, combining stressors generally exhibited a stronger biological (either +ve or -ve) effect. Using a subset of orthogonal studies, we show that four of five biological responses measured – calcification, photosynthesis, reproduction, and survival, but not growth – interacted synergistically [more than additively] when warming and acidification were combined. The observed synergisms between interacting stressors suggest that care must be made in making inferences from single-stressor studies. Our findings have implications for the development of adaptive management strategies, given that the frequency of stressors interacting in marine systems will likely intensify in the future. There is now urgent need to move toward more robust, holistic, and ecologically realistic climate change experiments that incorporate interactions. Without them, it will not be possible to accurately predict the likely deleterious impacts to marine biodiversity and ecosystem functioning over the next century.

10 B

Seb J Hennige[1], LC Wicks[1], NA Kamenos[2] & JM Roberts[1]

[1] Heriot Watt University
[2] University of Glasgow

Impact of warming and ocean acidification upon the growth and physiology of the cold-water coral *Lophelia pertusa*

Cold-water corals (CWC) are key habitat forming organisms. Their complex 3-dimensional framework supports high levels of biodiversity from deep to shallow seas (30 – 3000m water depth). A key question is how these vulnerable marine ecosystems will fare in the face of future climate change. This study provides the first longterm (1 yr) multi-stressor data on the impacts of ocean warming and OA on the CWC *Lophelia pertusa*. We demonstrate that *L. pertusa* can acclimate to multiple stressors of temperature and CO_2 over a year, but at a cost as indicated by short-term suppressed metabolism. The question remains whether *L. pertusa* can meet this cost in the longterm, or whether lipid reserves are used to facilitate acclimation, which is a finite strategy. Interestingly, only the increased temperature treatments elicited metabolic suppression; that may indicate that *L. pertusa's* mechanisms for dealing with increased temperature are not as developed as their capacity for up-regulating internal pH. Skeletal and growth regulation also changed between treatments, with high CO_2 treatments having significantly longer and thinner polyps than control corals, indicating an additional unmeasured cost associated with newly accreted material.

11 B Suzanne Jennions[1], Daniela N Schmidt[1], Claire Morely[1], Katrin Linse[2], Loren Picco[3] & Tom Scott[3]

[1] University of Bristol (Earth Sciences)
[2] British Antarctic Survey
[3]University of Bristol (Physics)

Assessing the structural integrity of marine calcifiers under changing environmental conditions

Globally decreasing ocean pH and increasing temperature affect the calcification process of marine calcifying organisms and increase dissolution of pre-existing biogenic calcium carbonate. Although organisms may continue to calcify in high pCO_2 conditions, crystal size, organisation, chemistry, and material properties are influenced. Such changes combined with heightened dissolution can impact on the structural integrity of shells and skeletons, and thus their long term ability to provide habitats for other marine organisms. We observed changes in crystal size and orientation in bivalve shells and determined Young's modulus (elasticity) and Vickers hardness to quantify their structural properties. To test how such changes influence the overall integrity of the shells, we incorporated the data into 3D finite element models which were applied with relevant loads simulating predation. These methods have enormous potential and may be applied to any calcifying organisms in order to quantify the effect of OA on biogenic calcium carbonate.

12 A David Morris, Douglas Speirs & Mike Heath

University of Strathclyde

Identifying key parameters affecting commercial species under CO_2 induced ecosystem change: Global sensitivity analysis of end-to-end model of the North Sea

End-to-end ecosystem models are ideally suited to examine the effects that multiple anthropogenic pressures will have on fisheries. The importance of using global sensitivity analysis (GSA) to examine these models is widely recognised. Recently an end-to-end model was developed to represent the North Sea. This model (StrathE2E) simulates the nitrogen fluxes between detritus, inorganic nutrients and guilds of taxa from phytoplankton to mammals. A two-step quantitative GSA was conducted on StrathE2E. This generated sensitivity indices relating to the overall influence of parameters and their level of interactions in the model. For each fishery output, a unique profile of influential parameters was identified. A notable result was that parameters representing rate of biomass conversion into fishery biomass were important for all outputs. This parameter has been highlighted in experimental studies, across species groups, as influenced by CO_2 induced environmental change. This is the first time a GSA has been conducted on any end-end marine ecosystem model. The analysis determined those environmental and biotic parameters of influence and therefore provides insight into the potential impacts of environmental change on current UK fisheries.

13 B Tessa M Page[1], **P** Calosi[2] & JH Stillman[1]

[1] San Francisco State University, USA
[2] University of Plymouth

Effects of lowered pH on the exoskeleton composition of porcelain crabs

Physiological processes are altered in response to lowered ocean pH/high *p*CO_2, the process known as ocean acidification. OA is known to affect the deposition and composition of biominerals in arthropod exoskeletons. Here, we look at the effects of medium-term exposure to pH (pH 8.0, 7.40 for 24 days) on the ionic composition of the exoskeleton of different species of porcelain crabs, *Petrolisthes cinctipes*, *Petrolisthes manimaculus*, and *Porcellana platycheles* to different pH/*p*CO_2 levels. These species occupy different levels of the intertidal zone off the coasts ofCalifornia and the United Kingdom and experience varying levels of pH on a daily basis. In order to characterise the skeletal composition of the porcelain crabs and their sensitivity to low pH, their carapace composition was characterised using an Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Skeletal concentration of [Ca2+], [Mg2+], [K+], [Mn2+], [Na+], [P3-], [Sr2+], as well as [Ca-2+]:[Mg2+] and [Ca2+]:[Sr-2+] ratios were determined; these results were compared across treatments as well as across geographic range and species.

