

Institution: Plymouth University
Unit of Assessment: Earth Systems and Environmental Sciences B7
Title of case study: Understanding the consequences of Ocean Acidification on the environment and society
<p>1. Summary of the impact (indicative maximum 100 words)</p> <p>The Plymouth University marine carbon team was the first to investigate ecological consequences of ocean acidification, and carbon capture and storage leakage. The findings have impacted on US legislation and are key to the UK ocean acidification research programme. The research is highlighted in the European Science Foundations' <i>Science Policy Briefing on Impacts of Ocean Acidification</i> (2009), the United Nations' Emerging Issues Bulletin on '<i>Environmental consequence of ocean acidification: a threat to food security</i>' (2010), the US '<i>National Strategy to Meet the Challenges of a Changing Ocean</i>' (2010) and the Intergovernmental Panel on Climate Change '<i>Ocean Acidification Report</i>' (2011).</p>
<p>2. Underpinning research (indicative maximum 500 words)</p> <p>This case study highlights the impact of a body of research into marine carbon undertaken at Plymouth University by Hall-Spencer (Royal Society University Research Fellow 2002-2008, Professor of Marine Biology Plymouth University) and Spicer (Professor of Marine Zoology 2005-2013 Plymouth University). This research is vital to inform society of the consequences of unprecedented changes to the ecology and chemistry of our coasts. Without this information, policy makers are unable to assess the true costs and dangers of continued carbon dioxide emissions. The first indication that exposure to CO₂-rich water could result in biological effects that were not straight-forward to interpret came from a NERC-funded studentship (2006, Spicer as principal supervisor). This found that ocean acidification increased, not decreased, calcification in fish – but that there were trade-offs as we also found evidence of muscle wastage. Our team built the first aquaria used to study biological effects of CO₂, based on designs Spicer had been using to investigate oxygen and carbon dioxide effects on marine life since 1987. We have used these world-class facilities to show how carbon dioxide affects marine organisms, data that are used to predict future impacts on ecosystems in the UK and worldwide. The award of a major NERC consortium grant has allowed us to investigate the long-term effects of ocean acidification on a range of marine life and to study the evolutionary responses of marine animals to ocean acidification and temperature.</p> <p>To augment this laboratory work Hall-Spencer spearheaded the use of natural analogues for predicting future effects of ocean acidification on society and to inform policy on Carbon Capture and Storage. He assembled a team of researchers; Dr Rodolfo-Metalpa is his Plymouth University PDRA, Ms Rowley and Ransome were both Plymouth University students who with Dr Martin from CNRS France carried out the fieldwork. Dr Fine from Bar-Ilan University Israel provided expertise on corals, Dr Turner from UEA provided expertise on trace gases, Dr Tedesco from University of Naples provided expertise on volcanology and Dr Buia from Stazione zoologica Naples provided seagrass expertise. By studying marine organisms along natural gradients of CO₂, he was able to show the ecosystem-level effects of long-term exposure. This resulted in a land-mark publication in <i>Nature</i> (Hall-Spencer et al. 2008), which has set the standard for working with natural analogues, generating considerable public and scientific interest (223 ISI citations). Our natural analogue approach is being adopted worldwide with our team now involved with similar studies in the Pacific (US, Canada, Mexico, Australia, Papua New Guinea) and around Europe (Azores, Greece, Italy). The biological responses observed along CO₂ gradients have been used to predict how coasts will change over the coming decades and are being used to inform policy decisions. Our peer-reviewed published studies show the effects of increasing carbon dioxide levels on marine bacteria, algae, plankton, sponges, corals, worms, crustaceans, molluscs, bryozoans and echinoderms as well as fish and the fishing industry. The CO₂ gradients around volcanic vents have also been used as an opportunity to train a new generation of professionals from a multitude of different countries and to highlight the importance of reducing carbon dioxide emissions, exploring carbon capture options and increasing protection for coastal habitats (e.g., http://medsea-project.eu/training/co2-vents-training-activity/).</p>

Impact case study (REF3b)

3. References to the research (peer reviewed publications, Plymouth University personnel in bold). This work is published in the top (*Nature*), third (*Nature Climate Change*) and fourth (*Global Change Biology*) most-cited journals in Climate Change Research as well as leading subject-specific journals (*Proceedings of the Royal Society B*, *Journal of Experimental Marine Biology and Ecology*).

