DEEP-OCEAN STEWARDSHIP INITIATIVE

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Survey on minimizing and addressing ocean acidification

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NOTE: This contribution will focus on the deep ocean (the deep half of the planet) in both national and international waters (> 200 m water depth).

Status and trends

1. What is the status, underlying trends and emerging issues in relation to ocean acidification?

Deep-water corals form large reefs and critical biological habitat that hosts a wealth of biodiversity and provide key food and refuge support functions for commercial and non-commercial fishes (see Cordes et al. 2016 for review). Deep-sea corals, including reef-forming and solitary stony corals as well as sea fans or octocorals, lie very close to the aragonite saturation horizon, much closer than any of the shallow-water reef-forming corals (Thresher et al. 2011, Lunden et al. 2014). Deep waters are indeed naturally rich in CO2 due to the absence of photosynthesis and remineralization of organic matter produced in surface and sedimenting. The increased anthropogenic CO_2 is critical while approaching thresholds for the corrosive conditions that are encountered in large regions of the deep ocean. There appears to be variation in the response to low pH among different deep-sea coral species, displaying a much larger diversity than shallow water counterparts, but also within species (Georgian et al. 2016). Some studies have shown a consistent response among different genotypes tested, suggesting the potential for an adaptive response (Lunden et al. 2013). However, the ability of deep-water corals to maintain calcification and continue to form reefs under conditions that were previously thought to exclude scleractinian corals remains vastly understudied. Understanding the mechanism underlying the deep-water corals' resistance to naturally low pH, or low aragonite saturation index, reflecting ocean acidification in different deep-sea basins could be informative for mitigation activities on shallow-water reefs. They will also inform about the sustainability of activities depending on the presence of deep-water corals, such as fisheries associated with seamounts and canyons that benefit from the nursery and nutrient-rich habitat provided by these deep-water reefs or coral gardens.

High CO_2 input can cause hypercapnia in many species. The stress of maintaining acid-base balance is energy consuming; we now realise there is high variability among species to regulate that balance.

Predator-prey relationships will change with ocean acidifcation. Mollusc shells are one example in which predator- induced calcification can be compromised.

It is essential to study and address ocean acidification within the context of broader ocean changes. The same carbon dioxide that dissolves in our oceans and causes acidification also warms our atmosphere and ultimately our oceans. This warming causes our oceans to lose oxygen (Keeling et al. 2010). This occurs through changes in solubility (warmer water holds less oxygen) and through increased stratification, which reduces oxygenation of the ocean interior Addition of nutrients from land, upwelling and the atmosphere contribute to oxygen loss by enhancing production, and subsequently decay and microbial respiration consuming oxygen in the deep waters. Reduced oxygen reduces the capacity for species to counter acidification while forming their shells, since this process requires higher energy budgets in more corrosive conditions.

Globally, greenhouse gas emissions cause both acidification and the loss of oxygen, and all 3 stressors – warming, acidification, and deoxygenation occur. The deep seabed and overlying waters, which largely lack of observations (despite efforts from the oceanographic community) is particularly vulnerable. The most recent estimate indicates that the volume of water in the open ocean that is completely devoid of oxygen has quadrupled since 1960 (Schmidtko et al. 2017). Many other areas experience hypoxia (oxygen shortage) at dangerous levels, which is already shown to reduce significantly the habitat of migratory fish species. Ocean acidification and ocean deoxygenation commonly occur together at depth of c.a. 200 to 1000m depth (Levin and Breitburg 2015). Increases in upwelling (Sydeman et al. 2014) are bringing high CO_2, low oxygen waters into shallow waters and onto shelves (Feeley et al. 2008), where they can have major impact on coastal fisheries and livelihoods.

Ocean acidification and ocean deoxygenation must be observed and researched together and with warming, which is a master variable that affects oxygen limitation and response to acidification. Solutions must address all 3 problems in concert(Breitburg et al. 2015). Although the surface ocean is changing the fastest, the uptake of heat and CO_2 from the atmosphere is also rapidly changing the temperature, pH and oxygenation of the deep oceans with consequences for its ecosystems (Levin and LeBris 2015).