14 A

Laura R Pettit[1], CW Smart[2], M Milazzo[3], MB Hart[2], MJ Attrill[1] & JM Hall-Spencer[1]

[1]*Plymouth University (Marine Institute)*
[2]*Plymouth University (Geography)*
[3] *DiSTeM Univ of Palermo, CoNISMa, Italy*

Benthic foraminifera along shallow water CO_2 gradients

Epiphytic foraminifera living on the brown seaweed *Padina pavonica* were sampled near to shallow water CO_2 vents off the island of Vulcano, Italy. These shallow water CO_2 vents alter the chemistry of the surrounding seawater and create a gradient in carbonate saturation, providing a natural laboratory for investigations of the long-term OA effects. Few studies have examined the effects of OA on benthic foraminifera, yet this is a matter of major environmental concern. One reason for this is that rapid shoaling of the carbonate saturation horizon is exposing vast areas of marine sediments to corrosive waters worldwide. We tested the hypothesis that algal surfaces would provide refugia for benthic foraminifera along a gradient of overlying seawater acidification, since algal photo-synthesis raises the pH of seawater in the diffusion boundary layer. In fact, we found a dramatic reduction in the number of species of epiphytic foraminifera and the community assemblage changed from one dominated by calcareous forms at reference sites (pH ~8.1) to ones dominated by agglutinated forms near to the CO_2 vents (pH ~7.6). The same pattern has been found in sediments along carbonate saturation gradients, with serious implications for the survival of calcareous foraminifera under future OA.

15 B

Edward C Pope[1], RP Ellis[2], M Scolamacchia[1], JWS Scolding[1], A Keay[1], P Chingombe[1], RJ Shields[1], C Lewis[2], DC Speirs[3], RW Wilson[2] & K J Flynn[1]

[1] *University of Swansea*
[2] *University of Exeter*
[3] *University of Strathclyde*

Early developmental stages of European seabass show resiliency, but an increased metabolic rate, under near-future oceanic conditions

There is an acknowledged bias in research on the effects of OA towards studies investigating calcifying invertebrates. Whilst the potential effects on these organisms are undoubtedly important, there are relatively few corresponding studies for other taxa. In particular there remains a dearth of information for species of commercial relevance. This study grew larvae of European seabass *Dicentrarchus labrax* under combinations of two different temperatures (17 and 19°C) and two different CO_2 regimes (representing atmospheric conditions of 380 and 750ppm pCO_2) for 42 days. The upper pCO_2 (750ppm) was selected to comply with the IPCC A2-SRES emission trajectory which predicts atmospheric CO_2 concentrations of between 730 and 1020ppm by 2100, with a projected corresponding decline in oceanic pH from 8.2 to 7.8. Seabass larvae (d_{0-42} post-hatch) showed resiliency to predicted near-future OA conditions, with no significant effects on survival, growth, or feeding. However, the routine metabolic rate of metamorphosed fish (d_{67-69} post-hatch) was significantly greater under warmer, more acidic conditions (19°C, 750ppm pCO_2) compared with all other treatments. This higher metabolic rate may impact on resiliency under a more restricted feeding regime mimicking natural prey abundance.

16 A Mariana Ribas-Ribas[1], VMC Rérolle[1], DCE Bakker[2], V Kitidis[3], I Brown[3], N Greenwood[4], EP Achterberg[1] & T Tyrrell[1]

[1] *NOC, Southampton*
[2] *University of East Anglia,*
[3] *Plymouth Marine Laboratory*
[4] *Cefas Lowestoft*

Carbonate chemistry inter-comparison in North West European seas

Four separate carbonate system parameters were measured during a UKOA cruise to NW European seas in summer of 2011. High resolution data were collected of partial pressure of CO_2 (pCO_2, using two independent instruments) and pH, in addition to many discrete measurements of total alkalinity and dissolved inorganic carbon (DIC). Because the carbonate system, with two degrees of freedom, was greatly over-determined (five measurements) we were able to evaluate the degree of agreement between parameters and obtain a reliable determination of the carbonate system in these waters at the time of the survey. We computed Pearson´s linear correlation coefficient, average differences, average absolute differences and root mean square differences between each pair. Good agreement was found between all five independent datasets. However, it was found that *p*CO2 and pH do not make a good pair for predicting the rest of the carbonate system. This is to be expected, because pCO_2 and pH are not fully independent parameters.

