New York, XX February 2012

Stephen Mathias

Assistant Secretary-General in charge of the Office of Legal Affairs

United Nations Secretariat

New York

Excellency,

In reply to your letter dated 12 December 2012 regarding the report of the Secretary-General on oceans and the law of the sea, Ref: Los/SG Report/2013, the EU and its Member States have the honour to transmit the following information related to the Informal Consultative Process:

The European Union:

Legislative context

The European Union adopted its Marine Strategy Framework Directive (which came into force on 15 June 2008) in order to protect more effectively the marine environment across Europe (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32008L0056:EN:NOT). The Directive aims to achieve Good Environmental Status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. In order to achieve GES by 2020, each Member State is required to develop a strategy for its marine waters which must be kept up-to-date and reviewed every 6 years. The Marine Strategy Framework Directive will allow the EU to tackle, through various management measures, the whole range of pressures and impacts on marine ecosystems, including those resulting from climate change, such as acidification. In developing their respective marine strategies, EU Member States need to monitor and specify, where appropriate, any evidence of climate change impacts, and incorporate such changes into the way they set their environmental targets in order to reach good environmental status.

R&D Projects relating to Ocean Acidification co-funded under the European Union's Seventh Framework Programme for Research (EU FP7)

1. **EPOCA** - European Project on Ocean Acidification
   From: 2008-05-01 **to** 2012-05-01 (Completed)
   Total cost: EUR 15 945 582
   EU contribution: EUR 6 548 995
   http://www.epoca-project.eu/

   The EPOCA consortium brought together more than 160 researchers from 32 institutes and 10 European countries (Belgium, France, Germany, Iceland, Italy, The Netherlands, Norway, Sweden, Switzerland and United Kingdom). The overall goal of this project was to advance

understanding of the biological, ecological, biogeochemical, and societal implications of ocean acidification. It aimed to:

- document the changes in ocean chemistry and biogeography across space and time
- determine the sensitivity of marine organisms, communities and ecosystems to ocean acidification
- integrate results on the impact of ocean acidification on marine ecosystems in biogeochemical, sediment, and coupled ocean-climate models to better understand and predict the responses of the Earth system to ocean acidification
- assess uncertainties, risks and thresholds ("tipping points") related to ocean acidification at scales ranging from sub-cellular to ecosystem and local to global .

EPOCA was the first large-scale international project on ocean acidification and contributed to advance the state of knowledge of ocean acidification and its impact on marine organisms and ecosystems. EPOCA produced 21% of the total research papers on ocean acidification published during the period 2009-2012. The project highlighted that ocean acidification in the Arctic is proceeding faster and is more severe than expected. Furthermore, it provided robust evidence that many calcifying organisms and key biogeochemical processes are adversely affected by ocean acidification. Model simulations also demonstrated the high vulnerability of nearshore regions and that acidification-induced changes in primary productivity and carbon export will counter general reductions from climate change. Globally, the project raised awareness of policy-makers and researchers on ocean acidification. In 2010, the EPOCA team published a 'Guide to best practices for ocean acidification research and data reporting' (http://www.epoca-project.eu/index.php/guide-to-best-practices-for-ocean-acidification-research-and-data-reporting.html).

2. **MedSeA** – Mediterranean Sea Acidification in a Changing Climate
From: 2011-02-01 **to** 2014-02-01 (In execution)
Total cost: EUR 6 000 000
EU contribution: EUR 3 490 169
http://medsea-project.eu/

This project includes 10 nations with 13 institutes (Egypt, France, Germany, Greece, Israel, Italy, Morocco, Spain, Tunisia and United Kingdom).

MedSeA is assessing the chemical, climatic, ecological, biological, and economical changes of the Mediterranean Sea driven by increases in CO2 and other greenhouse gases. In particular, it aims to identify where the impacts of acidification in Mediterranean waters will be more significant. Its objectives are:

- To identify where the impacts of acidification on Mediterranean waters will be more significant, taking into account the sequence of causes and effects, from ocean chemistry through marine biology to socio- economic costs.

- To generate new observational and experimental data on Mediterranean organism and ecosystem responses to acidification and fed into existing fine-scale models of the Mediterranean Sea that are modified to better represent key processes, and then used to project future changes. The MedSeA focuses on a selected set of key ecosystem and socio-economic variables that are likely to be affected by both acidification and warming, studying the combination of both effects through ship-based observations, laboratory and mesocosm experiments, physical-biogeochemical-ecosystem modelling, and economical analyses.

- To provide best estimates and related uncertainties of future changes in Mediterranean Sea pH, CaCO3 saturation states, and other biogeochemical-ecosystem variables, assessing the changes in habitat suitability of relevant ecological and economically-important species.

The analysis of historical data has confirmed that anthropogenic carbon has penetrated all Mediterranean Sea waters and that calcifying organism responded negatively to changes in atmospheric CO2. The economic impacts of ocean acidification in the region are currently being studied.

3. **CoralFISH** - Assessment of the interaction between corals, fish and fisheries, in order to develop monitoring and predictive modelling tools for ecosystem based management in the deep waters of Europe and beyond
From: 2008-06-01 **to** 2013-02-28 (In execution)
Total cost: EUR 10 885 692
EU contribution: EUR 6 499 905
http://www.eu-fp7-coralfish.net/

CoralFISH aims to support the implementation of an ecosystem-based management approach in the deep-sea by studying the interaction between cold-water coral habitat, fish and fisheries. Among other things, the project estimated the global acidification threat to cold-water stony corals through a species modelling approach. So far, the results suggest that anthropogenic-induced changes in ocean chemistry are likely to severely impact cold-water stony coral habitat in North Atlantic, and have a low-to-moderate impact elsewhere. Although, seamounts may serve as temporary refuges as coral communities on the summits and upper slopes will be less susceptible than those of surrounding seafloor.

4. **MEECE** - Marine ecosystem evolution in a changing environment
From: 2008-09-01 **to** 2013-02-28 (In execution)
Total cost: EUR 8 577 985
EU contribution: EUR 6 499 744
http://www.meece.eu/

MEECE is developing predictive coupled models to explore the impacts of both climate drivers and human induced drivers on marine ecosystems. For ocean acidification, the project built on the work developed by EPOCA and other projects and developed modelling parameters. The models developed were stored in an online library of models that is accompanied by technical guides and metadata, and can be used by any programmer to assess how ecosystems are impacted by global change. To validate the developed models the project reviewed existent datasets for ocean acidification in geographical areas of interest.

