IMPACTS OF CLIMATE CHANGE ON OCEAN ACIDIFICATION

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Executive Summary

Atmospheric carbon dioxide concentrations have increased from 280 ppm to around 380 ppm over the last 200 years through human activities, in particular the burning of fossil fuels. Projections are that CO_2 concentrations will increase substantially to 700 – 1000 ppm by the end of this century as fossil fuel reserves are consumed. However, nearly half of this anthropogenic CO_2 has already been absorbed by the surfaces of our seas and oceans and more will be absorbed in the future as we continue to increase our CO_2 emissions to the atmosphere (Sabine *et al.,* 2004). The ocean uptake of CO_2 is effectively buffering even more serious climate change than that predicted by clear evidence-based scientific consensus (e.g. IPCC, 2001). However, there is a "cost", as CO_2 reacts with seawater to form carbonic acid, the seas are becoming more acidic (Caldeira & Wickett, 2003). A strong scientific consensus is emerging about the rate and degree of change in acidity (measured in pH units) that will be experienced by surface waters (summarised in Royal Society, 2005) should CO_2 emissions continue at the same rate. The simplicity of the chemical reaction of CO_2 with seawater makes it very predictable on global (Orr *et al.,* 2005) and more local scales (Blackford & Gilbert 2006). These models show that there has already been a decline of 0.1 pH unit (a 30% increase in H+) since pre-industrial times and surface waters may experience a total reduction of around 0.7 pH units should all fossil fuels be burnt.

It is the impact of this rate of change as well as the level of change on marine organisms and ecosystems that concerns marine scientists all around the world (Royal Society, 2005; JRG, 2005; Turley, 2006; Kleypas, 2006; Haugan *et al.,* 2006) as pH has been relatively stable for over 20 million years. Calcareous (shelled) organisms are common in the sea (e.g. warm and cold water corals, some plankton, shellfish and sea urchins) and there is increasing evidence indicating that their ability to produce their shells will be reduced by 2050 (Kleypas, 2006).

Whilst we begin to recognise the potential impacts of increasing acidification in our oceans (e.g. a recent report by OSPAR: Haugan *et al.,* 2006) we have little evidence of what changes are actually occurring in waters around our coasts. Seawater pH does vary around UK waters because of natural processes; however, model predictions demonstrate that pH change this century due to significant atmospheric CO_2 increases exceeds this natural variation (Blackford & Gilbert, 2006). These predictions for shelf waters agree with those for open oceans (Caldeira & Wicket, 2003). How these chemical changes might affect marine food webs and biogeochemical cycles are of concern (Haugan *et al.,* 2006) but are less certain because of their complexity and require further research. In addition, the combined impacts of ocean acidification and climate change (e.g. increased seawater temperature and thermal stratification) on UK marine waters have not yet been addressed.

Level of confidence

High, that ocean pH is changing and will change in the future and unless we substantially and urgently reduce CO_2 emissions that these will have major impacts on aragonitic organisms this century.

We have a moderate level of confidence that this will have a knock-on effect on marine ecosystems and foodwebs, according to evidence from modelling and experimental observations.

Impacts of pH on other than aragonitic and calcitic organisms is theoretically serious (e.g. impact on nutrient speciation and therefore primary production and biodiversity) but there has been little research on this.

We have a high degree of confidence that reducing emissions is the only way of reducing ocean acidification

Key Sources of Information

Blackford, J.C., Gilbert, F.J., (2006). pH variability and CO_2 induced acidification in the North Sea. *Journal of Marine Systems*. Available online doi:10.1016/j.jmarsys.2006.03.016.

Caldeira K. and M. E. Wickett (2003). Anthropogenic carbon and ocean pH. *Nature* **425**, 365.

Feely R. A., Sabine C. L., Lee K., Berelson W., Kleypas J., Fabry, V. J., & F. J. Millero (2004). Impact of anthropogenic CO_2 on the $CaCO_2$ system in the ocean. *Science* **305**, 362–366.

Guinotte, J.M., Orr, J., Cairns, S., Freiwald, A., Morgan, L., & R. George (2006). Will human-induced changes in seawater chemistry alter the distribution of deep-sea scleractinian corals? *Front. Ecol. Environ.*, **4**, 141–146.

Haugan, P.M., Turley, C & Poertner H.O, 2006. Effects on the marine environment of ocean acidification resulting from elevated levels of CO_2 in the atmosphere, DN-utredning 2006-1, 1-36.

