Where next with the science of ocean acidification?

Farmed scallops at threat from ocean acidification, Chile. Photo credit: Nelson Suarez

Ocean acidification first came to global attention in 2004. The last ten years of research have provided a sound basis on which to begin to understand the magnitude and diversity of effects ocean acidification may have on the ocean, its ecosystems and all those who depend on ocean resources for health, wealth, sustenance and wellbeing.

Now is an appropriate moment to reflect and consider what scientific advances are needed in the coming decade to increase our understanding of this progressive ocean problem. This is particularly relevant to recent welcome developments such as a new IPCC Special Report on the ocean and cryosphere.

This brief report presents views from a recent 2015 meeting of the Ocean Acidification international Reference User Group. It is intended to stimulate discussion over the direction and nature of research in the future, and will be annually updated between now and 2019.

Introduction

Over the last decade the science around ocean acidification has grown rapidly and results from the most recent research are changing our initial perceptions of the nature, scale and complexity of possible impacts on ocean ecosystems. This body of research has shown that rising levels of carbon dioxide (CO_2) being absorbed by the ocean are the root cause of ocean acidification, and that very many species of ecological, commercial and cultural importance are likely to be adversely impacted as a result. However, physiological responses towards ocean acidification vary greatly between marine species, and some may even be positively affected; furthermore, responses can vary over time through acclimation and multi-generational adaptation (also termed micro-evolution). Thus there remains considerable uncertainty regarding the overall impact at both species and ecosystem scales. However, what has become clear is that Earth history documents that it will take hundreds of thousands of years to restore ocean chemistry to pre-industrial conditions, and that the anthropogenic carbon perturbation currently being experienced is probably 10 times faster than at any point over the last 300 million years.

Most of the early experiments were 'short and simple' and showed a wide range of variability in design and trends in their findings. Subsequently there has been greater appreciation and acceptance of the importance of method standardisation, experimental duration, physiological condition and interactions with other factors that will concurrently be altered by ocean global change (e.g. temperature) – providing better understanding and hence improving our forecasting skill for 'real world' conditions. The number of ocean acidification publications (and hence the community of researchers involved) has increased considerably since 2008, following the Second Ocean in a High CO_2 World symposium. Research now explores the cocktail of effects caused by a changing ocean, including the potentially severe impacts ocean global change has on the ecosystems and the services they provide.

In this context the Ocean Acidification international Reference User Group (OAiRUG) met in Paris in July 2015 to take stock of research to date and look to the future. The outcomes of these discussions are set out in the following pages and explore the issue from four perspectives:

- Immediate science priorities
- Longer-term partnerships and science evolution
- Geographical priorities
- Socio-economic priorities

It is important that momentum in studying and understanding ocean acidification is not just maintained but continues to increase. This is not only so we capitalize on recent work but also in the realization that acidification impacts are already being detected in open ocean environments, affecting industries such as aquaculture and sensitive areas as varied as estuaries and open-coast upwelling systems.

Immediate science priorities

Building on scientific knowledge gained up to and including 2015, the meeting concluded that there is a need to improve data availability, demonstrating the ocean acidification effects globally. At present material used to illustrate effects of ocean acidification to inform policy makers or drive action on addressing this issue are being drawn from too few examples. Diversification is critical as ocean acidification has now been recognized with its own target under the Sustainable Development Goals: *Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels*[1].

Clearly the need to advance the underlying scientific knowledge on ocean acidification will vary depending on regional demands and capacity. The OAiRUG encourages tailored observation programmes to speak to specific societal needs. A multi-disciplinary approach, including experimental, observational, and modelling measurements is increasingly important to link experimental design to specific management goals (e.g. the measurements of pH, saturation state, biological indicators and how these relate to the information needs of differing sectors of the community or use) in ways that are societally relevant.

As part of this it is important to more frequently and comprehensively engage end users to better assess their needs whether at regional scale or from specific sectors of use. Through such a strategy demand driven science will underpin the identification of thresholds and tipping points for marine species and ecosystems, and direct further resources towards CO_2 reduction strategies. Greater engagement with the fledgling geo-engineering (i.e. climate intervention) community is critical to ensure that ocean acidification and its impacts are included when evaluating the likely efficacy and value of proposed new approaches and how these work to reduce (or not) CO_2 levels in the atmosphere (and hence prove effective steps towards addressing the root cause of ocean acidification). Thinking 'outside the box' will also be needed to work in making CO_2 reductions – not just the obvious emissions cuts but also exploring the CO_2 footprint of less obvious operations (e.g. paint production, rechargeable battery production) to see where additional reductions can be made.