5. **EURO-BASIN -** European Union Basin-scale Analysis, Synthesis and Integration
From: 2010-12-31 **to** 2014-12-30 (In execution)
Total cost: EUR 9 652 000
EU contribution: EUR 6 996 407
http://www.euro-basin.eu/

EURO-BASIN aims to advance understanding on the variability, potential impacts, and feedbacks of global change and anthropogenic forcing on the structure, function and dynamics of the North Atlantic and associated shelf sea ecosystems as well as the key species influencing carbon sequestering and ecosystem functioning. Among other impacts, the project is studying the pelagic ecosystem response to increasing ocean acidification, focusing on trophic coupling and carbon and energy transfer and is collaborating with the UK Ocean Acidification research programme.

6. **HERMIONE -** Hotspot ecosystem research and Man's impact on European seas
From: 2009-04-01 **to** 2012-09-30 (Completed)
Total cost: EUR 10 982 142
EU contribution: EUR 7 998 955
http://www.eu-hermione.net/

The HERMIONE project focused on the functioning of deep-sea ecosystems and their contribution to the production of goods and services. HERMIONE studied the effects of ocean acidification on the microbial loop and meiofauna biodiversity and on the calcification rates and resilience of cold-water corals. Project results suggest that present day cold-water calcification in the Mediterrenean Sea has already drastically declined as a consequence of anthropogenic-induced ocean acidification.

7. **Additional Information: Ocean Acidification International Coordination Centre**

Some EU projects co-funded under the EU's Seventh Framework Programme for Research (EU FP7) undertaking research in ocean acidification and related issues (such as EPOCA, MedSea and CARBOCHANGE) have been involved in the establishment of the Ocean Acidification International Coordination Centre (OA-ICC), operated by the International Atomic Energy Agency (IAEA) in Monaco.

Project	EC Contribution	Status	General Aim	Main Results – Ocean	Website
EPOCA	6 548 995 €	Completed	Advance the state of knowledge of ocean acidification and its impact on marine organisms and ecosystems.	Ocean acidification in the Arctic is more severe and proceeding faster than expected. Calcifying organisms and key biogeochemical processes are adversely affected. Acidification-induced changes in primary productivity and carbon export will counter general	http://www.epoca-project.eu/

				reductions from climate change. Raise awareness on ocean acidification	
MedSeA	3 490 169 €	In execution	Evaluate the chemical, climatic, ecological, biological, and economical changes of the Mediterranean Sea driven by increases in CO2 and other greenhouse gases.	Anthropogenic carbon has penetrated all Mediterranean Sea waters. Calcifying organism responded negatively to changes in atmospheric CO2.	http://medsea-project.eu/
HERMIONE	7 998 955 €	Completed	Assess the functioning of deep-sea ecosystems and their contribution to the production of goods and services	Cold-water calcification in the Mediterranean Sea has declined drastically.	http://www.eu-hermione.net/
EURO-BASIN	6 996 407 €	In execution	Understand the potential impacts, and feedbacks of global change and anthropogenic forcing on the structure, function and dynamics of the North Atlantic and associated shelf sea ecosystems.	Pelagic ecosystem response to increasing ocean acidification	http://www.euro-basin.eu/
MEECE	6 499 744 €	In execution	Develop predictive coupled models to explore the impacts of climate drivers and human induced drivers on marine ecosystems.	Online library of models to assess how ecosystems are impacted by global change.	http://www.meece.eu/
CoralFISH	6 499 905 €	In execution	Support the implementation of an ecosystem-based management approach in the deep-sea by studying the interaction between cold-water coral habitat, fish and fisheries.	Seamounts as refugia for coral communities. Anthropogenic-induced changes in ocean chemistry are likely to severely impact cold-water stony coral habitat in North Atlantic.	http://www.eu-fp7-coralfish.net/

Belgium:

- In reply to the DOALOS letter of December 12th 2012, inviting the EU to contribute to the Secretary General's report's section on the 2013 Informal Consultative Process (topic: Impacts of ocean acidification on the marine environment), Belgium would like to highlight the following initiatives, projects and studies:

o Belgium funded a number of projects which did not have, as a main topic, ocean acidification, but which did study it:

- PEACE (http://www.co2.ulg.ac.be/peace/index.htm): This project evaluated the role in climate regulation of calcification, primary production and export processes during coccolithophorid blooms, by using a transdisciplinary approach that combines process-oriented field investigations with laboratory experiments and modelling tools. Specific objectives were to study the net ecosystem dynamics during coccolithophorid blooms, to unravel the link between the bacterial community, grazing, TEP dynamics, carbon export and DMS cycling during coccolithophorid blooms, to assess the effects of ocean acidification on coccolithophorid metabolism and TEP production, and to model coccolithophorid dynamics and their impact on ocean dissolved inorganic carbon (DIC) chemistry. Publications of the results can be found on the website or via these links:
  http://www.belspo.be/belspo/ssd/science/Reports/PEACE%20Final%20Report%20-%20Chou%20et%20al.pdf (full report),
  http://www.belspo.be/belspo/ssd/science/Reports/PEACE%20Final%20Report%20-%20Summary.pdf (summary).

- Belcanto (http://www.co2.ulg.ac.be/belcanto/): This project focused on the role of the Southern Ocean in the global biogeochemical cycling of elements and in climate regulation, notably through its capacity to absorb atmospheric CO2, a major greenhouse gas. The overall objective was to construct and validate a realistic 3D ice-ocean biogeochemical model for the area south of 30°S. This required a thorough understanding of the factors regulating ocean-atmosphere interactions, oceanic circulation and biogeochemical processes involving biogenic matter. Links to the final results and reports:
  http://www.belspo.be/belspo/ssd/science/Reports/BELCANTO_FinRep.ML.pdf and
  http://www.belspo.be/belspo/ssd/science/Reports/BELCANTO_FinRep_2.ML.pdf.

o At the EU level, Belgium would like to highlight:

- The recently completed EPOCA (European Project on OCean Acidification) resulted in a vast amount of information which can be accessed via its website: http://www.epoca-project.eu/. The aim of the project was to document the changes in ocean chemistry and biogeography across space and time; determine the sensitivity of marine organisms, communities and ecosystems to ocean acidification; integrate results on the impact of ocean acidification on marine ecosystems in biogeochemical, sediment, and coupled ocean-climate models to better

understand and predict the responses of the Earth system to ocean acidification; and to assess uncertainties, risks and thresholds ("tipping points") related to ocean acidification at scales ranging from sub-cellular to ecosystem and local to global.