1. **Hall-Spencer JM, Rodolfo-Metalpa R**, Martin S, **Ransome E**, Fine M, Turner SM, **Rowley SJ**, Tedesco D, M-C Buia (2008) Volcanic carbon dioxide vents reveal ecosystem effects of ocean acidification. *Nature* 454: 96-99. World-leading peer-reviewed journal. Impact Factor 38.6. 90% of this research was carried out by Plymouth University staff and students.
2. **Johnson VR**, Russell BD, Fabricius K, Brownlee C, **Hall-Spencer JM** (2012) Temperate and tropical brown macroalgae thrive, despite decalcification, along natural CO₂ gradients. *Global Change Biology* 18: 2792-2803. Impact Factor 6.9. 80% of this research was carried out by Plymouth University staff and students.
3. **Rodolfo-Metalpa R**, Houlbrèque F, Tambutté E, Boisson F, **Baggini C**, Patti FP, Jeffree R, Fine M, **Foggo A**, Gattuso J-P, **Hall-Spencer JM** (2011) Coral and mollusc resistance to ocean acidification adversely affected by warming. *Nature Climate Change* 1: 308-312. Impact Factor 14.5. . 80% of this research was carried out by Plymouth University staff and students.
4. Widdicombe S, **Spicer JI** (2008) Predicting the impact of ocean acidification on benthic biodiversity: What can physiology tell us? *Journal of Experimental Marine Biology and Ecology* 366: 187–197. Leading international journal for biochemistry, physiology, behaviour, and genetics in ecology. Impact Factor 2.3. 50% of this research was carried out by Plymouth University staff.
5. Widdicombe S, **Spicer JI**, Kitidis V: 'Effects of ocean acidification on sediment fauna', Chapter 9, and James P. Barry, Stephen Widdicombe, and Jason M. Hall-Spencer: 'Effects of Ocean Acidification on Marine Biodiversity and Ecosystem Function', Chapter 10. In, *Ocean Acidification* (eds Gattuso, J.P. and L. Hansson). Oxford University Press (2011). Research level text from leading peer-reviewed press. 40% carried out by Plymouth University staff.
6. **Wood H, Spicer JI**, Widdicombe S (2008) Ocean Acidification may increase calcification rates- but at a cost. *Proceedings of the Royal Society*, London, Series B. 275: 1767 – 1773. Royal Society's flagship biological research journal. Impact Factor 5.7. 90% carried out by Plymouth University staff and students.

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

The main impacts of our research are on marine policy, regulation and guidelines designed to bring environmental improvements and through informing governments and industry on carbon capture and storage leaks as well as threats of ocean acidification to food security.

The research has had international impact. As a result of research into ocean acidification and carbon capture, Hall-Spencer has contributed to the drafting of the science basis of the next round of policy documents for the Intergovernmental Panel on Climate Change (Evidence 1). Through EU FP7 programmes (EPOCA, KnowSeas, MedSeA) he has provided presentations and draft policy documents to staff responsible for informing governing bodies on ocean acidification at the United Nations Environment Programme, EC DG Research and Innovation, the European Science Foundation and the International Union for the Conservation of Nature. As highlighted by the Senior Advisor of the International Union for Conservation of Nature "The influence of the research carried out by the marine carbon group at Plymouth University has ensured that ocean acidification, and the potential of carbon sequestration leaks to cause harm to the marine environment, are now being considered in depth alongside potential solutions to the problem such as improved marine conservation and the role of seagrasses as a Blue Carbon resource."

The research has been used as evidence in drawing up the US FORAM Act in 2008, has been incorporated into the US school curriculum, and has had impact on knowledge and behaviours of practitioners/policy makers having been incorporated into national and international strategies (e.g. National Research Council of the National Academies 2010). As stated by the United States

Impact case study (REF3b)

Department of Commerce “*The influence of the research carried out by the Marine Carbon Research Group at Plymouth University is international. In the USA there was explicit reference to the Plymouth University ocean acidification work in the U.S. Senate when hearing evidence for the federal Acidification Research and Monitoring Act*”

The research on natural analogs for CO₂ exposure is being used as evidence for the need to boost ‘Blue Carbon’ IUCN initiatives and the shift from fossil fuels to renewable sources of energy (see Evidence 2-3).

