Global Biodiversity Sub-Committee (GBSC)

Meeting papers

Ocean Acidification

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Department for Environment Food and Rural Affairs

JOINT NATURE CONSERVATION COMMITTEE

Ocean Acidification

1. Summary of the Issue

1.1 In recent years it has been well documented that approximately 50% of anthropogenic carbon dioxide (CO_2), released into the atmosphere has been taken up by the oceans (Sabine *et al*, 2004). Hydrolysis of CO_2 in seawater increases the hydrogen ion concentration [H+] (Orr *et al.*, 2005) and thus reduces the pH. The ability of seawater to absorb and buffer the effects of CO_2 is due to reactions with carbonate ions. The dissolved CO_2 reacts with carbonate ions (CO_3^{2-}) to produce bicarbonate (HCO_3^-). Thus the overall effect is a removal of carbonate ions and production of bicarbonate ions.

$$CO_2 + CO_3^{2-} + H_2O \rightarrow 2HCO_3^-$$

As additional CO_2 is absorbed, the concentration of bicarbonate ions increases, this then forces an equilibrium reaction which results in the dissolution of bicarbonate and a reduction in the pH of the seawater (Turley *et al.*, 2004).

$$HCO_3^- \rightarrow H^+ + CO_3^{2-}$$

1.2 To date the pH of surface waters has reduced by 0.1 units and it has been predicted that by 2100 the pH may have decreased by approximately 0.3 to 0.5 units under a ‘business as usual’ scenario (Caldeira and Wickett, 2005). The current changes are 100 times faster than those seen over the last 100,000 years (Haugan *et al.*, 2006).

1.3 Even though there are references in the scientific literature dating back 10 years, our current understanding of the effects of ocean acidification are limited (Haugan *et al.*, 2006). In the past there has been little political uptake, however more recent outputs from symposiums and the publication of reports, which provided a clear overview of the issue and the potential impacts on the marine ecosystem, have raised the profile of the topic with politicians and the public (IOC/SCOR Symposium 2004; Royal Society report, (Raven *et al.*, 2005); Intergovernmental Panel on Climate Change (IPCC), 2007).

1.4 Ocean acidification is expected to have an impact on marine organisms and the environment that they inhabit. Examples of the potential effects include; a reduction in calcification rates, changes in nutrient speciation, phytoplankton diversity and growth, altered life span, reduced tolerance to environmental fluctuations, changes to community structure and regime shifts (Turley, 2006, *personal communication*).

2. Current predictions of pH change

2.1 Table 1. (taken from Blackford *et al.*, 2007) shows the current predictions of pH change from 1800 to 2150.

2.2 It is known that acidification of the oceans is likely to continue, however it is not understood what the critical levels will be for marine organisms and ecosystems. Orr *et al.*, (2005) have raised concerns over calcifiers inhabiting high latitudes (polar and sub-polar regions). Calcifiers (e.g. coccolithophores, pterpods etc) either form calcite or aragonite shells, tests or liths. It has been predicted that the surface waters of the polar regions could become under-saturated for aragonite by 2050, and for calcite by 2100, thus reducing the availability of compounds required to enable calicifier shell/test formation. The potential removal of these organisms will alter the marine food web and will also impact upon rates of carbon removal from the marine ecosystem. Effects on other organisms may be more subtle, for example, the increased acidity may affect enzymes necessary for metabolic reactions and functioning.

Approximate date	**Atmospheric CO_2 (µmol/mol)**	**Marine pH**	**% increase in H^+ ions**
1800	260	8.2	
1880	280	8.18	5%
1900	285	8.17	7%
1950	315	8.14	15%
2000	375	8.08	32%
2050	500	7.97	70%
2100	700	7.84	130%
2150	1000	7.70	216%

Table 1 Predicted changes in pH and Hydrogen ion concentration with increasing atmospheric pCO_2 (taken from Blackford *et al.*, 2007)

3. Current International Activities and Research

3.1 The International Oceanographic Committee (IOC, under UNESCO) and the Scientific Committee on Oceanic Research (SCOR) organised a symposium in 2004 'Oceans in a High CO2 world', a second symposium is planned for 2008. A website has been set up as a source of information for researchers. The IOC and SCOR also co-sponsor the International Ocean Carbon Coordination Project (IOCCP), (which is an affiliate of the Global Carbon Project). The IOCCP promotes a global network of ocean carbon observation research via technical coordination and communication services, international agreements on standards and methods, as well as links to the global carbon observing system.

3.2 IMBER (Integrated Marine Biogeochemistry and Ecosystem Research) and SOLAS (Surface Ocean-Lower Atmosphere Study) have set up a joint SOLAS-IMBER Carbon Implementation Group (SIC), which is working in co-ordination with the IOCCP. The SIC group has two main areas of global research: 1. Carbon inventories, fluxes and transports and 2. Sensitivities of carbon-relevant processes to changes occurring in the ocean.