- The MedSea project (http://medsea-project.eu/): The European Mediterranean Sea Acidification in a changing climate initiative assesses uncertainties, risks and thresholds related to Mediterranean acidification at organismal, ecosystem and economical scales.

o On a multilateral level, Belgium would like to draw the attention to:

- The CBD Technical Series n° 46: Scientific Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity, which can be downloaded via http://www.cbd.int/doc/publications/cbd-ts-45-en.pdf.

- The 2011 IPCC Workshop on Impacts of Ocean Acidification on Marine Biology and Ecosystems, whose report can be found on https://www.ipcc-wg1.unibe.ch/publications/supportingmaterial/OceanAcidification_WorkshopReport.pdf.

France:

1. Information regarding the activities currently undertaken related to the impacts of ocean acidification on the marine environment :

Besides the scientific projects related to ocean acidification already mentioned by our British and Belgian colleagues, France would like to mention two other elements :

- The eFOCE project (European Free Ocean Carbon dioxide Enrichment Experiment) :

The objective of this project is to understand the long-term effects of ocean acidification through *in situ* experiments. eFOCE is aimed at developing over a 3 years time experimental systems that enable scientists to investigate *in situ* the long-term effects of acidification on benthic marine communities (those organisms which live on or near the seabed). Systems will be developed and tested in the Mediterranean Sea for long experiments (more than 6 months). The ultimate goal is to increase the number of these systems in order to make them available to the international scientific community.

The project is co-funded by the European Commission and is being carried out in cooperation with the Monterey Bay Aquarium Research Institute (USA). It involves several European laboratories (such as France's Laboratoire d'Océanographie de Villefranche-sur-mer and Station Biologique de Roscoff) involved in the EPOCA and MedSeA.

Attached is a document presenting the eFOCE project (it is only in French). More information can be found at : http://www.efoce.eu/

- A scientific review on ocean acidification and coral reefs carried out under the Coral Reef Initiatives for the Pacific (CRISP):

The Initiative for the Protection and Management of Coral Reefs in the Pacific (CRISP), mainly funded the French Development Agency (AFD) and the French Global Environment Facility (FGEF), aims to develop a vision for the future of these unique ecosystems and the communities that depend on them. Ocean acidification has been a major topic for the CRISP programme, which sponsored a scientific review to address the consequences of ocean acidification for the sustainability of coral structures.

A document presenting this scientific project (in French, English and Spanish) is attached.

2. Matters which may require further consideration on this issue, with an emphasis on areas where coordination and cooperation at the intergovernmental and inter-agency levels could be enhanced :

In France's view, one interesting issue for consideration regarding ocean acidification under UNCLOS and other regulatory instruments could be whether the current international legal framework is sufficient for regulating CO_2 removal methods and techniques. Ocean alkalinisation (a well-know technique which has been used to counteract acidification in lakes for many years) would fall under the scope of the 1996 Protocol to the London Convention on the prevention of marine pollution by dumping wastes and other matter. Still, further discussions may be needed on the various other additives, the applicable regime and their potential environmental impacts.

MPAs can be seen as a tool to increase resilience and alleviate the pressure from various stressors that are of primary importance for ocean acidification. Therefore, the absence of a clear legal framework to establish marine protected areas in areas beyond national jurisdiction represents an important regulatory gap that may hamper responses to ocean acidification.

Ireland:

1. Information regarding the activities currently undertaken related to the impacts of ocean acidification on the marine environment

Research Projects and Publications

- The Marine Institute is the Irish national agency responsible for Marine Research, Technology Development and Innovation. The Institute is broadly responsible for: undertaking marine research and development services; advising Government on policy relating to marine research and development; carrying out policy on marine research and development; and promoting the development of Irish shipping and shipping services and seafarer training. (http://www.marine.ie/Home/)

- In 2007, the Irish Government launched the National Sea Change programme (2007-2013), a Marine Knowledge, Research and Innovation Strategy supported by the Marine Research Sub-Programme of the National Development Plan (2007-2013). As part of this project, the Marine Institute and the National University of Ireland, Galway engaged in a two year collaborative project entitled **"Impacts of Increased Atmospheric C02 on Ocean Chemistry and Ecosystems"**. (http://www.marine.ie/home/research/ProjectsDatabase/CurrentProjects/Climate+Change+CO2.htm) In 2011, the project team produced a summary report which is available at: http://oar.marine.ie/bitstream/10793/703/1/Impacts%20of%20Increased%20Atmospheric%20CO2%20on%20Ocean%20Chemistry%20and%20Ecosystems.pdf. The project is intended to increase understanding of the impact of increased levels of CO2 and to assist in clarifying future research priorities in the area. The project team are required to: develop national capabilities for research into ocean carbon chemistry; improve the quantification and understanding of carbon processes essential for climate change models and for understanding changes to ocean chemistry; and to provide a detailed plan for an ongoing multidisciplinary research and monitoring work programme to investigate and predict the impacts of changing ocean carbon chemistry on ecosystems in Irish waters. The project will create new research capabilities to contribute to knowledge about ocean acidification. The delivery of a plan for future research will then inform policy development and research planning.

- In 2010, as part of this project, the Marine Institute published a desk-top study entitled **"Ocean Acidification: An Emerging Threat to our Marine Environment".** The full report is available at: http://oar.marine.ie/bitstream/10793/80/1/No.%206%20Ocean%20Acidification%20Foresight%20Report.pdf. The study provides a concise overview of the present state of scientific knowledge of ocean acidification and its likely impacts on organisms and ocean ecosystems. It covers topics such as: ocean acidification as an emerging cause for concern; how anthropogenic CO2 emissions are changing ocean chemistry; the consequences of ocean acidification; international policy drivers, strategies and necessary actions; and current research and information gaps. The study summarises the issues and the current state of knowledge and communicates ongoing monitoring and research needs into acidification.