Challenges and opportunities

2. What are the main challenges to minimize and address ocean acidification, and possible ways to address them?

This is a pervasive threat, related to the continued emission of CO_2 into the atmosphere, its equilibration with surface waters in the ocean, and the subsequent transport of anthropogenic carbon to the deep sea. The ultimate way to address this challenge only comes from a coordinated effort to reduce carbon emissions. However, this is a multi-stressor problem, where corals (and other species) are able to survive and grow at lower pH levels if other stressors are reduced. This makes it a more local issue, where reducing pollution, runoff, eutrophication, etc all contribute to a more resilient community.

Shutting down emissions will not make the problem go away because of long residence times in the ocean; predictive models of long-term dynamics of the carbonate system are poor, at best, for the deep ocean. Furthermore these model lack of a comprehensive integration of multistressor impacts, encompassing changes in the productivity of surface waters due to warming and acidification and export of this material at depth. The export of organic material to the dark layers of the ocean and seabed is a key to the ability of adaptation that is not well documented so far and parameterized in models.

One size does not fit all. Ocean basins and their ecosystems have evolved separately thus responses to changing pH, oxygen and temperature will be different. For example, the Northeast Pacific is experiencing greater changes than the northern Atlantic yet some organisms may be more tolerant. Marginal or semi-enclosed seas such as the Mediterranean Sea may have a high diversity reflecting its complex geological history. Regional models are necessary for predictions. Ultimately, we can only manage our "ocean use" and further stressors in this context as changes in ecosystems seem almost inevitable (e.g. pteropod declines in the Alaskan region and consequences for the trophic structure there).

3. Are there any untapped opportunities to minimize and address ocean acidification?

Greater efforts to mitigate the effects of habitat damage to deep-water corals can foster long-term adaptation especially in very long-lived 'groves' and specimens. The opportunity lies in long-term vision: how do we plan for 100-200 years from now when effects may have ameliorated? Can we, as a society, plan that far ahead? Can we even think of some tools for conservation, even genetic engineering, that may give more resilience to key species?

For the deep ocean - international coordination both within and beyond national jurisdictions can be advanced in the areas of research, spatial planning, reduced fishing pressure and damage, stronger environmental regulation and management. IOC, BBNJ, the CBD, ISA, FAO and the IPCC have much to contribute.

Existing partnerships

4. What are the existing partnerships covering ocean acidification? Are there identified gaps in coverage (e.g. regional level, topics not covered)?

There is generally a gap in attention to ocean acidification (and warming and deoxygenation) in the deep ocean and high seas.

In the US, NOAA has a program to examine and monitor ocean acidification. However, the focus has solely been on shallow waters. There has not been a concerted effort to study the problem in the deep sea, where the aragonite saturation horizon lies.

Both PICES and ICES monitor the states of the northern oceans. However, high seas are never the priorities for States yet the deep circulation and water mass behaviour will affect what ends up on the coasts, and migratory marine species - some of them have an important economic or food value - obviously don't have such frontiers.

The newly formed Deep Ocean Observing Strategy (www.deepoceanobserving.org), a program within the Global Ocean Observing Strategy (GOOS) offers an international program that can expand and integrate carbonate system (ocean acidification) measurements in the deep ocean (below 200 m). This can inform deep-sea scientists about needs and opportunities, including collaboration with or capacity building for small island (large ocean) developing states which have large areas of deep sea, and are considering or have active use of deep water (for energy, mining, fishing).

In addition, the Deep Oean Stewardship Initiative (www.dosi-project.org) brings together deep ocean scientists, industry, regulators, and policy experts and is able to address the intersection of climate-related ocean changes, including acidification, with societal uses of the ocean (e.g., fishing, energy extraction mining, waste disposal).

5. Who are the main actors typically involved in existing partnerships?
Government agencies typically sponsor long-term monitoring programmes but many academics contribute through in-depth focussed projects. To this we could add the managers of large MPAs that have included vulnerable deep-sea habitats in their management plans, and identify the development of knowledge as a priority for effective mitigation strategies.