17 B J Murray Roberts & the shipboard party JC073 (including C Alt, K Attard, S Birchenough, R Boyle, J Büscher, R Byrne, G Cook, A Cotton, P Donohue, H Findlay, S Fitzek, S Hennige, V Huvenne, G Kazanidis, N Lyman, J Moreno Navas, C Orejas, J Polanski, L Victoreo Gonzalez & L Wicks)

Heriot-Watt University, and other institutions

Changing Oceans expedition 2012: deep-sea ecosystem function and OA impacts on cold-water coral ecosystems in the North East Atlantic Ocean

In summer 2012, the RRS *James Cook* embarked on an ambitious expedition to study the functional ecology of cold-water coral ecosystems west of the UK and Ireland. Cold-water corals form amongst the most complex biogenic structures in the deep sea. Providing habitat to many other species, the aragonitic reef frameworks formed by scleractinian corals are believed to be particularly vulnerable to ocean warming and acidification. At sea, ship-board experiments examined coral biology and ecophysiology under both elevated temperature and pCO_2 treatments. In parallel, the Changing Oceans Expedition used a deep-sea remotely operated vehicle (ROV) to experiment *in situ* within coral habitats. A range of experiments were undertaken by the international team, including seabed deployments of a novel aquatic eddy correlation lander to assess O_2 flux and benthic spreader chambers to examine uptake of dissolved organic matter in deep-sea reef organisms. Here we present an overview of the initial results from this interdisciplinary expedition. The poster also summarise the expedition's public outreach activities involving schoolchildren from the Hebridean Islands and their participation in debates on deep-sea conservation issues facilitated by Scotland's national geoscience outreach centre 'Our Dynamic Earth'.

18 A Kate Salmon[1], P Anand[1], P Sexton[1], M Conte[2] & J Bijma[3]

[1]*Open University*
[2]*MBL Woods Hole, USA*
[3]*AWI, Bremerhaven, Germany*

Environmental controls on seasonal changes in planktonic foraminiferal abundance, shell mass and trace element geochemistry

Planktonic foraminfera make up 23-56% of the total ocean calcite flux and play an important role in CO_2 burial. However, the exact mechanisms that control their calcification are still under debate. Many culture studies are trying to understand the environmental controls on their calcification and trace element composition but there is a lack of open ocean studies of these organisms. This study shows the seasonal changes in the abundance of 13 different species, and changes in shell mass, thickness and trace element geochemistry of three species of planktonic foraminifera collected in sediment traps from the Sargasso Sea, near

Bermuda. These measurements are combined with nearby hydrographic data collected as part of the Bermuda Atlantic Time Series Study, recording temperature, salinity and carbonate system parameters. Satellite altimetry data is also used to monitor the seasonal eddy patterns. Early results suggest that all species bloom seasonally, agreeing with exisiting literature. Seasonal eddies influence the abundance of deeper dwelling species but have less influence on surface dwellers. Environmental controls on seasonal changes in shell mass and thickness are found to be species specific. Changes in trace element geochemistry are compared to changes in environmental and shell parameters to give a better constraint on what controls planktonic foraminiferal calcification and trace element composition. Current results give a more detailed insight into species-specific controls, relevant to species' usefullness as geological proxies. However, we need a better understanding of what controls shell mass/thickness over a seasonal cycle before it can be used as a proxy for past OA events.

*19 A Ute Schuster

University of Exeter (University of East Anglia)

Interannual variability of sea surface pH

The oceanic uptake of excess, 'anthropogenic', atmospheric CO_2 chemically reduces the pH of seawater, resulting in potentially significant effects on marine biogeochemical cycles. Major challenges are the effects on marine biota, and the identification of longterm trends and inter-annual variability. Here, the spatial and temporal variability of surface pH are presented, estimated from regular observations of sea surface pCO_2 and related parameters in the North Atlantic (Watson *et al*., 2009; Schuster *et al*., 2009). These estimations are compared with a recent pH climatology (Takahashi & Sutherland, 2013). Results show spatial variability between the tropical, subtropical, and temperate North Atlantic waters between the mid-1990s and 2008, with the pH decrease being especially significant in more north-eastern latitudes.

20 B AW Paganini[1] & Jonathon Stillman[2]

[1] University of California, Berkeley, USA
[2] San Francisco State University, USA

Interactive effects of present and future daily variability of pH and temperature on thermal sensitivity of metabolism and thermal limits of cardiac function in an intertidal zone porcelain crab

Intertidal zone organisms experience daily fluctuations in temperature and pH, and these fluctuations are expected to increase along the California coast under climate change scenarios. How intertidal organisms respond to environmental variability of multiple abiotic factors is largely unknown. We investigated performance of the porcelain crab, *Petrolisthes cinctipes*, under intertidal zone conditions of variation in temperature and pCO_2. Adult *P. cinctipes* were exposed to three temperature spikes during a simulated daytime low tide (11°C, 25°C or 30°C), or were not immersed or heated. At night the crabs in each treatment were exposed to constant pH (8.1) or to pH spikes to 7.6, or 7.15. Following two weeks of acclimation, we measured respiration rates at 11 and 18°C and upper thermal limits of cardiac performance (CT_{max}). Metabolic depression was observed in crabs that experienced aerial daily heat spikes, and the depression was stronger in low pH acclimated individuals. CT_{max} was elevated with acclimation temperature, and the elevation was higher under low pH acclimation. Our results indicate that there are interactive effects of pH and temperature variability on the temperature sensitivity and thermal limits of these intertidal zone crabs.