3.3 Individual research groups are conducting various experiments to gauge the effects of ocean acidification on marine organisms and the ecosystem. There are several papers which discuss the global research effort to date, for example, Kleypas *et al.* (2006), examine the current research on the effects of ocean acidification on coral reefs and marine calcifiers, while Haugan *et al.* (2006), provide a good overview of the current research effort. In recent years, researchers from around the globe are sharing current knowledge via participation in symposiums and workshops.

4. Current European Activities and Research

4.1 CARBOOCEAN is an EU 6th Framework funded programme in which a consortium of 47 groups (including some from North America) are working together to fulfil the aim of determining the oceans quantitative role for uptake of CO_2. The main focus is gathering knowledge on the time-span between the past and future 200 years in the Atlantic and Southern Oceans. The programme has 5 core themes; 1. To determine the air-sea exchange on a seasonal to inter-annual scale; 2. To detect decadal to centennial ocean carbon inventory changes; 3. To determine carbon uptake and release on a European scale; 4. To investigate biogeochemical feedbacks on the ocean-carbon sink and 5. To look at future scenarios for marine carbon sources and sinks.

4.1.1 CARBOOCEAN has enabled a European monitoring network for observation of ocean and shelf sea to be observed (by University of East Anglia, UEA, in the UK). Additional observations are made by National Oceanography Centre (NOC) and Plymouth Marine Laboratory (PML) under Natural Environment Research Council (NERC) funded CarbonOps. There is a disparity between changes observed in-situ and the predictions of numerical models. It is therefore essential that in-situ observations are maintained so that the real rate of change in the oceans is documented.

4.1.2 After 2008 there will be no European funding to maintain the CARBOOCEAN network; the NERC CarbonOps observations are funded until 2009. Both networks are based on using Voluntary Observing Ships therefore the sums involved to maintain operations are relatively small.

4.2 OSPAR (Oslo Paris) Commission for the protection of the North East Atlantic commissioned a report on the *Effects on the Marine Environment of Ocean Acidification resulting from elevated levels of CO_2 in the Atmosphere* (Haugan *et al.*, 2006). The report, gave an overview of the issue of ocean acidification. OSPAR are not carrying out any research *per se*, but are now considering their response to ocean acidification, which will be discussed at the Commission in January 2008.

4.3 An ICES workshop on the significance of Changes in Surface CO_2 and Ocean pH in Shelf Sea Ecosystems was held on the 2-4th May 2007 in London. The workshop looked at the current state of our knowledge and identified future research directions specifically relating to the spatial and temporal variability of the surface ocean pH and CO_2 – carbonate system in shelf seas. Our ability to predict rates of pH and thus acidification change was also discussed along with the effects of pH and the CO_2 carbonate system on nutrient chemistry, contaminants and ecosystem components (fish, plankton, shellfish, coldwater corals).

A workshop summary is in preparation see http://www.cefas.co.uk/science/Workshops/WKCpH/default.htm.

4.4 As in the international arena, individual research groups are investigating various aspects of Ocean acidification. Within the UK key research groups are working not only to answer scientific questions but also to promote public awareness of ocean acidification:

- Scientists at PML, NOC, Scottish Association for Marine Science (SAMS), Marine Biological Association (MBA) and University of Cambridge are part of an EU-wide consortium, 'EPOCA', who are developing a proposal to be submitted to the EU 7th Framework Programme in May 2007.
- Some of the current research being undertaken includes; the impacts of catastrophic releases on marine organism physiology, effects on the marine ecosystem (via modelling), the use of ships of opportunity to gain measurements, the effects on phytoplankton and bacteria (metagenomics study - in association with the Bergen mesocosm), Aragonite saturation in the Southern Ocean, calcification rates and effects on copepod growth and reproduction.

5. Research Issues

5.1 Most research to date has generated data on the effects to marine organisms under abrupt and large changes in pH, rather than the realistic changes that can be expected from the gradual introduction of CO_2 from the atmosphere (Haugan *et al*, 2006). Different methods to generate lower pH (CO_2 bubbling or acid addition) have also been used making it difficult to compare experimental results. As further experiments, using more realistic conditions, are conducted our knowledge of the effects will grow. Initial in situ experiments have been undertaken by the Monterey Bay Aquarium Research Institute, however logistics and licensing problems must be overcome before progress is made.

5.2 Current changes in pH are estimated to be 0.003 pH units per year. It is difficult to accurately measure pH to this level and at present there is no accepted, readily available procedure for the monitoring of seawater pH. To achieve the accuracy required the current method is to calculate pH from measurements of any two of the other carbonate system parameters (pCO_2, total alkalinity, total CO_2 (which is also known as Dissolved Inorganic Carbon, DIC)). This in itself can pose problems; there are two definitions of alkalinity that differ in the way minor chemical species are treated; there are four pH scales (total, seawater, free and Natural Bureau of Standards – now the National Institute of Standards and Technology); and there are differences in the formulations of the constants K1 and K2 required to complete the calculation of pH. Historical datasets do not often record which parameters have been used, therefore comparison of data is difficult. In the future there is a need to ensure that the metadata, detailing the parameters used, accompanies the reported data so that datasets can be compared (Hydes, presentation at ICES workshop, 2007).