2. Matters which may require further consideration on this issue, with an emphasis on areas where coordination and cooperation at the intergovernmental and inter-agency levels could be enhanced

- One of the principal challenges regarding ocean acidification is the need for sustained programmes of *in situ* measurements and the need for international cooperation in the development of a coordinated global network of ocean observations.[1]

[1] Marine Institute Report, "Ocean Acidification: An Emerging Threat to our Marine Environment", page 60.

- International cooperation to create a data management and synthesis programme for new ocean acidification data, as well as data mining and archives for relevant historical data sets.[2]

- The use of standardized measurement protocols and data reporting guidelines for ocean acidification research is another issue which will require international coordination. In particular, agreement is needed on appropriate indicators for the biological and ecological impacts of ocean acidification.[3]

- There are a number of priority areas in need of further research. These include, among others, further research into species, function groups and ecosystems that are most sensitive to ocean acidification and the rate at which these organisms can adapt to the changes;[4] the link between ocean acidification and biogeochemical cycles and feedbacks; specific biological and ecological tipping points beyond which irreversible influences on species and ecosystems will occur; modeling studies in order to predict future pH and carbonate change and identify geographical areas most at risk; and the possible implications of carbon sequestration.[5]

United Kingdom:

1. UK activities currently undertaken related to ocean acidification impacts on the marine environment

1.1 Introduction

Ocean acidification (OA) is not just a decrease in pH (i.e. increase in H^+ concentration): it involves a suite of chemical reactions, driven by increasing atmospheric CO_2 as a result of human activities. Whereas there is now high scientific confidence in our knowledge of the underlying chemical processes[6], our understanding of the interactive impacts of OA on marine biodiversity, food webs, biogeochemical processes, ecosystems and human society is far less certain (Annex 1).

The UK has played a major role in bringing scientific and policy attention to OA and its implications. or example, through the Royal Society's 2005 review[7] that subsequently led to the joint Statement of Concern by over 100 National Academies[8].

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2 Orr J.C., Caldeira K., Fabry V., Gattuso J.-P., Haugan P., Lehodey P., Pantoja S., Pörtner H.-O., Riebesell U., Trull T., Hood M., Urban E., Broadgate W. (2009) Research Priorities for Ocean Acidification, report from the Second Symposium on the Ocean in a High- CO2 World, Monaco, October 6-9, 2008, convened by SCOR, IOC-UNESCO, IAEA, and IGBP, page 10.

3 Marine Institute Report, "Ocean Acidification: An Emerging Threat to our Marine Environment", page 59.

4 Raven J., Caldeira K., Elderfield H., Hoegh-Guldberg O., Liss P., Riebesell U., Shepherd J., Turley C., and Watson A. (2005): Ocean Acidification due to Increasing Atmospheric Carbon Dioxide. Policy Document 12/05. The Royal Society, London, page 49.

5 Marine Institute Report, "Ocean Acidification: An Emerging Threat to our Marine Environment", pages 60-64.

6 Gattuso, J.-P., Mach, K.J. & Morgan, G. (2012) Ocean acidification and its impacts: an expert survey. *Climatic Change* (online); doi: 10.1007/s10584-012-0591-5

7 Royal Society (2005). *Ocean acidification due to increasing atmospheric carbon dioxide*. Policy document 12/05; The Royal Society

Scientific work on OA and its impacts has been carried out by a wide range of UK research centres, university groups, governmental bodies and other organisations. In 2010, most of that effort was brought together - and much-enhanced - by the UK Ocean Acidification (UKOA) research programme, a £12.4m five year initiative to increase the understanding of OA processes, reduce uncertainties in predicting OA impacts, and improve relevant policy advice. These aims are being achieved by seven multi-partner research teams, an analytical laboratory, 12 research studentships and a small coordination group. In total, the programme involves ~120 researchers at 26 institutions. Strong international science connections were built into UKOA from the start, particularly with the EU European Project on Ocean Acidification (EPOCA, now completed) and the German BIOACID programme.

Such linkages have been further developed by the UK's active engagement with the international OA Reference User Group (RUG); the joint OA Working Group of the Surface Ocean-Lower Atmosphere Study (SOLAS) and the Integrated Marine Biogeochemistry and Ecosystem Research project (IMBER); the Monaco/IAEA-hosted International Coordination Centre for Ocean Acidification research (OA-ICC); and other relevant international science activities

1.2 UK research on ocean acidification impacts

For any specific component of marine ecosystems, the impacts of CO_2-driven changes in pH and seawater chemistry may be negative, positive or without significant effect. The magnitude of overall implications for ecosystem function (and hence ecosystem services) will depend on the interactions of those single-component impacts; it will also directly depend on future emission pathways[9], and the wider responses of the Earth's climate system. UK researchers, primarily through the UKOA programme, are currently investigating OA impacts in five topic areas, these are namely;

- *Impacts on upper ocean biogeochemistry.*
- *Impacts on benthic (seafloor) ecosystems.*
- *Impacts on commercially-important species and socio-economic implications.*
- *Impacts of previous ocean acidification events, on geological timescales.*
- *Regional and global modelling of impacts, including ecosystem responses and climate feedbacks.*

A fuller explanation of how these impacts are being investigated is provided at Annex 2.

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8 The Interacademy Panel Statement on Ocean Acidification (June 2009) http://royalsociety.org/policy/climate-change/reports-statements

9 Joos F, Fröliucher TL, Steinacher M & Plattner G-K (2012) Impact of climate change mitigation on ocean acidification pathways. Chapter 14 (p 272-290) In: *Ocean Acidification* (ed J-P Gattuso & L Hansson); Oxford University Press, 326 pp.

1.3 Ocean acidification observations

A primary goal of UK marine policy (consistent with wider international commitments) is to achieve healthy and biologically-diverse seas. Although OA is considered to be a 'prevailing condition' rather than a manageable descriptor within the EU statutory requirements for good environmental status[10], pH change presents a significant threat to ecosystem health that therefore requires monitoring and assessment. The UKOA programme recognised that national need, and supports a consortium (with government-funded partners) to establish systematic measurements of OA conditions in UK shelf seas and adjacent waters. A list of these organisations and summary information on their OA observation activities is provided at Annex 3.