21 A Alison Webb[1], PS Liss[1], G Malin[1], F Hopkins[2], R von Glasow[1], S de Mora[1] & C Hughes[3]

[1] University of East Anglia
[2] Plymouth Marine Laboratory
[3] University of York

Dimethylsulphide dynamics under the effects of ocean acidification: a mesocosm comparison

The human-induced increase in atmospheric CO_2 has led to increased oceanic carbon uptake and changes in seawater carbonate chemistry, resulting in lowering of surface water pH. Since the beginning of the industrial revolution, surface ocean acidity has increased 30%. Dimethylsulphide (DMS) is a climatically important gas produced by marine algae: it is a major route of sulphur into the atmosphere and therefore a strong influence on biogeochemical climate feedbacks such as particle and cloud formation. Its precursor DMSP is produced intracellularly, and is released through processes of viral lysis, exudation, senescence and grazing, and is broken down by bacterially mediated DMSP-lyase activity. Previous studies have suggested a direct relationship between lowered seawater pH and reduction in DMS and DMSP. Data show this DMS reduction in coastal environments and the low salinity, high nutrient Baltic Sea, but not always in axenic laboratory culture. This indicates that changes are either a result of altered cell biochemistry and DMSP production, or changes to microbial populations which break down the DMSP outside the cell. A change in production will have a significant impact on the atmospheric cycling of sulphur, and on climatically important atmospheric reactions.

22 A Maria C Williams[1], Daniela N Schmidt[1], Morten Andersen[1], Carin Andersson[3], Paul Bown[2]

[1] University of Bristol
[2] University College London
[3] Bjerknes Centre for Climate Research, Bergen, Norway

Environmental forcing on pelagic carbonate production

On-going OA is widely expected to affect the ability of marine calcifying organisms to precipitate their $CaCO_3$ exoskeletons due to a reduction in $\Omega_{calcite}$. Here we assess whether historical changes in seawater [CO_3^{2-}] and pH since the beginning of industrialisation have already had discernible impacts on two groups of calcifying plankton, the coccolithophores and foraminifers which together contribute >90% of marine pelagic carbonate production. We focus on two marine sediment cores from the sub-polar North Atlantic and Nordic Seas covering the Holocene and the Anthropocene. The application of $^{230}Th_{xs}$ has identified focusing of sediments throughout most of the Holocene although variability in sediment transport is evident around 4-5 m depth which may alter the palaeo-record of coccolithophore calcification and must therefore be considered when interpreting the coccolithophore record. Analysis of sub-polar foraminifera, including two morphotypes of *N. pachyderma* reveal a 30-40% decrease in size-normalised shell weights (SNW) from the early to the late Holocene. Similarity of response between and within species indicates a common environmental control on foraminiferal calcification. Tenuous links can be observed between Mg/Ca of foraminiferal calcite and SNW which may reflect a sea surface temperature control on calcification or post-depositional dissolution in the sediments.

23 B Chris Williamson[1,2,] B Goss[1], S Lee[1], M Yallop[3], J Brodie[2] & R Perkins[1]

[1] Cardiff University
[2] Natural History Museum,
[3] University of Bristol

Rock pools as refugia: photosynthetic communities negate ocean acidification

As atmospheric concentrations of CO_2 reach 400 ppm, there is urgent need to understand associated OA impacts, i.e. increased seawater CO_2 partial pressure (pCO_2), bicarbonate (HCO_3^-) and proton (H^+) concentrations, and reduced carbonate (CO_3^{2-}) availability, on marine calcifying species. Numerous future-scenario OA studies have incubated species collected from near-shore environments in reduced, yet constant, pH conditions, neglecting potential natural fluctuations in carbonate chemistry experienced *in-situ*. This is important as it has been suggested that exposure to natural pH variation confers increased resilience of calcifying species to future OA. Here we show that the irradiance-driven, photosynthetic activity of rock pool communities, dominated at our study sites by calcifying macroalgal species of the cosmopolitan genus *Corallina*, rapidly decreases rock pool pCO_2 and HCO_3^- concentrations over periods of summer and winter daytime tidal immersion, shifting the carbonate equilibrium to create more favourable conditions for calcification, i.e. supersaturation of CO_3^{2-} ions. Photosynthesis, driven by irradiance, thus serves as a self-protecting mechanism for calcifying rock pool macroalgae, mitigating against the impacts of OA. It is thus imperative to incorporate natural fluctuations of carbonate chemistry into future-scenario incubations aiming to assess near-shore species and community responses to OA.

*24 A

Phil Williamson[1], Carol Turley[2] & the UKOA research community

[1] *NERC/University of East Anglia*
[2] *Plymouth Marine Laboratory*

Overview of the UK Ocean Acidification research programme

The £12m UKOA research programme (2010-2015) involves over 120 scientists in 26 research laboratories across the UK, working closely with European partners and other relevant international activities. Seven multi-institute consortium projects address: observation and synthesis; upper ocean biogeochemistry; OA impacts on benthic ecosystems; commercially important species and socio-economic implications; effects of palaeo- OA events; and regional and global modelling of OA processes and future impacts. Ship-based fieldwork, now complete, has included research cruises in European shelf seas (2011), the North East Atlantic and Arctic (2012), and the Southern Ocean (2013), and studies of cold-water corals (2011, 2012). UKOA outreach and knowledge exchange includes work with UNFCCC, CBD and other international bodies.