The research contributed substantially to the UK setting up a £12 million Ocean Acidification research Programme (2010-2014). The team a) assist the UK government (via DEFRA and DECC) in their delivery of statutory obligations under national legislative drivers (e.g. UK Biodiversity Action Plan, UK Marine and Coastal Access Bill), provide information to aid the assessment process for the UK Regional Seas via the UKMMAS Charting Progress III (in 2015) and the OSPAR Assessment Framework and support the design and implementation of measures needed to achieve Good Environmental Status in UK Regional Seas; (b) assist overseas governments with similar environmental protection remits; (c) allow government-backed international initiatives such as EPOCA, BIOACID, MedSeA, Mares & UKOOA to contextualise the work they are doing separately on Ocean Acidification (see Evidence 4). As stated by the Knowledge Exchange Coordinator of the UK Ocean Acidification Research programme “*The team’s work has made a major contribution to a number of key national and international research initiatives to inform policy makers of the future impact of OA on marine ecosystems and society*”.

More widely the research has had impacts on public discourse and raised societal interest in the effects of ocean acidification. Work by the marine carbon research group has been covered extensively by newspapers and on TV, the National Geographic Magazine, and in several science documentaries that have been shown globally (see Evidence 4). Thus the marine carbon research has intrinsic interest, but is also designed to predict the effects of ocean acidification and marine carbon capture and storage driven by legislative and regulatory considerations.

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

1. Factual Statement from the Co-Chairs of Working Groups I and II of the Intergovernmental Panel on Climate Change including invitation to Hall-Spencer, as a leading international expert, to join the IPCC Workshop to report on Impacts of Ocean Acidification on Marine Biology and Ecosystems. (Report at http://www.ipcc-wg2.gov/meetings/workshops/OceanAcidification_WorkshopReport.pdf). This letter confirms the impact Plymouth’s marine carbon group is having on international policy.
2. **Factual Statement** from the Chair of the U.S. Interagency Working Group on Ocean Acidification and Director of NOAA Fisheries, United States Department of Commerce. This letter confirms that the Plymouth University marine carbon team has had impacts on US legislation and environmental monitoring.
3. **Factual Statement** from Vice Chair – Marine, IUCN World Commission on Protected Areas. This letter confirms the impact of the Plymouth University marine carbon group on international marine conservation policy.
4. **Factual Statement** from Knowledge Exchange Coordinator of the UK Ocean Acidification Research Programme. This sets out the range of impacts that Plymouth University research has had on marine policy, education and public climate change debate.
5. **Factual Statement** from Hilary Benn the Secretary of State appointing Hall-Spencer onto the UK Government Scientific Advisory Panel on marine protected areas. This confirms that he has direct input to marine policy initiatives in Government based on research conducted at Plymouth University.
6. International Union for Conservation of Nature (IUCN) video on ocean acidification and consequences for the multimillion dollar shellfish industry in the USA. Features Jason Hall Spencer (Plymouth University): <http://www.youtube.com/watch?v=cAwZ7VCYn44>
7. Science and Innovation Policy Officer at Canadian Foreign Commonwealth Office interview with

Hall-Spencer: <http://blogs.fco.gov.uk/nicolarbour/2012/02/21/sin-podcast-jason-hall-spencer-on-ocean-acidification/>

8. Request from Executive Secretary at the United Nations that Hall-Spencer assist in providing advice on the impacts of ocean acidification on coastal biodiversity. This confirms that Plymouth University research findings are being used to inform intergovernmental organisations of the threats posed by ocean acidification.

9. Policy Document on ocean acidification, citing work by Hall-Spencer:
<http://www.oceanacidification.org.uk/pdf/OA.english.web.pdf>

10. Committee on the Development of an Integrated Science Strategy for Ocean Acidification Monitoring, Research, and Impacts Assessment, National Academy of Sciences, USA, ***Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean*** (2010) Cites Plymouth University research prominently. http://www.nap.edu/catalog.php?record_id=12904