

**Impact case study (REF3b)**

<p><b>Institution:</b> University of Exeter</p>
<p><b>Unit of Assessment:</b> Biological Sciences</p>
<p><b>Title of case study:</b> Ocean acidification Research as a model for Environmental Education in Secondary Schools</p>
<p><b>1. Summary of the impact</b> (indicative maximum 100 words)</p> <p>Dr Ceri Lewis’ research expeditions to the Canadian High Arctic to investigate impacts of ocean acidification, have informed educational material, introducing oceans education to schools, both nationally and internationally. Lewis worked with Digital Explorer, a non-profit organisation, to provide free lesson plans and multi-media resources on ocean acidification and Arctic climate change to classrooms, both nationally and internationally. The resulting education resources, informed by Ceri’s fieldwork, are already being used by 1,225 UK secondary schools (i.e. 30% of secondary schools in the UK), reaching over 658,000 pupils within the first year of being launched. These school resources are also being used internationally including a training programme in Alaska and outreach examples across Europe.</p>
<p><b>2. Underpinning research</b> (indicative maximum 500 words)</p> <p>Lewis’ research focuses on understanding how marine invertebrates adapt and survive in a changing marine environment, and the potential interactions between multiple anthropogenic stressors on their physiology and reproductive biology. In 2009, Lewis was awarded an Independent NERC Fellowship at Exeter University to investigate the susceptibility of marine invertebrate sperm to environmentally induced disruption from combined exposures to pollution and ocean acidification [1,2]. Ocean acidification, the change in ocean pH that is occurring as a result of increased carbon dioxide in the atmosphere dissolving into the oceans and altering seawater chemistry, has been recognised as one of the major threats to ocean biodiversity and ecosystem health. In addition to her Fellowship research, Lewis leads the invertebrate component of a consortium (SD4) for the current NERC UK- Ocean Acidification Research Programme (<a href="http://www.oceanacidification.org.uk/">http://www.oceanacidification.org.uk/</a>) that focuses on commercially important species [3] and involved in collaborative work with CEFAS. These projects have provided novel evidence that ocean acidification increases the toxicity of metal contaminants to a range of benthic invertebrates [1, 2].</p> <p>In 2010 and 2011 Lewis was invited to join the Catlin Arctic Survey – a privately funded international collaboration to investigate the rate and biological effects of ocean acidification in the Canadian High Arctic. This was an international expedition involving leading researchers from the Cambridge University, Plymouth Marine Laboratories, Edinburgh University, Old Dominion University, Virginia and Fisheries and Oceans Canada. Models have recently predicted that the Arctic Ocean will be the area most rapidly affected by ocean acidification caused by increasing carbon dioxide levels, with predictions that Arctic waters will be under-saturated with calcium carbonate within the next 30-60 years, together with associated increased dissolved inorganic carbon concentration (DIC) and decreased pH. The novel research undertaken by Lewis and her collaborators focused on collecting data to determine the current state of Arctic seawater carbonate chemistry and its relationship to the beneath-ice microbial [4], and plankton communities during the important winter-spring transition period, a time of year when research vessels cannot access the frozen Arctic waters resulting in very little existing data. The result is a unique two-year, time series data-set detailing the changes in carbonate chemistry, inorganic and organic nutrients and the corresponding changes in beneath ice phytoplankton, zooplankton and microbial communities during the two-month winter-spring transition.</p> <p>Lewis, together with colleague Helen Findlay of Plymouth Marine Laboratory (PML), collected novel data on key Arctic copepod species revealing that their differing exposures to natural variability in extant pCO<sub>2</sub> throughout the under ice water column parallels their differing sensitivities to projected ocean acidification. Copepods undertaking vertical migrations through areas of naturally high pCO<sub>2</sub> were robust to ocean acidification whilst smaller copepods trapped in a layer of stable pCO<sub>2</sub> seawater directly beneath the ice were very sensitive to projected ocean acidification</p>

## Impact case study (REF3b)

[4]. Lewis' and colleagues' data provide a comprehensive insight into the biogeochemical cycling and food chain dynamics of the Arctic ocean ecosystem, with the ultimate aim of facilitating more accurate predictions of climate change impacts for the Arctic ocean.

### 3. References to the research (indicative maximum of six references)

**Evidence of the quality of the research:** this work has been published in high quality peer reviewed journals and has attracted significant external grant funding.