25 A

Jamie Wilson[1], Eleanor John[1], Stephen Barker[1], Paul Pearson[1] & Andy Ridgwell[2]

[1] *Cardiff University*
[2] *University of Bristol*

The biological pump in warm climates

The production of organic matter (OM) in the ocean surface, its subsequent sinking and remineralisation is a significant control on the distribution of nutrients and carbon in the ocean interior. New reconstructed ambient $\delta^{13}C$ (DIC) profiles off Tanzania through the Eocene (55.5 – 33.7 Ma) exhibit steep shallow gradients and large offsets between surface and deep values compared to modern profiles. OM remineralisation is a key control on the modern profiles of $\delta^{13}C$, suggesting faster remineralisation rates in the Eocene, which may be an important analogue for future climate change. We present the initial findings of a data-model comparison exploring a potential role for the temperature dependence of remineralisation. Temperature dependent remineralisation rates are incorporated into cGENIE and calibrated to the modern ocean and applied to an Eocene simulation. We find a significant shoaling of the focus of OM remineralisation to shallower depths, reconstructing the steep $\delta^{13}C$ gradients observed in data. The model also predicts a shoaling and intensification of oxygen minimum zones. This further highlights the potential combined impacts of acidification, warming and de-oxygenation associated with future climate change.

26 A Andrew Yool[1], EE Popova[1], AC Coward[1], D Bernie[2] & TR Anderson[1]

[1] *National Oceanography Centre, Univ of Southampton*
[2] *Met Office/Hadley Centre, Exeter*

Climate change and ocean acidification impacts on lower trophic levels and the export of organic carbon to the deep ocean

Most future projections forecast significant and ongoing climate change during the 21st century. A major sink for atmospheric CO_2, and a key source of biological resources, the world ocean is widely anticipated to undergo profound physical and - via OA - chemical changes. Here we examine large-scale responses under IPCC Representative Concentration Pathways (RCPs) 2.6 and 8.5 using an intermediate complexity ecosystem model, Medusa-2.0. The primary impact is stratification-led declines in the availability of key nutrients in surface waters, which in turn leads to a global decrease (1990s vs. 2090s) in ocean productivity (-6.3%). Concomitantly, the flux of organic material to seafloor communities decreases (-40.7% at 1000m), while the volume of ocean suboxic zones increases (+12.5%). Removing an acidification feedback on calcification finds that change in this process significantly impacts benthic communities, suggesting that a better understanding of the OA-sensitivity of calcifying organisms, and their role in ballasting sinking organic carbon, is required. For all processes, there is geographical variability in change; e.g. productivity declines -21% in the Atlantic and increases +59% in the Arctic, and changes are much more pronounced under RCP 8.5 than the RCP 2.6 scenario.

27 B Clara Manno[1,2], Nathalie Morata[3] & Geraint A Tarling[1]

[1]*British Antarctic Survey, Cambridge*
[2]*University of Tromsø, Norway*
[3]*Institut Universitaire Européen de la Mer, Brest, France*

Swimming behaviour response of pteropods to the synergic impact of OA and freshening

Anthropogenic CO_2 emissions induce ocean acidification (OA), thereby reducing carbonate ion concentration, which may affect the ability of calcifying organisms to build shells. Pteropods, the main planktonic producers of aragonite in the world ocean, may be particularly vulnerable to changes in sea water chemistry. The negative effects are expected to be most severe at high latitudes, where natural carbonate ion concentrations are low. In this study we investigated the combined effects of OA and freshening (reduced salinity) on *Limacina retroversa*, the dominant pteropod in sub polar areas. Living *L. retroversa*, collected in Northern Norwegian Sea, were exposed to four different pH values ranging from the pre-industrial level to the forecasted end of century OA scenario. Since over the past half-century the Norwegian Sea has experienced a progressive freshening with time, each pH level was combined with a salinity gradient in two factorial, randomized experiments investigating shell degradation, swimming behaviour and survival. The perturbation experiments were performed on both juvenile and adult life stage. Mortality and the ability of pteropods to swim upwards were strongly affected only when both pH and salinity reduced simultaneously. Results suggest that *Limacina retroversa* should be able to counteract the dissolution and freshening when stress factors are not combined. However, the organisms may be more vulnerable to OA when freshening occurs at the same time, probably due to the extra energy cost of maintaining ion balance and avoiding sinking in a low salinity environment.