It is important to think a couple moves ahead and to identify policies that will address ocean acidification or take it into account, within the context of a changing ocean. The scope of scientific research should accordingly expand to better inform societal adaptation and solutions to improve our perspective on how sustainable management of ocean resources might buy time in order to improve our assessment of risks associated with ocean acidification. Within this context, priorities include:

- Conduct long-term experiments at the species and ecosystem level to understand better how ecosystem or species provide services, and the mechanisms through which ocean acidification and other environmental stressors affect such ecosystem services.
- Place ocean acidification studies within the context of multiple stressors (e.g. oxygen, temperature, nutrients, harmful algal blooms), species' natural variability, adaptation potential, and acclimation capacity (i.e. short and long term).
- Develop and integrate chemical and biological observations to support biogeochemical (BGC) models to advise sea users and management, and better define societal needs.
- Evaluate the use and applicability of natural systems (e.g. vent sites, estuaries, etc.) as proxies (for ocean acidification) and identify "analogues" from the geological record to investigate ocean acidification and responses of the biogeochemical cycle.

[1] https://sustainabledevelopment.un.org/sdg14

Longer-term partnerships and science needs

Alongside immediate science priorities are a range of longer-term partnership and science needs. Whilst much progress has been made - on science, on collaboration (e.g. the SCOR WG on global ocean change biology and the similarly themed Gordon Conferences), on development of sensors (e.g. X-prize), on platforms from which to deploy sensors (e.g. ships and aquaculture farms), and on societal impacts - there is a critical gap that needs to be closed. This critical gap can only be closed effectively through informing and then bringing together the views and perspectives of people most at risk from ocean acidification, with data and observation systems to detect impacts, together with appropriate communication approaches so we can lever full value from previous and future investments. A greater cohesion of understanding and action is needed to align efforts toward ocean acidification assessment and response. Beyond that, better definition is then needed to the actions that those people who are most at risk from ocean acidification should be taking to mitigate its impact.

Important partnerships already exist but need to be strengthened, including intergovernmental agencies (UNESCO's International Oceanographic Commission, the International Atomic Energy Agency, the World Maritime Organization (WMO)), monitoring networks such as the Global Ocean Acidification Observing Network (GOA-ON), the Global Ocean Observing System (GOOS), maritime industries (fisheries), non-governmental organizations, and concerned and impacted citizens. Additional strategic action is needed to better grow regional partnerships (place-based, but connected to global effort), sector-specific partnerships, and to regularly update the overall transdisciplinary story on ocean acidification impacts, risks and understanding. It will be as important to engage the ocean business community in ocean acidification monitoring – for example common-cause investigations with the carbon capture and storage community, as it will be to increasingly engage journalists about how the unfolding story around ocean acidification can be highlighted and told, without waiting for major periodic global events such as COP21.

The evolution of scientific knowledge to provide answers to society, industries and politicians greatly depends on sustained research programmes and partnerships to carry that on. Integrated science requires partnerships to address, *inter alia:* inter-comparison of experimental approaches, ecosystem responses, conceptual and mathematical modelling, socio-economics, and coupled biogeochemical-physical observations that inform and improve model projections.

Priorities include:

- Focus at the national level on integrative strategies for preventing and preparing for ocean acidification impacts (e.g. integrating ocean acidification science into fishery and environmental monitoring, include ocean acidification sensors on industrial shipping fleets – 'ships of opportunity', and international collaboration around issues such as coral tourism). The International Atomic Energy Agency's Ocean Acidification International Coordination Centre has a key role to play here in fostering such approaches and enabling information transfer.
- Focus on developing observing systems that enable regional projections in the short- (days to months) and long- (years to decades) term to address socio-economic issues and pressures. This requires partnerships that integrate local with global scales in an inter-operable fashion. There is already a good basis to do this by building on partnerships with GOOS, GOA-ON, WMO, Group on Earth Observation (GEO), etc., and working to implement a global network of regional efforts.
- Coordinated citizen science offers the opportunity for mobilizing a workforce and engaging the public, but there remains quality assurance and infrastructure issues that need to be resolved. At the moment biological rather than chemical monitoring is better suited to this approach. The main challenge is in identifying the most appropriate questions for citizen scientists to effectively

address and involve parties such as recreational fishers, scuba divers or other similar focused, organized groups.

- Ongoing re-evaluation of whether current efforts really address the questions being asked. This is true both for within science and between science and policy. Ensuring that scientific efforts address trans-disciplinary issues with links to the climate policy community.
- Investigate how ocean acidification impacts may affect human food supply chains from providers through industry to end consumers.
- Showcase how partnerships (e.g. the NW U.S. shellfish industry) can affect industry and decision-makers' behaviour and policy.
- Evaluate how to strategically invest in ocean observing systems, coupled with modelling development and simulations, in order to close knowledge gaps.
- As scientific knowledge and understanding grows and evolves, the need to maintain a strong focus on finding solutions (adaptation, mitigation) is paramount. It will also be critical to assure linkages that inform and engage managers and decision makers in such efforts.