For additional information in this topic area, see UK section in the first report of the OSPAR-ICES Study Group on Ocean Acidification (*in preparation*). The UK is also contributing to the development of the Global OA Observation Network, and will be hosting – with international partners – the 2nd GOA-ON workshop at St Andrews, Scotland (24-26 July 2013).

1.4 Science-to-policy links

The UK has strong 'internal' science-to-policy links, including many substantive interactions between the UKOA research community, UN bodies and other intergovernmental organisations. Additional information is given in Annex 4

1.5 UK ocean acidification activities outside the UKOA programme

There is also relevant scientific work supported in other ways, primarily as follows:

- UK involvement in the EU FP7 Mediterranean Sea Acidification in a Changing Climate (MedSeA) programme; http://medsea-project.eu. Includes field mesocosm experiments and investigation of subsea CO_2 vent systems. Two UK partners: Plymouth Marine Laboratory and University of Plymouth.

- Additional government-funded OA research by Cefas (Lowestoft and Weymouth) and Marine Scotland Science (Aberdeen). Work at the former includes interactions between pH andmetal toxicity; impacts on disease progression; impacts on commercial species (scallops and flatfish). Between 2009 and 2010 Defra's Chief Scientist funded Cefas to participate in the 'TRANSACID' initiative. This project was aimed at building collaborative relationships between fishery scientists in the UK, USA and Canada.

- Additional OA research in universities, mostly funded by NERC through Research Studentships, Research Fellowships and Research Grants.

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[10] EU Marine Strategy Framework Directive, adopted 2008. See http://ec.europa.eu/environment/water/marine/ges.htm

2. OA issues requiring further consideration, with emphasis on areas where inter-governmental and inter-agency coordination and cooperation could be enhanced

2.1 Strengthened research coordination, cooperation and capacity building

Although based in marine chemistry, OA is an inherently multi/interdisciplinary research problem, covering a large number of fields. Thus it involves observational, experimental, palaeo- and modelling studies – linking interactions of processes that are physico-chemical, physiological/behavioural, genetic, ecological, biogeochemical and socio-economic. Major knowledge gaps in these areas are identified in Table 1, in the context of the scientific and policy-relevant uncertainties given in Annex 1.

Table 1. *Some key research issues in ocean acidification – that are best investigated in an interdisciplinary and international framework.*

OA topic area	Research question(s)
Physico-chemical processes	What is the current variability of ocean carbonate chemistry at ecologically-significant temporal and spatial scales? How will this change in future under climate change scenarios, with associated changes in temperature, ocean circulation and river inputs? Which areas of the world (e.g. polar regions, upwelling zones, shelf seas) will experience greatest and most rapid change?
Physiological and behavioural processes	What are the unifying mechanisms linking species' molecular, metabolic and behavioural responses to ocean acidification? (e.g. based on energy metabolism and internal acid-base regulation). Do such mechanisms help understand high taxonomic variability - and complex interactions with other stressors (e.g. temperature, low oxygen and food/nutrient availability)?
Genetic processes	How can information from relatively short-term studies (weeks to months) on individuals be applied to longterm (decadal), multi-generational responses by populations, involving adaptation and evolution? Does genetic variation give population resilience?
Ecological processes	How can experimental studies on OA impacts be best scaled-up to ecosystem functions, delivered by interacting multi-species communities subject to other environmental changes ? i.e. allowing for multi-stressor effects, and recognising that negative (or positive) impacts of OA on one species may indirectly benefit (or disadvantage) another.
Biogeochemical processes	Will future OA provide significant feedback to the global carbon cycle and climate change, through global-scale changes in calcification, particle sinking in the ocean, and effects on other climatically-active gases, eg DMS and N_2O?
Socio-economic	What will be the future socio-economic impacts arising from ocean acidification? How best can we quantify the risks to non-market ecosystem

processes	services (e.g. tropical coral reefs) as well as to aquaculture and fisheries? How can ocean acidification science best contribute to risk management, the sustainable use of natural resources and national/international policy development?

In most countries, such research is funded by many different routes, and it can be difficult to achieve the necessary connections between different disciplines. There is also risk of inefficient overlap or duplication of effort between countries, rather than cost-effective complementarity. To minimise the former and maximise the latter, the International Centre for Ocean Acidification Research (OA-ICC) was established in 2012 under the auspices of the International Atomic Energy Authority (IAEA) in Monaco, with wide recognition by governments and international science bodies.

The primary role of the OA-ICC is to stimulate OA research coordination, collaboration and information exchange. But it is also envisaged that the OA-ICC will provide the international focus for capacity building, e.g. through short training courses, whilst also promoting efficient linkages between national OA research communities and the wide range of international/intergovernmental bodies with OA interests, as identified Annex 4..

The UK provides formal support for the OA-ICC and encourages other countries and bodies[11] to do the same, as appropriate to their interests and resources, in order that it might carry out these much-needed functions.

2.2 Development of global and regional networks for ocean acidification observations

Making OA measurements at the national level is a necessary first step in providing information to policy-makers and wider public on OA status, its implications for ecosystem health, ecosystem services and Earth system feedbacks. But it is only the first step: a structured international system is also needed since:

- Local impacts are driven by global change in atmospheric chemistry; worldwide integration and synthesis are therefore fundamental to understanding the underlying processes
- Development and testing of predictive skills requires data at appropriate scales, nesting local observations within global context
- Internationally-agreed protocols help to ensure data quality and comparability, hence synthesing information in order to derive knowledge and understanding
- An international approach identifies gaps in global coverage, that might be in particularly vulnerable or ecologically- important areas (e.g. the tropical coastal zone, and polar regions), that risk being neglected by a nationally-focussed observational effort by countries with well-developed OA expertise.