Participants in UKOA Annual Science Meeting

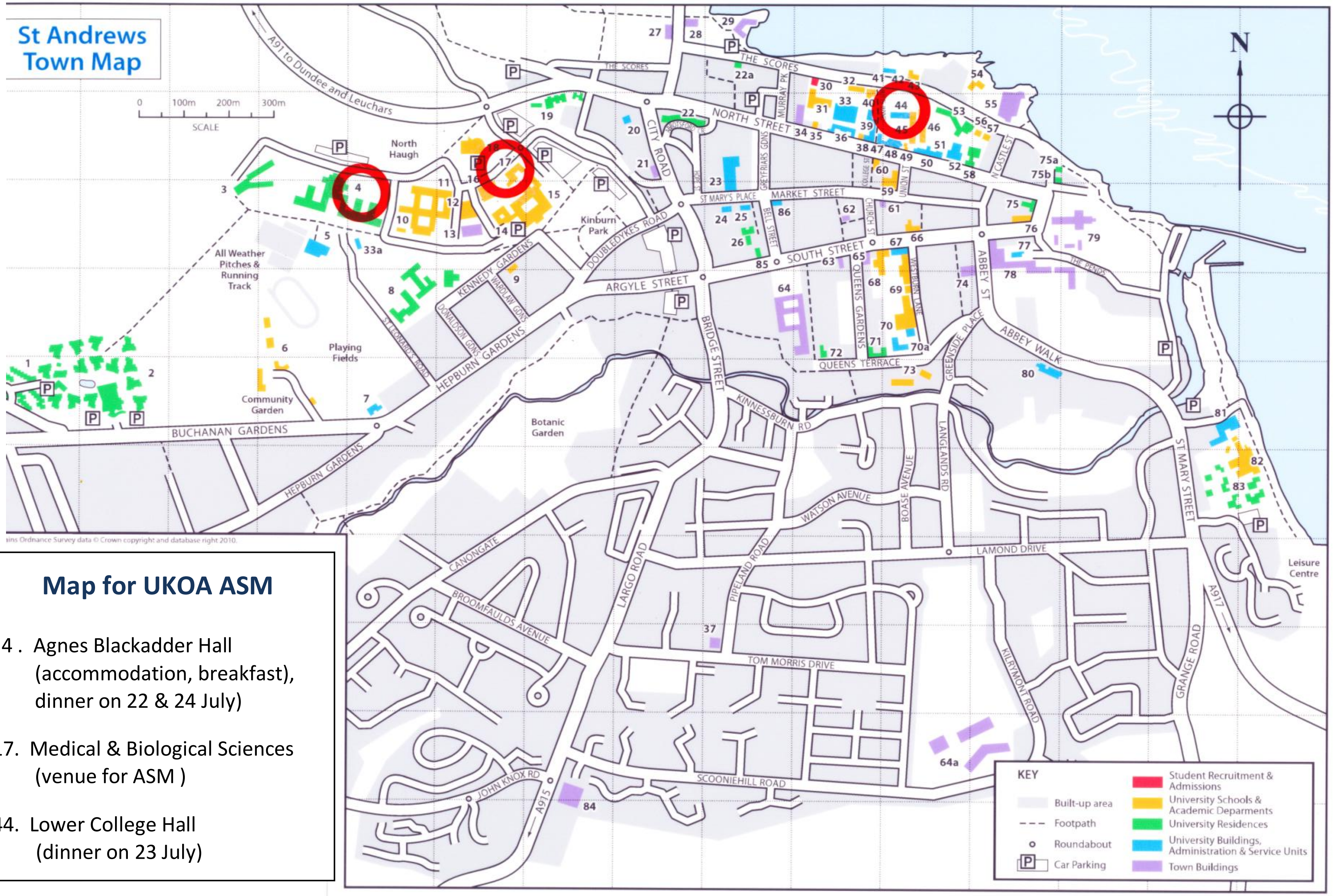
Blue-shaded names: Funder, stakeholder or programme management role
*Also participant in GOA-ON Workshop. *Information as on 10 July*