Geographical priorities

The future geographical installation of industrial/economic investments will partly depend on the knowledge about the expected nature and scale of impacts from ocean acidification. This requires identification of regions in which the biota is most susceptible to ocean acidification, not just where ocean acidification effects will be largest

Ocean acidification will impact everyone, BUT there is a critical need for greater regional and even local emphasis to:

- Obtain greater diversity of case studies, including local socio-economic values and costs, especially where dependency on services provided by ocean ecosystems is particularly high.
- Gather/document local information on suspected vulnerabilities, threats and impacts to help focus and drive future scientific scrutiny and research priorities.
- Provide guidance for engagement and capacity building and for practical support (e.g. funding, partnering, scientific exchanges) from academia, industry and citizens.

Bodies such as the OAiRUG can play a useful facilitative and catalytic role in a strategic and opportunistic way, helping identify priority areas for monitoring and perhaps 'piggy-backing' on other regional initiatives and events (UN Regional Seas, International Maritime Organization, etc.). Working alongside the International Coordination Centre on Ocean Acidification hosted by the IAEA in Monaco and in concert with the IOC-UNESCO there is great potential to continue and expand regional efforts to develop capacity and understanding.

Socio-economic priorities

Equally critical for the future development are the socio-economic implications of ocean acidification. Solutions for one problem may be very different depending on the geographical and political setting of the issue concerned. So for example, whilst intake seawater treatment may provide a (temporary) reprieve for in-tank oyster hatcheries in NW USA, the same problem will need very different solutions for say the scallop industry in Chile that occurs in coastal waters. Thus the priorities will vary geographically and even within the same broad category of impact.

Much more thinking and work is required in this area to better link science to socio-economic priorities. Often science has been brought in 'after the event' to explain socio-economic impacts that have been experienced. Getting ahead of the curve in the future will be a key objective to be achieved, so that solutions can be found through collaborative multi-stakeholder processes. Working towards such a goal, some immediate priorities become evident:

Undertake vulnerability assessments.

- Determine which areas, resources, economic activities and communities globally are most at risk from ocean acidification, including in relation to food security, unrest, migration.

Document, understand, communicate and improve social adaptation.

- Assess the local and regional capacity to adapt to ocean acidification.
- Document what people, societies, industry are doing/can do to adapt, e.g. industries monitoring sea water and adjusting practices in response to their concerns.
- Identify the choices that have win-win benefits and have science define whether these choices make a difference (and avoid 'mal-adaptation').
- Communicate what people need to know in order to adapt, to increase and maintain the natural resilience of marine ecosystems, e.g. reduce other stressors.

Increase and improve coordination of ocean acidification communication and education.

- Worldwide.
- At the scale necessary and appropriate.

Determine the socio-economic ocean acidification messages that most resonate and why

- Develop customized messages at the appropriate scale for the targeted audience, e.g. local economic and /or cultural impacts for local politicians, national economic loss for national policy input.

Educate and communicate to vulnerable areas/communities.

- Raise awareness and understanding of ocean acidification in vulnerable areas/communities.
- Identify and cultivate socio-economic spokespeople.
- Identify and cultivate spokespeople from vulnerable communities and business sectors, i.e. other than NW US shellfish industry.
- Encourage and develop monitoring strategies in vulnerable areas.
- Develop and deploy OA monitoring networks, e.g. science, government, industry, citizens - and develop coordination/collaboration between these entities.

Raise awareness of ocean acidification with non-business ocean users, e.g. recreational fishers, scuba divers, etc.

Raise awareness of ocean acidification with other ocean industries.

- Via industry sectoral or regional events/conferences.

Engage ocean business community in OA monitoring.

- Do this as part of broader efforts to engage ocean industries in ocean observations, e.g. WOC Smart Ocean-Smart Industries programme.

Engage other key vulnerable economic sectors more thoroughly and with targeted efforts,

- Shellfish aquaculture worldwide (i.e. beyond NW shellfish) food and non-food, e.g. pearl industry.
- Coral reef resort and marine tourism industry.
- Other sub-sectors of aquaculture industry that may be vulnerable.
- Fishing industry sub-sectors that may be vulnerable.

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Online paper

Download a copy of this review and the full report at: http://www.iaea.org/ocean-acidification/page.php?page=2198

Sources and contributors

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Updating of this document

This is a 'living' document and will be updated annually by the OAi RUG. If you have text suggestions please send them to danlaffoley@btinternet.com, Chair of the OAiRUG.