Proposal for a SCOR Working Group:

Response of marine biota to complex global environmental change: co-ordination and harmonization of experimental approaches

Abstract

All climate models project concurrent changes to multiple oceanic properties, due to the effects of anthropogenic climate change, in the coming decades. There is also a growing body of evidence from ocean observatories to support model predictions of simultaneous modification of temperature, CO_2/pH, O_2, nutrients and irradiance. Hence, a major and urgent challenge for the ocean science community is to establish how widespread alteration of oceanic conditions will manifest itself as cumulative environmental stress on ocean biota and ecosystems. This challenge is multi-faceted as it will test our abilities ranging from conceptualization/modeling of how a changing ocean will alter the physiology and ecology of the biota, to how to design and conduct manipulation experiments to mimic such ongoing and complex shifts in the oceanic environment. This challenge is further compounded by forcing individual scientists to consider a major dilemma – *the need as an ocean science community to collectively make sense of the next decade of global environmental research requires co-ordination and harmonization (as opposed to standardization) of experimental approaches, yet such co-ordination may be seen as violating a fundamental right for researchers to conduct independently planned research based on the need to address very specific questions.*

Experiments investigating how biota will respond to environmental manipulation have, until recently, mainly focused on the perturbation of a sole oceanic property such as iron or pH. Such relatively 'simple' studies have revealed a wide range of responses to perturbations. Subsequent analysis of these experiments has uncovered a wide range of protocols *such that the reason(s) for the experimental outcome could be the environmental manipulation but also the adopted protocol and/or incubation apparatus.* Increasingly, investigators are conducting experiments in which multiple properties are altered – to mimic model projections of complex environmental change. For example, in 2012, 1/3 of the 225 papers which reported a biological response to Ocean Acidification (OA) also manipulated at least one other property. The challenges associated with conducting more complex manipulation experiments are technological but also relate to experimental design (replication vs. regression approach, pseudo-replication, number of treatments etc.). We have learnt much from the last decade of OA studies. Perhaps most importantly, that there is a real danger that unless a group of experts provides leadership in raising awareness about this "Co-ordination dilemma", followed by clear guidance on the issues surrounding implementation of best practices and experimental approaches, the international research community will generate a divergent and disparate range of datasets in the coming decade. Such datasets are time-consuming and expensive to produce, yet they will potentially make data synthesis and interpretation extremely difficult, possibly leaving our understanding no further along.

This SCOR Working Group will tackle this pressing issue of co-ordination and harmonization of experimental approaches head on by:

a) Publicizing - the issues surrounding a lack of co-ordination/harmonization of experimental approaches to the effects of complex environmental change on biota.

b) Gauging the wide range of opinions across our research community to the "Co-ordination dilemma' using questionnaires and complex-decision making software to assess the weighting that scientists give to these issues. This is essential prior to the WG planning workshops to continue this debate.

c) Conversing with the climate change modeling community to assemble the best estimates of a complex matrix of environmental change, to help explore the co-ordination of experimental approaches – how will each individual property change and at what rate.
d) Communicating with experimental evolutionary biologists to gauge how acclimation times, to altered oceanic conditions, will impact the outcome of the manipulation experiment, to assist the debate around co-ordination and harmonization of experimental approaches.
e) Discussing with engineers, chemical engineers, chemists (carbonate, trace metal), bio- statisticians, the issues surrounding the design of robust incubation systems that can be mass-produced but also customized for specialized experiments – for example in polar waters, and which provide replication of treatments.
f) Using outcomes a) to d) to build on the seminal advance, of publishing a Best Practices Guide (BPG) to OA Research (Riebesell et al., 2010), to produce a new format of BPG's that take into account: changes to multiple oceanic properties; acclimation of different organisms to a range of altered conditions; and critically a recommended suite of incubation systems to be paired with the BPG approach.