	Name	Affiliation	email	accommodation‡					
				21	22	23	24	25	26
1	Eric Armstrong	UC Berkeley, USA	armstrong-at-berkeley.edu	■	■	■	■		
2	Yuri Artioli	Plymouth Marine Laboratory	yuti-at-pml.ac.uk	■	■	■	■		
3	Tracy Aze	Cardiff University	azetl-at-cf.ac.uk	■	■	■			
4	Dorothee Bakker*	University of East Anglia	d.bakker-at-uea.ac.uk	■	■	■	■	■	■
5	Arwen Bargery	British Oceanographic Data Centre	arry-at-bodc.ac.uk	■	■	■			
6	John Baxter*	Scottish Natural Heritage	john.baxter-at-snh.gov.uk		■	■	■	■	
7	Silvana Birchenough	Cefas Lowestoft	silvana.birchenough-at-cefas.co.uk	■	■	■	■		
8	Jerry Blackford	Plymouth Marine Laboratory	jcb-at-pml.ac.uk	■	■	■	■		
9	Kelvin Boot	PML Associate	kelvinboot-at-yahoo.co.uk	■	■	■	■		
10	Paul Bown	University College London	p.bown-at-ucl.ac.uk	■	■	■	■		
11	Laura Bretherton	University of Essex	lmjbre-at-essex.ac.uk	■	■	■	■		
12	Piero Calosi	Plymouth University	piero.calosi-at-plymouth.ac.uk	■	■	■	■		
13	Stuart Capstick	University of Cardiff	capsticksb-at-cardiff.ac.uk		■	■			
14	Liqi Chen*	3rd Inst of Oceanography, Xiamen, China	lqchen-at-soa.gov.cn	■	■	■	■	■	■
15	Jodie Clarke	NERC	jodark-at-nerc.ac.uk	■	■	■			
16	Gemma Cripps	Swansea University	581604-at-swansea.ac.uk	■	■	■	■		
17	Julia Crocker*	Plymouth Marine Laboratory	jlc-at-pml.ac.uk	■	■	■	■	■	■
18	Emma Cross	Univ of Cambridge & British Antarctic Survey	emmoss-at-bas.ac.uk	■	■	■	■		
19	Kim Currie*	NIWA, New Zealand	kim.currie-at-niwa.co.nz		■	■	■	■	■
20	Kelly-Marie Davidson	Plymouth Marine Laboratory	kdav-at-pml.ac.uk	■	■	■	■		
21	Emma Defew	University of St Andrews	ecd2-at-st-andrews.ac.uk						
22	Athena Drakou	NOC Southampton	a.drakou-at-soton.ac.uk	■	■	■			
23	Robert Ellis	University of Exeter	r.p.ellis-at-exeter.ac.uk	■	■	■	■		
24	Richard Feely*	NOAA Pacific Marine Environmental Laboratory	richard.a.feely-at-noaa.gov			■	■	■	■
25	Helen Findlay*	Plymouth Marine Laboratory	hefi-at-pml.ac.uk	■	■	■	■	■	
26	Kevin Flynn	Swansea University	k.j.flynn-at-swansea.ac.uk	■	■	■			
27	Leila Fonseca	Defra	leila.fonseca-at-defra.gsi.gov.uk			■	■		
28	Hernan Garcia*	NOAA National Oceanographic Data Center	hernan.garcia-at-noaa.gov	■	■	■	■	■	■
29	Samantha Gibbs	Univ of Southampton NOC	sxg-at-noc.soton.ac.uk	■	■	■	■		
30	Jasmin Godbold	University of Southampton	j.a.godbold-at-soton.ac.uk	■	■	■	■		

‡ *If none shown, "own arrangements" apply*

				21	22	23	24	25	26
31	Naomi Greenwood	Cefas Lowestoft	naomi.greenwood-at-cefas.co.uk						
32	Lauren Gregoire	University of Bristol	lauren.gregoire-at-bristol.ac.uk	■	■	■			
33	Marcus Gutjahr	GEOMAR Kiel, Germany	mgutjahr-at-geomar.de	■	■				
34	Paul Halloran	University of Exeter & Met Office	p.halloran-at-exeter.ac.uk	■	■	■			
35	Ben Harvey	Aberystwyth University	beh14-at-aber.ac.uk	■	■	■	■		
36	Angela Hatton	Scottish Association for Marine Science	angela.hatton-at-sams.ac.uk		■	■			
37	Debbie Hembury	NERC/Defra	deborah.hembury-at-defra.gsi.gov.uk	■	■	■	■		
38	Seb Hennige	Heriot Watt University	s.hennige-at-hw.ac.uk		■	■			
39	Suzanne Jennions	University of Bristol	suzanne.jennions-at-bristol.ac.uk	■	■	■			
40	Libby Jewett*	NOAA Silver Spring, USA	libby.jewett-at-noaa.gov		■	■	■	■	■
41	Rodrigo Kerr*	Univ Federal do Rio Grande (FURG)	rodrigokerr-at-hotmail.com		■	■	■	■	■
42	Nikki Khanna	University of St Andrews	nk274-at-st-andrews.ac.uk						
43	Caroline Kivimae*	NOC Southampton	anck-at-noc.ac.uk	■	■	■	■	■	
44	Nelson Lagos*	Universidad Santo Tomás, Chile	nlagoss-at-ust.cl			■	■	■	
45	Ray Leakey	Scottish Association for Marine Science	rjl-at-sams.ac.uk		■				
46	Ceri Lewis	Exeter University	c.n.lewis-at-exeter.ac.uk	■	■	■	■		
47	Clara Manno	British Antarctic Survey	clanno-at-bas.ac.uk	■	■	■	■		
48	Evin McGovern*	Marine Institute, Ireland	evin.mcgovern-at-marine.ie		■	■	■	■	
49	Michael Meyerhöfer	GEOMAR Kiel, Germany	mmeyerhoefer-at-geomar.de		■	■			
50	Caron Montgomery	Defra	caron.montgomery-at-defra.gsi.gov.uk	■	■	■	■		
51	David Morris	University of Strathclyde	david.morris-at-strath.ac.uk	■	■	■			
52	Jan Newton*	University of Washington, USA	newton-at-apl.washington.edu	■	■	■	■	■	■
53	Mark Ohman*	Scripps Institute of Oceanography, USA	mohman-at-ucsd.edu	■	■	■	■	■	■
54	Erica Ombres*	NOAA, USA	erica.h.ombres-at-noaa.gov			■	■	■	■
55	James Orr*	CEA-CNRS-UVSQ France	james.orr-at-lsce.ipsl.fr	■	■	■	■	■	
56	Tessa Page	San Francisco State Univ & Univ of Plymouth	tpage-at-sfsu.edu	■	■	■			
57	David Paterson	University of St Andrews	dp1-at-st-andrews.ac.uk						
58	David Pearce*	Cefas Lowestoft	david.pearce-at-cefas.co.uk	■	■	■	■	■	
59	Paul Pearson	Cardiff University	pearsonp-at-cardiff.ac.uk	■	■	■			
60	Laura Pettit	University of Plymouth	laura.pettit-at-plymouth.ac.uk	■	■	■	■		
61	Edward Pope	Swansea University	e.c.pope-at-swansea.ac.uk	■	■	■	■		
62	Katy Pozerskis	RS Aqua	k.pozerskis-at-rsaqua.co.uk						
63	John Raven	University of Dundee	j.a.raven-at-dundee.ac.uk		■	■			
64	Mariana Ribas Ribas	University of Southampton	m.ribas-ribas-at-soton.ac.uk	■	■	■	■		
65	Andy Ridgwell	University of Bristol	andy-at-seao2.org	■	■	■			