For the deep ocean - many international observing programs exist. They do not all measure the carbonate system (OA) parameters but can be used to inform the subject or develop new instrumentation - ARGO, Deep ARGO, Biogeochemical ARGO, Go-Ship, OceanSITES, GOA-ON (UNESCO network), Deep Cables, Observatories (ONC, OOI, Hausgarten etc), and newly formed OA Alliances. Integration of the IOC activities of GO2NE (Global Ocean Oxygen Network) and GOA-ON will be helpful. The FAO has become interested in climate change effects on vulnerable marine ecosystems and high-seas fisheries. The International Seabed Authority also is beginning to incorporate climate change into environmental management/spatial planning for seabed mining. UNFCCC - IPCC would be a logical partner to address acidification and other ocean changes.

6. Do we know how well existing partnerships are performing? What have been success factors? What are the main challenges identified with existing partnerships?

There has yet to be a deep-ocean focused OA program, but one could be established, or this could be a subgroup within another alliance such as the Deep Ocean Observing Strategy (within GOOS).

7. Have successful partnerships on minimizing and addressing ocean acidification been narrowly focused in scope, or more holistic, encompassing several related areas?

The deep sea is conspicuously lacking from these formal partnerships.

8. How to strengthen and enhance effectiveness of existing partnerships?

Create a clearinghouse and hub for information exchange that brings together different efforts.

Possible areas for new partnerships

9. Given challenges, opportunities and gaps, how could new partnerships help with implementation?

Capture young minds and future leaders in science, social responsibility and ocean governance by investing in international programs that cross-train young people in academic and applied settings and problems.

10. What actors would need to be involved for new partnerships to succeed?

There is a need for training programs for scientists globally, including developing nations.
State sponsorship and support are required

11. What would critical success factors be?

Partners need to acquire (a) understanding the depth of the aragonite saturation horizon in all parts of the global ocean, and how this shapes ecosystems and (b) understanding how deep-sea species adapt to low pH and/or low aragonite saturation under different nutrient and oxygen conditions (that are both likely to change in the context of global change) . This would provide key insight into the areas that should be focused on most immediately, in order to reduce the effects of other stressors on sensitive communities located there.

Guiding questions for the dialogue

12. In your view, what are the key questions that should guide the partnership dialogue at the Ocean Conference on minimizing and addressing ocean acidification?

- Where is ocean acidification having the most detrimental effects at this time, ie which areas have thus far been overlooked?
- Where is anthropogenic carbon penetrating the ocean's depths to the greatest degree, and how fast is this happening? Do these locations overlap with any sensitive deep-sea habitats supporting key ecosystem services?
- What partnerships need to be formed to equip existing ocean observatories and developp new observation systems with adequate pH and carbonate system sensors to monitor and track ocean acidification?
- What are the greatest risks looking out over a long time-frame? What moves can we make to begin 'adaptive' measures to manage risks?

A major risk is the possibility that our deep-water ecosystems and the biodiversity and resources they support will degrade under OA (and warming and deoxygenation) without our knowing, with potential loss of significant ecosystem services.

- What adaptive measures can be taken to improve sustainability of resources and the ecosystems they rely on in the face of stress from ocean acidification?

The increasing number of large MPAs that have been designed, need a robust science-based information to support their management plans and identify what is really at risk, and where the most import reduction of additional stresses should be established.

- Should we restrict specific bottom fishing activities or fishing gear in deep-water habitats vulnerable to OA?

- Can we extend further protections to vulnerable marine ecosystems like deep-water corals?

We definitely need better knowledge about their nutritional requirement, sensitivity to oxygen decline, in order to better assess their capacity of resilience to trends and to extreme conditions.

- Should we target more OA tolerant fish and shellfish for harvest and reduce fishing pressure on vulnerable species? ...and especially those already threatened by habitat change (such as those related to cold-water coral grounds or living close to oxygen minimum zones) ?

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