[11] The OA-ICC is currently supported by Australia, China, France, Italy, Monaco, New Zealand, Spain, UK and USA; also by IAEA, IMBER and SOLAS

As noted under1.3 above, initiatives are underway to establish both a global OA observation network and at least one regional component (for the North Atlantic). The International Ocean Carbon Coordination Project (IOCCP) and the Global Ocean Observing System (GOOS) have played a leading role in stimulating the development of the global network, and OSPAR and ICES for the North Atlantic network. That parentage is important not only to give the developing networks scientific and political credibility, but also to enable them to build on existing relevant measurements and data synthesis systems (e.g. the Surface Ocean CO_2 Atlas, SOCAT).

Over sixty participants from 23 countries[12] have been involved to date in the global OA observation network. Their future involvement needs to be encouraged and facilitated at the intergovernmental level, and additional participation stimulated.

2.3 Reducing the problem: policy implications

Ocean acidification and climate change are very closely linked, since both are caused by the accumulation of CO_2 in the atmosphere due to human activities. However, ocean acidification is often perceived as a symptom of climate change, rather than as a significant, additional problem – that warrants significant, additional attention[13,14]. Whilst the global economic consequences of OA may not be as severe as for unconstrained climate change[15], we may already be as close to a 'dangerous' pH decrease, if not closer[16] , as we are to 'dangerous' increases in global temperature. Thus there is urgent need for intergovernmental bodies, such as UNFCC, to consider what OA-specific mitigation and adaptation measures to be developed, alongside other mechanisms and efforts.

The role of UNCLOS in this area requires further discussion. A specific issue is whether anthropogenic CO_2 uptake by the ocean and its subsequent acidification should be considered as a "pollution of the marine environment" under UNCLOS Article 1 "the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities".

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12 Australia, Bermuda, Canada, China, Chile,, France Germany, Iceland, India, Israel, Italy, Japan, Mexico, New Zealand, Norway, Poland, South Africa, South Korea, Sweden, Taiwan, UK, USA and Venezuala.

13 Harrould-Kolieb ER & Herr D (2011) Ocean acidification and climate change: synergies and challenges of addressing both under the UNFCCC. *Climate Policy* 12, 378-389.

14 Kim RE (2012) Is a new multilateral environmental agreement on ocean acidification necessary? Review of European Community and International Law (RECIEL) 21, 243-258

15 *Turn Down The Heat – Why a 4 degree warmer world must be avoided* (November 2012). Report to the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics; http://climatechange.worldbank.org/content/climate-change-report-warns-dramatically-warmer-world-century

16 Veron JEN, Hoegh-Guldberg O, Lenton TM, Lough JM, Obura DO, Pearce-Kelley P, Sheppard CRC, Spalding M, Stafford-Smith MG & Rogers AD (2009). The coral reef crisis: the critical importance of <350 ppm CO_2. *Marine Pollution Bulletin,* 58, 1428-1436; doi: 10.1016/j.marpolbul.2009.09.009.

Whichever intergovernmental body takes the lead role for addressing OA, there is widespread scientific and policy recognition that the following policy measures are necessary to reduce its impacts:

- *Mitigation*, primarily by rapid, global-scale reductions in CO_2 emissions (rather than for greenhouse gases in general), together with some potential for local reduction in anthropogenic sources of acidification[17]

- *Adaptation* to improve resilience of ocean ecosystems and species to OA impacts, primarily by reduction of other environmental pressures (e.g. marine pollution and overfishing).

A third approach, climate geoengineering, has also been proposed. Whilst some 'enhanced weathering' techniques may be theoretically capable of directly countering acidification[18], their feasibility (even for local deployment) has yet to be demonstrated - and their acceptability is likely to be problematic. Other geoengineering techniques have only limited effectiveness in countering OA[19], and are unlikely to provide a viable policy option.

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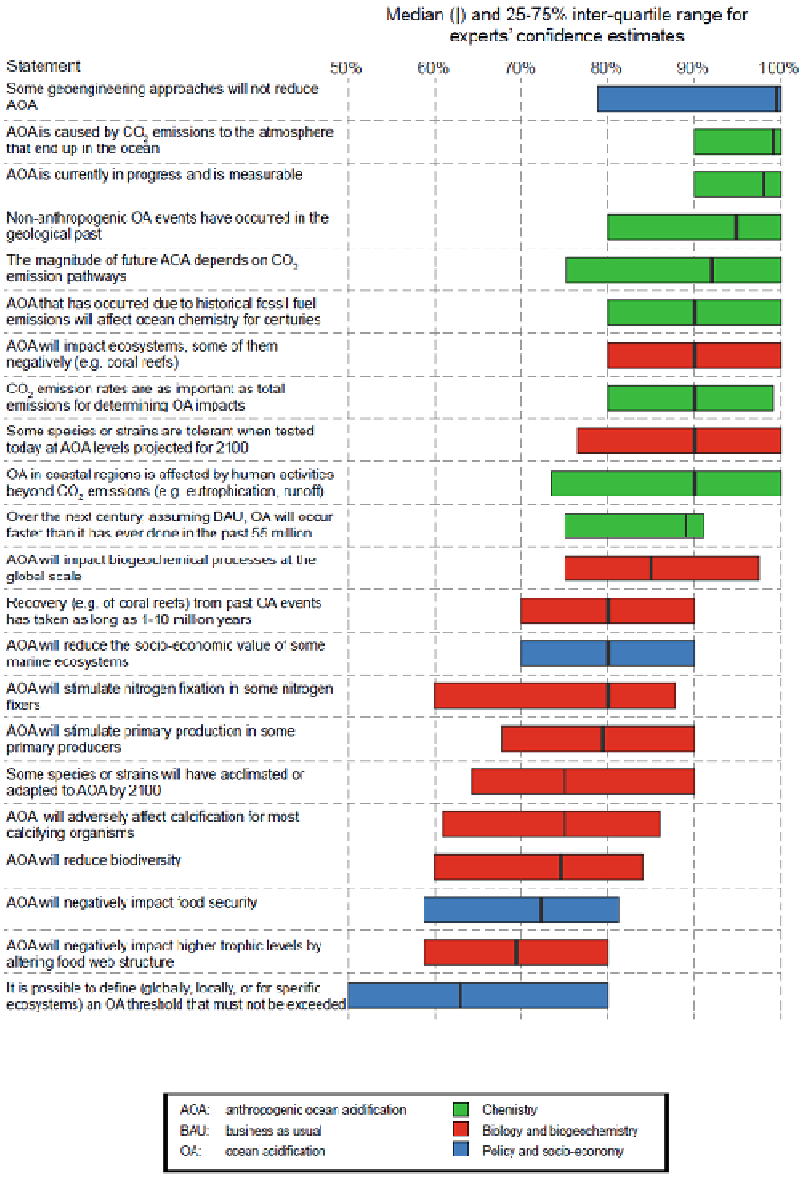
17 Kelly RP, Foley MM, Fisher WS, Feely RA, Halpern BS, Waldbusser GG & Calwell MR (2011) Mitigating local causes of ocean acidification with existing laws. *Science* 332:1036-1037; doi: 10.1126/science.1203815.