Rationale / Background
The recent SCOR-sponsored "Ocean in a high CO_2 world" provided two compelling datasets. Firstly, Sarah Cooley (Woods Hole Oceanographic Institution, USA) reproduced a talk at this meeting as an article (Cooley, 2012) revealing that increasingly investigators are designing and running multi-property perturbation experiments, for example pH and temperature manipulations. The second dataset was a collation, shown at the meeting, which revealed that despite the publication of the OA BPG (already cited ~100 times) some researchers continue to use a disparate range of CO_2 concentrations in perturbation experiments (Figure 1). There are certainly valid reasons for choosing different [CO_2] for different experiments; for instance, those examining 100-year projections will differ from others examining shorter or longer timescales, and incubations with organisms from CO_2-enriched upwelling zones necessarily employ different conditions from those testing biota from the central gyres. <u>It is, however, important to ensure that experiments simulating these different scenarios are internally consistent and comparable.</u>

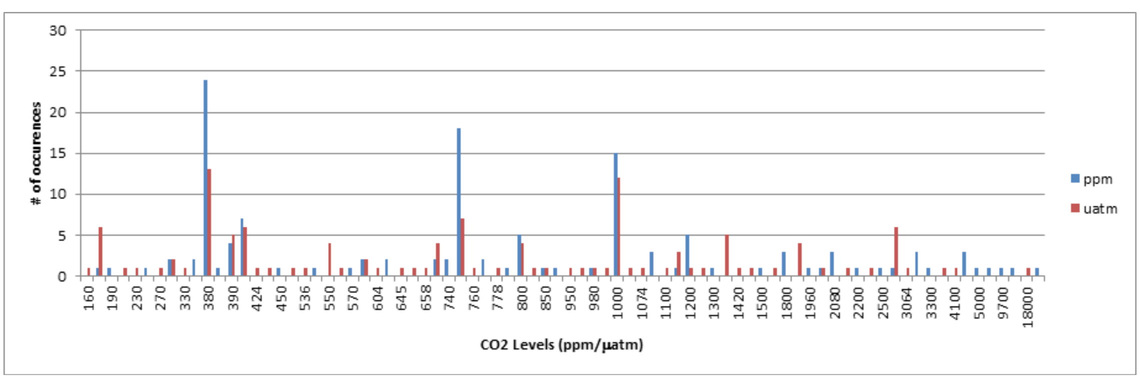

Figure 1 Summary of CO_2 concentrations used by researchers in recent OA manipulation studies.

Together, these two pieces of evidence provide a glimpse of both ongoing research trends, but also of where the rapidly evolving research field of global change biology is headed in the coming decade. It requires little imagination to picture that 10 years hence datasets could be ‘awash’ with a large number of permutations of different experimental conditions of pH, nutrients, irradiance etc. such that conducting robust analysis, meta-analysis and forming synthetic reviews of how a changing ocean will influence the biota becomes very difficult.

Gauging how the biota will respond to such altered conditions will be further confounded by labs using different acclimation times (from none to months) and a wide range of often in-house built incubation systems. There is much to learn from the seminal progress made by the “OA and biological responses” community, who foresaw this issue and published a BPG in 2010. Since then this field-leading community has advocated the deployment of multiple large-scale marine CO_2 experiments called Free Ocean CO_2 Enrichment (FOCE). Significantly, the FOCE approach enables both a mass-produced incubation system to be adopted but also one that can be customized for a particularly exacting set of environmental conditions. Thus, it provides a powerful illustrative example of a combination of a standardized basic format incubator whose accessory components can be modified as required. We believe that publicizing such an approach is a powerful way of *convincing a research community with a diverse set of views and opinions to co-ordinate and harmonize (as opposed to standardize) their research efforts such that we have a coherent intercomparable body of datasets being produced regularly over the coming decade, without the risk of alienating large parts of the research community by imposing the strictures imposed by co-ordination*. Such co-ordination will enable our community to address fundamental questions about the alteration of marine ecosystem structure and function, and any associated biogeochemical or climatic feedbacks.