				21	22	23	24	25	26
66	Ulf Riebesell*	GEOMAR Kiel, Germany	bi-sekr-at-geomar.de		■	■	■	■	
67	Aida F. Rios*	CSIC-Instituto de Investiga-ciones Marinas, Spain	aida-at-iim.csic.es	■	■	■	■	■	■
68	Murray Roberts*	Heriot-Watt University	j.m.roberts-at-hw.ac.uk		■	■	■	■	
69	Joseph Salisbury*	University of New Hampshire, USA	joe.salisbury-at-unh.edu	■	■	■	■	■	■
70	Kate Salmon	Open University	kate.salmon-at-open.ac.uk	■	■	■	■		
71	Ute Schuster*	University of Exeter	u.schuster-at-uea.ac.uk	■	■	■	■	■	■
72	Rosie Sheward	National Oceanography Centre, Southampton	rosie.sheward-at-noc.soton.ac.uk	■	■	■	■		
73	Robin Shields	Swansea University	r.j.shields-at-swansea.ac.uk		■				
74	Martin Solan	University of Southampton	m.solan-at-soton.ac.uk	■	■	■	■		
75	Elspeth Spence	Cardiff University	e.spence.05-at-aberdeen.ac.uk	■	■	■			
76	Philip Stamp	Defra	philip.stamp-at-defra.gsi.gov.uk	■	■	■			
77	Martin Stemp	RS Aqua	m.stemp-at-rsaqua.co.uk						
79	Jonathon Stillman	San Francisco State University, USA	stillmaj-at-sfsu.edu	■	■	■	■		
80	Geraint Tarling	British Antarctic Survey	gant-at-bas.ac.uk	■	■	■	■		
81	Rob Thomas*	British Oceanographic Data Centre	room-at-bodc.ac.uk	■	■	■	■	■	■
82	Bronte Tilbrook*	CSIRO Australia	bronte.tilbrook-at-csiro.au	■	■	■	■	■	■
83	Rodrigo Torres*	Universidad Austral de Chile	rtorres-at-ciep.cl	■	■	■	■	■	■
84	Carol Turley*	Plymouth Marine Laboratory	ct-at-pml.ac.uk	■	■	■	■	■	■
85	Eithne Tynan	University of Southampton	e.tynan-at-soton.ac.uk		■	■	■		
86	Toby Tyrrell	University of Southampton	tt-at-noc.soton.ac.uk	■	■	■			
87	Pamela Walsham*	Marine Scotland Science	pamela.walsham-at-scotland.gsi.gov.uk		■	■	■	■	
88	Andrew Watson*	University of Exeter	andrew.watson-at-exeter.ac.uk	■	■	■	■	■	
89	Alison Webb	University of East Anglia	alison.l.webb-at-uea.ac.uk	■	■	■	■		
90	Mike Webb	NERC	mweb-at-nerc.ac.uk		■	■			
91	Stephen Widdicombe*	Plymouth Marine Laboratory	swi-at-pml.ac.uk	■	■	■	■	■	
92	Maria Williams	University of Bristol	maricel.williams-at-bristol.ac.uk	■	■	■	■		
93	Christopher Williamson	Cardiff Univ & Natural History Museum	williamsoncj-at-cardiff.ac.uk	■	■	■	■		
94	Phil Williamson*	NERC & Univ of East Anglia	p.williamson-at-uea.ac.uk	■	■	■	■	■	■
95	Rod Wilson	University of Exeter	r.w.wilson-at-ex.ac.uk	■	■	■			
96	Jamie Wilson	Cardiff University	wilsonjd-at-cardiff.ac.uk	■	■	■			
97	Narumon Withers Harvey	Defra	narumonwithers.harvey-at-defra.gsi.gov.uk	■	■	■			
98	Ken Wright	DECC	ken.wright@decc.gsi.gov.uk	■	■	■			
99	Andrew Yool	National Oceanography Centre, Southampton	axy-at-noc.ac.uk		■	■	■		
100	Jeremy Young	University College London	jeremy.young-at-ucl.ac.uk	■	■	■	■		



Map for UKOA ASM

4 . Agnes Blackadder Hall (accommodation, breakfast), dinner on 22 & 24 July)

17. Medical & Biological Sciences (venue for ASM)

44. Lower College Hall (dinner on 23 July)