18 Köhler P, Abrams JF, Völker C, Hauck J & Wolf-Gladrow DA (2013) Geoengineering impact of open ocean dissolution of olivine on atmospheric CO2, surface ocean pH and marine biology. *Environmental Research Letters*, 8, 014009 (9pp); doi 10.1088/1748-9326/8/1/014009

19 Williamson P & TurleyC (2012) Ocean acidification in a geoengineering context. *Philosophical Transactions of the Royal Society. A,* 370, 4317-4342; doi: 10.1098/rsta.2012.0167

Annex 1. Summary of confidence in statements on ocean acidification and its impacts by experts (n = 53); data from Gattuso et al[20] with sequence re-arranged by Williamson et al[21] in order of median confidence estimates. Colour coding relates to topic area; see key below.



20 Gattuso, J.-P., Mach, K.J. & Morgan, G. (2012) Ocean acidification and its impacts: an expert survey. Climatic Change (online); doi: 10.1007/s10584-012-0591-5,

21 Williamson P, Turley C, Brownlee C, Findlay HS, Ridgwell A, Schmidt DN, Blackford J & Tyrrell T (2013) Ocean Acidification. In Annual report Card 2013 of the Marine Climate Change Impacts Partnership (in press).

Annex 2. UK research on ocean acidification impacts

- *Impacts on upper ocean biogeochemistry.* The UKOA sea surface consortium is quantifying the responses of bacteria, phytoplankton and zooplankton to present-day variability in the carbonate chemistry of the upper ocean and their sensitivity/tolerance to more extreme, future conditions. Research is field-based, with measurements and experiments on research cruises in UK shelf seas (2011), the North East Atlantic and Arctic Ocean (2012), and the Southern Ocean (2013). In a closely-linked study, pteropods (planktonic sea snails) have been found to be already adversely affected by high CO_2/low pH in upwelling Antarctic waters[22].

- *Impacts on benthic (seafloor) ecosystems.* Benthic organisms with calcified shells or exoskeletons (such as molluscs, crustacea, echinoderms, cold-water corals and crustose algae) have been found to be particularly vulnerable to OA[23,24]; such groups are also of high ecological importance. UKOA experiments have recently been completed on the longterm (18 months) effects of pH decrease and warming not only on calcifying macro-invertebrate species, but also sediment bacteria, micro-algae and foraminifera. Results from these studies will be used in models to predict the impact of future CO_2 scenarios on temperate benthic biodiversity, and its functional role in coastal and shelf-sea habitats.

- *Impacts on commercially-important species and socio-economic implications.* UKOA researchers are investigating the potential impacts of OA and temperature on the growth and survival of juvenile stages of exploited finfish and shellfish. Species selected include herring *Clupea harengus*, scampi/langoustine *Nephrops norvegicus*, and the Pacific oyster *Crassostrea gigas*. The likely consequences of OA-driven changes for a wider range of socio-economically important marine organisms and marine ecosystem services are also being assessed. In 2010 Cefas scientists worked to examine the economic consequences of ocean acidification for UK shellfish fisheries and aquaculture, a key component of the UK Climate Change Risk Assessment (CCRA) and a statutory requirement under the 2008 UK Climate Change Act.

- *Impacts of previous ocean acidification events, on geological timescales.* Relatively rapid OA has occurred in the geological past, in response to natural increases in atmospheric CO_2; e.g. during the Paleocene-Eocene thermal maximum, ~55 million years ago. Using marine micro-fossils, the biotic response to such events is being investigated both directly (speciation, extinction, migration, malformation etc) and indirectly (ecosystem function, biogeochemical

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22 Bednaršek N et al (2012) Extensive dissolution of live pteropods in the Southern Ocean. *Nature Geoscience*, 5, 881-885

23 Wicks LC & Roberts JM (2012) Benthic invertebrates in a high CO_2 world. *Oceanography & Marine Biology Annual Review,* 50, 127-188

24 Andersson AJ, Mackenzie FT & Gattuso J-P (2012) Effects of ocean acidification on benthic processes, organisms, and ecosystems. Chapter 7 (p 122-153) in *Ocean Acidification* (ed J-P Gattuso & L Hansson); OUP, 326 pp.

cycles). Comparisons with modern species' growth responses to environmental conditions[25] provide additional insights into the processes involved.

- *Regional and global modelling of impacts, including ecosystem responses and climate feedbacks.* Predicting future OA states for regional shelf seas is not straightforward, since the carbonate chemistry system is tightly coupled with the very strong physical and biological dynamics. As a result there can be high horizontal, vertical and temporal variability in pH and carbonate saturation (Ω) over a wide range of scales. A UKOA-supported modelling group is focussing effort on two regions: the shelf seas around the UK and northwest Europe (that have high resource relevance), and the Arctic (at early risk of major changes, with global-scale implications). A second UKOA modelling group is investigating global-scale biogeochemical impacts, including feedbacks to the global carbon cycle.

For additional details on the science content of the UKOA programme, see www.oceanacidification.org.uk.

Annex 3. UK ocean acidification observations

Measurements of ocean acidification parameters are currently being made by the following bodies and organisations:

- *Centre for Environment, Fisheries and Aquaculture Science (Cefas).* Time series stations for OA, based on TA (total alkalinity) and DIC (dissolved inorganic carbon) analyses of discrete water samples, were established in 2010 at SmartBuoy sites in the southern North Sea (Warp, West Gabbard and Dowsing). Additional spatial coverage in the North Sea, Channel, Celtic Sea, Irish Sea and Liverpool Bay was also started in 2010, with water samples collected on annual fisheries and other environmental monitoring cruises. Sediment cores were taken in summer 2011 and early 2012 at 30 North Sea stations to provide baseline pH data (currently lacking) for natural sediments. An underway pCO_2 system was installed on RV *Cefas Endeavour* in January 2012, and has delivered a full year of data. A detailed proposal has now been submitted to Defra (in February 2013) that would enable continuation of water-column monitoring (pCO_2, DIC, TA) in UK territorial waters for a further three years.