Three issues must be addressed by this WG in order to explore how to produce a BPG to better address complex environmental change in the ocean.

Assembling ‘best’ estimates of a complex matrix of environmental change
Ocean ecosystems are increasingly stressed by anthropogenic alteration of their physical, chemical and biological environment. The design of experimental incubation systems and recommendations on treatments requires the assembly of regional best estimates of how multiple oceanic conditions will be altered, and at what rates, in the coming decades. Recently, the accuracy of model projections has improved considerably, in conjunction with the preparation of IPCC AR5 report. For example, Bopp et al. (2013) used the most recent simulations performed in the framework of the Coupled Model Intercomparison Project 5 to assess how several drivers will evolve during the 21st century. The ten Earth System Models predict similar trends in ocean warming, acidification, deoxygenation and reduced primary productivity for each of the IPCC’s representative concentration pathways. Furthermore, although these stressors operate globally, they display distinct regional patterns which will be considered by this WG. Studies such as these will help to address an important consideration – how to design manipulation experiments that employ variables, such as iron supply, for which future projections are highly uncertain (Boyd et al., 2010).

Incorporation of acclimation, to altered oceanic conditions, into experimental design.
In the last 2-3 years, a growing number of studies have investigated how environmental conditioning time affects organismal responses to multiple environmental drivers. Researchers are also increasingly focussing on the relative roles of environmental acclimation, plasticity and adaptation by biota over different timescales. An important task of the WG will be to initiate discussions with the experimental evolutionary biology community to gauge how conditioning times to an altered oceanic environment affect outcomes and interpretation of experiments. The field of marine experimental evolution is

still in its infancy (Collins 2011, Schaum et al., 2012, Lohbeck et al. 2013, Reusch & Boyd, 2013, Tatters et al., 2013), but there is much current interest and nascent research activity in this discipline. One challenge for the WG will be to ensure recommendations for experimental conditioning times are responsive to newly emerging information in this rapidly moving field. For example, one critical question is, how many generations should an organism be conditioned to ensure its response represents mostly physiological acclimation and not genetic adaptation, and vice versa? As with other issues discussed above, the answers will be organism- and habitat-specific. For instance, adequate conditioning times will obviously vary widely between rapidly reproducing microbes and large, slowly reproducing metazoans. The WG will undertake to help the community define realistic conditioning time parameters for a range of important marine functional groups, with the ultimate aim of facilitating inter-comparability and quantitatively modelling of acclimatization and adaptive responses to global environmental change.

The power of widespread collaboration to design and produce incubation systems.
The FOCE system provides an illustrative example of new technology under development to meet the current needs of OA researchers. FOCE is based on successful large-scale terrestrial experiments (FACE) that released CO_2 into the local atmosphere at controlled rates to expose terrestrial vegetation to elevated CO_2 levels to simulate conditions expected in the late 21st century. Studies are presently underway around the globe using regional modification of the original FOCE concept.

FOCE experiments offer ‘closed loop control’ around variables such as current velocity, mixing dynamics and pH. Collaborations between scientists and engineers have demonstrated that systems can be built, integrated, and deployed in situ to successfully obtain inter-comparable datasets (Brewer et al., 2013). Two FOCE systems have tested the extremes of environmental conditions: Deep FOCE (Figure 2a), which operated for 18 months at 900 m depth at 4 °C and the Coral Prototype FOCE (Figure 2b), deployed on the Great Barrier Reef in currents > 1 m/s, temperatures of 18-29 °C, and a tidal range of ~ 3 m.