Hoegh-Guldberg O. (2005). Low coral cover in a high-CO_2 world. *J. Geochem. Res. – Oceans* **110**, C09S06, doi:10.1029/2004JC002528.

IPCC (2000). Special Report on Emission Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

IPCC (2001). Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp.

JGR (2005). The Intergovernmental Oceanographic Commission (IOC) of UNESCO and Scientific Committee of Oceanic Research (SCOR) of the International Council of Scientific Unions (ICSU) co-host a symposium on the potential environmental consequences of using the deep ocean for intentional storage of CO_2 and to address for

the first time the consequences of higher atmospheric CO_2 on the oceans, its chemistry and the organisms and ecosystems within them. The symposium “The Ocean in a High CO_2 World” was held in Paris in May 2004 (http://ioc.unesco.org/iocweb/co2panel/HighOceanCO2.htm)
Key scientific papers from the symposium were published in a special issue of the Journal of Geophysical Research, Volume 110 in 2005.

Kleypas, J.A., R.A. Feely, V.J. Fabry, C. Langdon, C.L. Sabine, & L.L. Robbins, (2006). Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research, report of a workshop held 18–20 April 2005, St. Petersburg, FL, sponsored by NSF, NOAA, and the U.S. Geological Survey, 88 pp.

Kurihara H, Shimode S & Shirayama Y (2004a). Sub-lethal effects of elevated concentration of CO_2 on planktonic copepods and sea urchins. *Journal of Oceanography* **60**, 743–750.

Kurihara H, Shimode S & Shirayama Y (2004b). Effects of raised CO_2 concentration on the egg production rate and early development of two marine copepods (Acartia steueri and Acartia erythraea). *Marine Pollution Bulletin* **49**, 721–727.

Kurihara, H. and Shirayama, Y. (2004c). Effects of increased atmospheric CO_2 on sea urchin early development. *Mar. Ecol. Prog. Ser*. **274**, 161-169.

Michaelidis, B., C. Ouzounis, A. Paleras and HO. Pörtner (2005). Effects of long-term moderate hypercapnia on acid-base balance and growth rate in marine mussels (*Mytilus galloprovincialis*). *Mar. Ecol. Progr. Ser.* **293**, 109-118.

Orr, J. C., V. J. Fabry, O. Aumont, L. Bopp, S. C. Doney, R. A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R. M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R. G. Najjar, G.-K. Plattner, K. B. Rodgers, C. L. Sabine, J. L. Sarmiento, R. Schlitzer, R. D. Slater, I. J. Totterdell, M.-F. Weirig, Y. Yamanaka, and A. Yool (2005), Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms, *Nature*, **437**, 681-686.

Riebesell U, Zondervan I, Rost B, Tortell P D, Zeebe R & Morel F M (2000). Reduced calcification of marine plankton in response to increased atmospheric CO_2. *Nature* **407**, 364–367.

Royal Society (2005). Ocean acidification due to increasing atmospheric carbon dioxide. Policy document 12/05 Royal Society: London. The Clyvedon Press Ltd, Cardiff, UK, 68pp.

Sabine C L, Feely R A, Gruber N, Key R M, Lee K, Bullister J L, Wanninkhof R, Wong C S, Wallace D W R, Tilbrook B, Millero F J, Peng T H, Kozyr A, Ono T & Rios A F (2004). The oceanic sink for anthropogenic CO_2. *Science* **305**, 367–371.

Shirayama, Y.; Thornton, H. (2005) Effect of increased atmospheric CO_2 on shallow water marine benthos. *J. Geophys. Res*., Vol. **110**, No. C9, C09S08 10.1029/2004JC002618

Turley, C., Blackford, J., Widdicombe, S., Lowe, D., Nightingale, P.D. and Rees, A. P. (2006) Reviewing the impact of increased atmospheric CO_2 on oceanic pH and the marine ecosystem. In: Avoiding Dangerous Climate Change, Schellnhuber, H J., Cramer,W., Nakicenovic, N., Wigley, T. and Yohe, G (Eds). Cambridge University Press, 8, 65-70.

Wolf-Gladrow, D. A., Riebesell, U., Burkhardt, S and Bijma, J.,1999. Direct effects of CO_2 concentration on growth and isotopic composition of marine plankton. *Tellus Series B-Chemical and Physical Meteorology* **51**(2): 461-476.

Zachos, J.C. (2005) Rapid acidification of the ocean during the Paleocene-Eocene thermal maximum. *Science*, **308**, 1611–1615.

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