- *Marine Scotland Science (MSS).* A 5-year, baseline OA monitoring programme was started in 2012, based on TA and DIC analyses of water samples. Such samples are taken weekly from Stonehaven (3 km offshore; ~20 km S of Aberdeen), and biannually from standard hydrographic lines in the Faroe-Shetland channel and between Orkney and Shetland. In addition, MSS has recently installed an underway pCO_2 system for its research and survey vessel, MRV *Scotia*, to provide (from early 2013) large-scale surface data for Scottish waters.

[25] Gibbs SJ et al (2013) Species-specific growth response of coccolithophores to Palaeocene-Eocene environmental change. *Nature Geoscience* (online) doi: 10.1038/ngeo1719 *[Citation 'in confidence' until publication, due 3 February*]

- *UK Integrated Marine Observation Network (UK-IMON).* Closely-linked to the above Cefas and MSS work and also involving the Agri-Food and Biosciences Institute (AFBI) Northern Ireland, discrete samples for carbonate chemistry analyses will be collected in 2013 from an Ullapool-Stornaway transect route, the North-West Irish Sea Mooring, and two Cefas SmartBuoys (Celtic Deep and Liverpool Bay). This work is a Defra-funded pilot study for UK-IMON.

- *University of East Anglia (UEA).* With EU funding from Carboocean and CarboChange, and national funding from UKOA and other sources, UEA researchers have deployed underway sampling systems on commercial vessels to obtain North Atlantic data on pCO_2 and related variables continuously since 2002, with earlier data from the 1990s. A new NERC-funded project, RAGNARoCC (Radiatively active gases from the North Atlantic region and climate change) will support these measurements from July 2013 to June 2015.

- *National Oceanography Centre (NOC) Southampton*. Work on OA observations includes: i) pCO_2 measurements at the Porcupine Abyssal Plain (PAP) monitoring site since 2005 using moored sensors, with additional annual *DIC and TA determinations since 2008; ii)* underway measurement system on a Swire Group ship to obtain global pCO_2 data, with additional sampling by the ship's crew; and iii) annual collection of carbonate chemistry data since 2008 on an ocean section between Oban, Rockall and Iceland (the "extended Ellett Line"), jointly with the Scottish Marine Institute.

- *Plymouth Marine Laboratory (PML).* Work on OA observations includes: i) carbonate chemistry measurements at the Western Channel Observatory, south of Plymouth, with other biogeochemical and biological parameters (pCO_2 data since 2005, with additional analyses since 2008); ii) underway pCO_2 sampling from NERC research vessels (RRS *Discovery, James Cook* and *James Clark Ross*) and two inshore vessels (RV *Prince Madog* and *Plymouth Quest*). The main dataset arising from (ii) is the *annual Atlantic Meridional Transect (AMT) survey.*

Annex 4. UK involvement in intergovernmental activities relating to ocean acidification

Interactions between the UK research community, UN bodies and other intergovernmental organisations are summarised below.

- *Intergovernmental Panel on Climate Change (IPCC):* UK chapter co-authorship on OA in 4th Assessment Report[26], with increased involvement in the more detailed review in 5th Assessment Report (in preparation)

[26] Fischlin A, Midgley GF, Price JT, Leemans R, Gopal B, Turley C**,** Rounsevell MDA, Dube OP, J. Tarazona J & Velichko AA (2007) Ecosystems, their properties, goods, and services. In:*Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Eds ML Parry, OF Canziani, JP Palutikof, PJ van der Linden & CE Hanson)., Cambridge University Press, Cambridge, p 211-272.

- *UN Framework Convention on Climate Change (UNFCCC)*: lead role in OA-related side-events and awareness-raising exhibits at UNFCCC COPs in 2009, 2010, 2011 and 2012; OA presentation at preparatory Science Workshop in 2011

- Intergovernmental Oceanographic Commission (IOC) of UNESCO: input to "Blueprint for Ocean and Coastal Sustainability"[27] (IOC/UNESCO, IMO, FAO and UNDP); work with IOC's International Ocean Carbon Coordination Project (IOCCP) and Global Ocean Observing System (GOOS), including UK chairing of Surface Ocean Carbon Atlas (SOCAT); contributions to other OA-relevant IOC activities

- *UN Environment Programme (UNEP):* UK authorship of "Environmental consequence of ocean acidification: a threat to food security" (UNEP Emerging Issues Bulletin, 2010)[28]

- *UN Conference on Sustainable Development (Rio +20)*: major inputs to OA-related side events and Parties' contributions to conference outcomes "The Future we Want"[29] and "The Oceans Compact"[30]

- *Convention on Biological Diversity (CBD):* involvement in 2009 review of OA impacts[31]; co-chairing of 2011 CBD Expert Meeting on OA; planned substantive role in 2013/14 OA synthesis report

- *Oslo-Paris Convention (OSPAR)* and *International Council for the Exploration of the Seas (ICES):* input re OA to OSPAR Quality Status Report (2010) and subsequent OA-related discussions at OSPAR Coordination Group; strong UK participation in Working Group to coordinate OA monitoring and assessment in North Atlantic, including recommended protocols for pH and carbonate chemistry measurements.

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27 www.unesco.og/new/en/rio20; Objective 1a is to "implement urgent actions to mitigate and adapt to ocean acidification".

28 www.unep.org/dewa/Portals/67/pdf/Ocean_Acidification.pdf

29 www.un.org/en/sustainablefuture; Para 166 of "The Future we Want" specifically calls for support of OA-related initiatives;

30 www.un.org/Depts/los/ocean_compact/SGs%20OCEAN%20COMPACT%202012-EN-low%20res.pdf

31 Secretariat of the Convention on Biological Diversity (2009) *Scientific Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity.* CBD Montreal, Technical Series no 46, 61 pp.