1. Metal contamination increases the sensitivity of larvae but not gametes to ocean acidification in the polychaete *Pomatoceros lamarckii* (Quatrefages). **Ceri Lewis**, Kirsty Clemow, Bill Holt *Marine Biology* (2013) 160:2089–2101. Citations: 1
2. Ocean acidification increases the toxicity of contaminated sediments. David A Roberts, Silvana, N.R. Birchenough, **Ceri Lewis** (joint first author), Mathew Sanders, Thi Bolam & Dave Sheahan. *Global Change Biology* (2013) 19(2):340-351. Citations: 3
3. **Is the perceived resiliency of fish larvae to ocean acidification masking more subtle effects?**  
E.C. Pope, R.P. Ellis, M. Scolamacchia, J.W.S. Scolding, A. Keay, P. Chingombe, R.J. Shields, R. Wilcox, D.C. Speirs, R.W. Wilson, **C. Lewis**, and K.J. Flynn. *Biogeosciences Discuss* (2013) doi:10.5194/bgd-10-17043-2013.
4. Sensitivity to ocean acidification parallels natural pCO<sub>2</sub> exposures in Arctic copepods under winter sea ice. **Ceri Lewis**, Kristine Brown, Laura Edwards, Glenn Cooper, Helen Findlay, P.N.A.S. (*in press* accepted 8<sup>th</sup> November 2013).

#### Grants:

5. NERC UK-Ocean Acidification Research Programme 'Added Value' Knowledge Exchange grant (£20,000) January 2012 for 1 year (Co-I in collaboration with PML and Swansea University).
6. NERC Ocean Acidification Directed Consortium Grant: 'Improved understanding of population, community and ecosystem impacts of ocean acidification for commercially important species'. NE/H017496/1 (Co-I) £750k (of which £102k to Exeter) collaborating with PML, Swansea University and Strathclyde University)
7. Catlin Arctic Survey full sponsorship to cover all costs incurred for my participation in the 2011 expedition to the Canadian High Arctic to conduct ocean acidification research. Awarded to C Lewis April-May 2011 (after a peer-reviewed application process).
8. Exeter University Internal Funding through a Research and Knowledge Transfer Link Fund awarded to C Lewis. £5000 for participation in the Catlin Arctic Survey April-May 2010.
9. NERC Independent Postdoctoral Fellowship. 'Broadcast spawning into a changing marine environment: are sperm the weak link in a marine invertebrate's life cycle?' Awarded to C Lewis October 2009-September 2012: £347,000, grant number NE/G014728/1.

### 4. Details of the impact (indicative maximum 750 words)

Lewis has teamed up with Digital Explorer, a non-profit organisation run by Royal Geographical Society committee member Jamie Buchanan Dunlop (section 5; source 1). This organisation pioneers educational expeditions to provide lesson plans and multi-media resources free of charge to classrooms both nationally and internationally. Following the successful Catlin Arctic Surveys, Catlin approached Digital Explorer to develop a schools education programme to deliver the research questions and findings straight from Lewis and her collaborating Arctic Survey scientists to the next generation, thus providing a lasting legacy of their expeditions and raising awareness of ocean acidification and Arctic climate change as global issues to the scientists of tomorrow. The resulting 'DE Oceans' Programme has produced a set of education resources that are informed by research, inspired by the Arctic field work of Lewis and her Catlin Arctic Survey colleagues' Dr Helen Findlay of the Plymouth Marine Laboratories and Dr Victoria Hill of Old Dominion University, Virginia, USA.

The DE Oceans Academy has produced the 'Frozen Oceans' education programme that provides free classroom resources for UK and international schools. This comprises resource booklets with

over 50 lesson plans and over 60 activity sheets (section 5; sources 2-4), and multimedia resources with over 30 videos and 200 photos for Key Stage 3 and GCSE Geography and Science. The DE Oceans Academy also provides educational events and workshops, and ocean ambassadors, including Lewis, to speak at schools across the U.K. The oceans do not feature prominently in the National Curriculum but they are undeniably important to our future. The DE Oceans approach has been to identify areas of the curriculum where oceans case studies and examples are appropriate, enabling them to be incorporated easily into existing classroom topics whilst introducing students to the oceans at the same time.

The free school resources also include multimedia resources, enabling teachers to build lessons around the latest scientific research carried out by Lewis and her colleagues through the Catlin Arctic Survey. With video clips of the scientists including Lewis at work in the Arctic, over 200 photographs plus maps and scientific diagrams, the materials not only share new science but also give insights into the way scientists live and work in this extreme environment. These lessons are full of practical ideas to bring carbonate chemistry and marine biology to the science classroom.

Since the 'Frozen Oceans' multi-media resources were launched online in September 2011 they have provided over 2,338 resources, which have been distributed and used in 1,224 schools or related organisations, representing 30% of all UK secondary schools (section 5; source 5). The Frozen Oceans Resources are also being used in schools internationally, including a teacher training workshop run for teachers from 15 schools run in Alaska by COSEE (Centre for Ocean Science Educational Excellence <http://www.cosee.net/>). Multiple downloads of the DE Oceans resources have been recorded for internationally in Australia, The United States, Portugal and The Philippines and the online DE Oceans channel has received visitors from 85 countries. The resources are also being used in Portugal and Sweden (Sven Loven Marine Station, Gothenburg University) by university education departments as a case study on oceans education. Gillian Reid (Perth Grammar School & Kinross High School) has made Scottish curriculum versions of the DE Oceans resources for use in Scottish Schools.