5.3 To fully understand the overall effects of ocean acidification, a holistic approach is required. Information gained from observations (research cruises, mesocosm experiments, fixed moorings, satellite data and ships opportunity) can be fed into and verify models which are addressing biogeochemical (carbon cycle) and ecosystem (functioning) questions. A significant issue is that long term data sets are rare and research programmes are often short term or opportunistic, therefore research and data are often fragmented and diverse (Blackford *et al.*, 2007).

5.4 Ecosystem model outputs require validation and parameterisation. To date there is a lack of real field and experimental data to effectively carry this out. This is particularly problematic for the formulation of functional relationships that describe physiological responses of species and populations to environmental gradients and changes. The modelling of trophic connections is also known to be a current area of weakness (Blackford *et al*, 2007).

5.5 Current funding for research is available to answer specific, fashionable policy questions or blue skies science, which can easily result in fragmented work and a lack of focus on the wider picture. Blackford *et al.*, (2007) suggest that a more coherent funding regime is required to ensure that quality science is conducted and that collaboration between research institutes and universities is facilitated. Experiments should be designed in collaboration with researchers, modellers and statisticians to ensure data collected can be used efficiently and inform the debate. They also suggest that the holding of annual international workshops, to bring together modellers and experimentalists, would enhance communication, encourage a synergistic approach and avoid duplication. Similarly the recent IOCCP-SOLAS-IMBER SOCOV (Surface Ocean CO_2 Vulnerability and Variability) workshop (11-14th April 2007, Paris) highlights the need for sustained funding of the global surface ocean CO2 network (Bakker 2007, personal communication).

6. Key Knowledge Gaps

6.1 There are significant gaps in our knowledge on the effects of ocean acidification on ecosystems, communities, functioning and biogeochemical processes.

6.2 The threshold level, over which the effects of ocean acidification are apparent in an organism, are generally unknown. Individual species are likely to react differently to decreasing pH, some will adapt whilst others may decline, therefore research on the responses of a large range of species to realistic changes in pH is required. This information is vital if we are to understand the potential for organisms to adapt or experience sub-lethal effects, which may alter growth and reproduction thus ultimately resulting in changes to the community structure.

6.3 It should be recognised that experiments may provide little insight into the population, community and ecosystem impacts and the likely consequences for fisheries. Factors important for population growth and resilience, such as migration and species interactions, cannot be readily manipulated experimentally. Insights into ecosystems and fisheries impacts are most likely to be derived from confronting population and ecosystem models with long-term, large-scale monitoring data such as that collected on plankton (by SAHFOS) and of higher trophic levels (e.g. Cefas, FRS, PML), therefore these datasets should continue to be supported. Research into community structure and populations should consider the relative effects on different life stages; it is already known that juveniles are more sensitive to stress and other impacts. However, for broadcast spawning species it will be difficult to translate the acute laboratory response into predictions of likely population and ecosystem impacts of acidification. This is because the early life stages of broadcast spawners contribute relatively little to the overall population growth rate and resilience compared to sub-adult and adult stages (Sadovy 2001; Dulvy et al. 2003).

6.4 Current knowledge on the effect of increasing pH on biogeochemical processes is lacking. Many processes such as nutrient speciation, nitrification, denitrification, dimethyl sulphide production and the biological carbon pump are of global importance and any changes may have strong feedbacks on the Earth System and climate. This information is also vital if we are to use modelling as an effective predictive tool.

6.5 Ocean acidification is not the only issue of concern to the marine environment. Climate change is increasing sea surface temperatures and is likely to result in cumulative or synergistic effects, however, little research into the combined effects of ocean acidification and climate change has occurred to date. Fishing is the main driver of change in higher trophic levels, the impacts of ocean acidification should be considered and understood in this context.

6.6 For coastal waters and shelf seas the background against which change in acidity will occur is poorly defined. Through a year, the range of values is likely to be large (Blackford *et al.*, 2006). The effects may be like those of temperature changes where although there is large annual range it is the shift in the mean that has been shown to be causing ecosystem shifts. Defra is currently developing a measurement programme which will provide these data.

6.7 Improved parameterisation and validation of ecosystem models (with observational data) is vital if we are to understand and make predictions of the impacts of ocean acidification on ecosystems in shelf seas. It is within these seas that the majority of ecosystem resources are concentrated, therefore politically the information will be vital to understand not only the economic and social impacts of ocean acidification, but also the ability to set and meet future marine obligations and commitments.

6.8 Advances in technology to develop automated pH sensors, that could monitor pH at the required accuracy for a long duration. Such instruments would provide information on the pH fluctuations and would enable underway measurements of pH to be obtained from research ships or vessels of opportunity.

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Andrea Leedale. May 2007
Working group Advisors; Carol Turley, Steve Hay, Nick Dulvy, David Hydes, Dorothee Bakker, Dan Laffoley, Jo Myers.