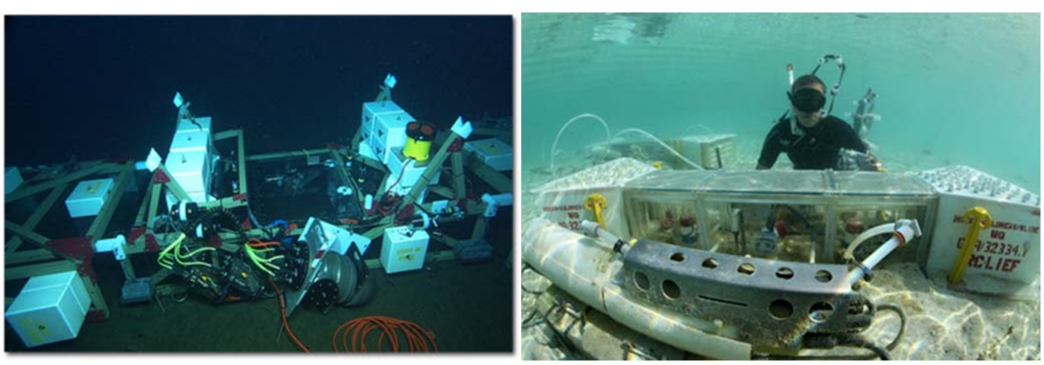

Figure 2 a) 1: dpFOCE deployed at 900 m; b) cpFOCE at Heron Island.
Although dpFOCE and cpFOCE look entirely different their underlying systems and algorithms are very similar.

FOCE experiments are particularly useful for examining longer term responses of sessile benthic organisms to altered pCO_2. Other types of incubation systems have recently been designed successfully by teams comprising chemical engineers, carbonate chemists, biologists and bio-statisticians to examine the responses of planktonic communities to climate change (Figure 3). Other commonly used incubation systems include: small-volume “batch” incubation systems, continuous culture systems, and very large (>> 1000 L) volume mesocosms. All of these systems are useful for particular applications and questions, but the selection of a combination of a range of standardised formats needs careful attention.

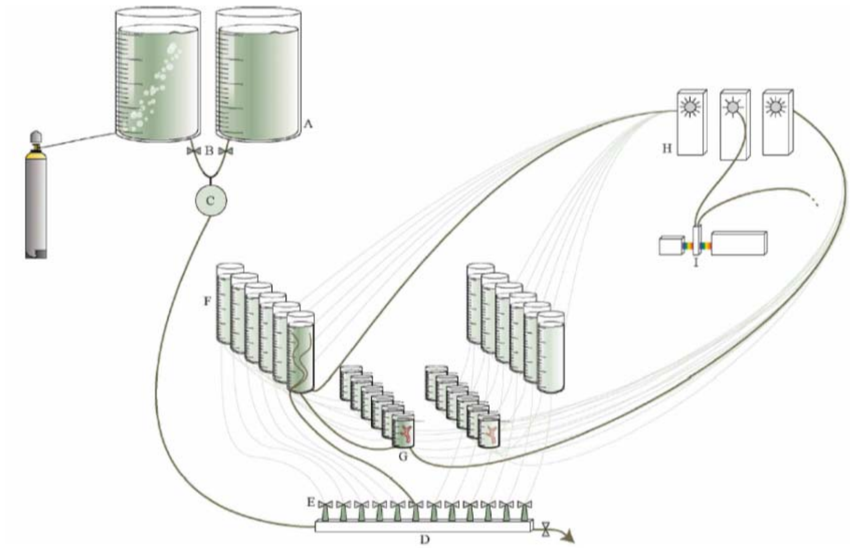

Figure 3 An example of a next-generation environmental manipulation incubator, designed an interdisciplinary team approach (McGraw et al., 2010).

Production of a new format of Best Practice Guides.
Together, the above approaches would inform the production of a BPG that critically will be linked and readily combined with a recommended incubation system(s) whose technology can be customized to meet the needs of a particular site (Figures 2 & 3).