Lewis also presented the DE Oceans resources at the International conference on 'Oceans in a High CO<sub>2</sub> World' to the 'Effective Practices for Communicating Ocean Acidification' workshop held at the Monterey Bay Aquarium, California in September 2012. Digital Explorer together with Lewis and Helen Findlay (PML) also ran three teacher training weekends for a total of 26 teachers, who then led cascade workshops for four of their subject colleagues, reaching a total of 104 teachers - 24 found the course excellent and 81% are very likely to use the Frozen Oceans resources with their pupils. These weekends trained teachers in a number of marine topics, such as ocean acidification, thermohaline circulation, and marine biodiversity, using the Arctic expedition as the main example but also covering the fundamental science underpinning the research of the expedition.

The Frozen Oceans resources won a Silver award from the Geographical Association in 2013 for 'being likely to make a significant contribution to geographical education' (section 5; source 6). Research Councils UK featured Lewis work with Digital Explorer as an example of Best Practice in linking science with education (section 5, source 7). The online channel at [oceans.digitalexplorer.com](http://oceans.digitalexplorer.com) was also established and received 8,430 visits, of which 5,748 were unique, and 20,232 page views from 85 countries. Lewis' work with Digital Explorer has featured in Geographical Association Magazine, Times Educational Supplement, Association for Science Educators magazine and numerous educational blogs. Digital Explorer have conducted a survey of the users of the Frozen Oceans Resources.

An example that demonstrates the impact that these schools' resources have had on the learning enjoyment of the children using them are the children of Magdalen College School, Brackley who, after using the DE Frozen Oceans resources, persuaded their teacher Daniel Waistell to develop an entire Oceans scheme of work to build on their enthusiasm for ocean science. **Inner-city** science summer school event: In July 2012 Lewis participated in a further Catlin sponsored educational outreach event run at St Paul's Way Trust School, a Faraday Specialist Science School in the East-end of London, run by the school's patron Prof Brian Cox and Lord Andrew Mawson and supported by the London Regeneration and Community partnerships, London Legacy Development Corporation (section 5; source 8 & 9). This event specifically targeted inner city London school children who might not consider a scientific career within their reach given their backgrounds. The Science Summer School offered Year 11 and 12 students studying science at GCSE or A level the opportunity to learn from and interact with some of Britain's leading scientists

**Impact case study (REF3b)**

through a programme of seminars, discussion and hands-on experiments. 150 children from St Paul's Way, the 14<sup>th</sup> most improved school in the country since becoming a Faraday Trust school, and 4 other local East London inner-city schools attended the 2-day summer school. Scientists presenting included Prof Brian Cox, Prof Jon Butterworth (CERN); Dr Nick Lane UCL), Prof Matthew Cobb (Manchester), Prof Hagen Bayley (Oxford) and Ceri Lewis, who talked about her Arctic Ocean acidification research and introduced the children to a sea urchin encounter.

**5. Sources to corroborate the impact** (indicative maximum of 10 references)

1. Digital Explorer is a web-based educational organisation that's bringing the ends of the earth into the classroom. Digital Explorer CIC, Studio 11, Netil House, 1 Westgate Street, London, E8 3RL. t: +44 (0) 20 3095 9749; Mobile: +447951 973249 [www.digitalexplorer.com](http://www.digitalexplorer.com)
2. The Digital Explorer Oceans schools resources are available to download for free at: <http://oceans.digitalexplorer.com/>
3. The DVD of the schools resources is additionally provided as a hard copy together with a hard copy of one of the accompanying classroom booklets.
4. The worksheet based on Ceri's Arctic copepod research is available online at: <http://oceans.digitalexplorer.com/resources/worksheets/>
5. The data on the number of schools using DE Oceans resources was compiled from Digital Explorer's Annual Report available as hard document or on request from Digital Explorer.
6. See <http://www.geography.org.uk/cpdevents/annualconference/derby2013/gaawards2013/>
7. RCUK are using Ceri's involvement in the DE Oceans educational resources as a case study of best practise in pathways to impact: <http://www.rcuk.ac.uk/media/brief/impactcase/pe/Pages/home.aspx>
8. The promotional brochure for the Catlin sponsored St Paul's Way science summer school is provided as a hard document. Catlin's Press release detailing the Science Summer School is available online at <http://www.catlin.com/en/NewsAndViews/PressReleases/2012/Catlin-runs-science-summer-school-20-07-2012>
9. Organiser of Summer Science School at St. Paul's Way Trust School.