Statement of Work/Terms of Reference

1. **Document the range of environmental conditions currently used for experiments on the effects of future global change** (pH, CO_2, temperature, salinity, light) on marine organisms.
2. **Identify problems arising from incomparable experimental conditions** in terms of statistical analysis and the ability to extrapolate research results and use in modeling.
3. **Seek the views of the ocean research community regarding the necessity for, and details of, a commonly agreed set of best practices for research on the biological effects of global changes.** The community will be canvassed through customized questionnaires (see Gattuso et al., 2013) and by developing interactive 'scripts' using complex decision-making tools to provide web-based tools on this topic (c.f. http://www.royalsociety.org.nz/expert-advice/information-papers/yr2011/geo-engineering-an-interactive-workshop/).
4. **Interact with the global modeling community to determine the experimental datasets most needed by climate modelers** and engage with ongoing efforts like Stanford University's Center for Ocean Solutions (www.centerforoceansolutions.org/).
5. **Communicate the findings of the activity to the scientific community through special sessions at scientific meetings and publication.** a) Organize at least two sessions at AGU and EGU meetings on the issue of co-ordination and harmonization

of experimental approaches to investigate the impact of climate change. Additionally, incorporate this theme as a session for future “Ocean in a High- CO_2 World” meetings; b) Publicize the growing complexity of global environmental change, and the need for a co-ordinated plan to guide manipulation experiments in the coming decade by communication in a popular science journal; c) Run a workshop with key experts/authors to discuss and plan the format of a BPG needed to cover a broad range of topics such as projected environmental changes, to scientific and technical issues, benthic and pelagic communities, acclimation and adaptation, biostatistics, data management. Incorporate this workshop to either precede or follow a future “Ocean in a High-CO_2 World” meeting. Note, partial financial support for such a workshop has already been secured from the OA International Coordination Centre.

Additional modes of communication will include the preparation of: a simple and short co-ordination plan - to be circulated to the environmental science and wider community - as a glossy poster/report card for manipulation experiments in the coming decade; a detailed web-based co-ordination plan - combining BPG’s and recommended incubation systems.

6. **Ensure capacity building through**: support for efforts like xFOCE which maintain open source access to the required knowledge base and techniques (www.xFOCE.org); stimulation of a new generation of researchers who are aware of the role, and drawbacks, of the co-ordination and harmonization of approaches as a metric of quality assurance; use of the BPG as a capacity building tool.

WG Meetings

WG meetings will be run in conjunction with a funded Gordon Research Conference (on Ocean Global Change Biology) in mid 2014 and 2016 meetings, and/or other venues such as American Geophysical Union Ocean Sciences, and/or European Geophysical Union to keep costs down for travel etc.

Working Group Membership

Boyd will chair the WG in year 1 if the proposal is successful, Hutchins and Gattuso will be co-chairs, and the position of chair will be circulated each year.

Philip Boyd (Australia), marine experimental manipulations.
David Hutchins (USA), global environmental change and marine biota.
Jean-Pierre Gattuso (France), ocean acidification.
Bill Kirkwood (USA), engineering solutions for researchers.
Christina McGraw (Australia), Chemical engineering solutions for biologists.
Peter O. Zavialov (Russia) ocean physics and climate change.
Sinead Collins (UK) Experimental evolutionary biology.
Marcello Vichi (Italy) Climate modelling.
Jorge Navarro (Chile) Environmental drivers on higher trophic levels.
Kunshan Gao (China) Marine photosynthesis and climate change.

Associate members
Peter Brewer (USA) Carbonate chemistry, OA, FOCE.
Graham Bell (Canada) Evolutionary rescue and climate change.
Gorann Nilsson (Norway) Fish and climate change.
Malcolm Marker (Australia) Engineering solutions for researchers.

Haruko Kurihara (Japan) Environmental impact assessment and marine ecosystems.
Laurent Bopp (France) Climate modelling.
Peter Dilligham (Australia) Bio-statistics.
John Havenhand (Sweden) Biostatistics and OA studies.
Catriona Hurd (Australia) hydrodynamics and experimental design.
Ulf Riebesell (Germany) Global environmental change and marine biota.

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