Bridging the Gap Between Ocean Acidification Impacts and Economic Valuation: Regional Impacts of Ocean Acidification on Fisheries and Aquaculture

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A short summary of the current knowledge on ocean acidification

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1- INTRODUCTION

The oceans have absorbed between 24% and 33% of anthropogenic carbon dioxide (CO₂) emissions during the past five decades (Le Quéré et al., 2009). While this uptake provides a valuable service to human societies by moderating the rate and severity of climate change, it comes at a cost for the oceans. The massive input of CO₂ generates sweeping changes in the chemistry of seawater, especially on the carbonate system. These changes are collectively referred to as “ocean acidification” because increased CO₂ lowers seawater pH (i.e. increases its acidity).

Ocean acidification, “the other CO₂ problem” (Donney et al., 2009), has recently emerged as one of the largest threats to marine organisms and ecosystems (reviewed in Gattuso & Hansson, 2011). Describing and quantifying the plausible consequences of ocean acidification on societies, however, remains a challenge. Those consequences will depend on interactions among and between species and ecosystems (all reacting at different rates and magnitudes), on the interaction of ocean acidification with other ocean stressors (Bopp et al., 2013), and on responses of each human group affected. Nevertheless, it is clear that the speed and magnitude of acidification is threatening many marine species and ecosystems. Calcifying organisms such as coral reefs, shellfish and zooplankton are among the first potential victims. Therefore ocean acidification will also impact various economic sectors (e.g. fisheries, aquaculture, tourism; see Cooley & Donney, 2009; Narita et al., 2012) and coastal communities, and may also have major indirect effects on much broader segments of the world economy and population.

Ocean acidification appeared on the research agenda about two decades ago (Smith & Buddemeier, 1992; Gattuso et al., 1998). It is now an important focal issue for the research community (Monaco Declaration 2009) and related societies (e.g. European Geosciences Union 2008; European Science Foundation 2009; Interacademy Panel on International Issues 2009).

2- CAUSES OF OCEAN ACIDIFICATION

There are two main causes of ocean acidification. By far the primary cause is the ocean’s uptake of atmospheric CO₂, and there is growing evidence for secondary enhancement of CO₂-driven acidification by other pollutants in coastal regions (Cai et al., 2011; Sunda & Cai, 2012).

2.1- Uptake of atmospheric CO₂

Rising atmospheric CO₂ is the major driver of ocean acidification globally. The increase of CO₂ in the surface ocean resulting from the uptake of anthropogenic CO₂ profoundly affects the seawater carbonate system through well-known chemical reactions. It lowers pH (increases acidity), increases the concentration of bicarbonate ions (HCO₃⁻), decreases the availability of carbonate ions (CO₃²⁻) and lowers the saturation state of the major shell-forming carbonate minerals such as calcite and aragonite. This process is known as “ocean acidification” because, even though the surface waters remain alkaline, seawater pH is decreasing.

Average surface water pH values1 are in an accelerating decline: it was 8.3 during the last glacial maximum, 8.18 just prior to the industrial era, and 8.10 at present. Measured trends agree with those expected from the atmospheric CO₂ increase, with uncertainties larger for the high latitudes, deep ocean, coastal areas, and marginal seas. The basic chemistry of ocean acidification being well understood, future projections are quite reliable for the surface open ocean for a given atmospheric CO₂ trajectory (Orr, 2011). Those based on the International Panel on Climate Change (IPCC) scenarios give reductions in average global surface pH of between 0.14 and 0.35 units over the 21st century, which means surface pH may reach 7.8 in the year 2100 (Orr, 2011).

Despite anthropogenic CO₂ emissions being the primary driver of acidification, the chemical and biological impacts of ocean acidification would continue to intensify for many years thereafter even if emissions were halted altogether by the end of this century (Joos et al., 2011). Nevertheless, mitigating CO₂ emissions would substantially ease the trajectory of acidification over the course of the 21st century (Joos et al., 2011).

1 pH is expressed on the total scale throughout this report.
2.2- Coastal acidification due to inputs from land

Several anthropogenic inputs also exacerbate the effects of ocean acidification at smaller spatial scales (Feely et al., 2010; Cai et al., 2011). These inputs act disproportionately along coastal margins where anthropogenic stressors are most acute and where oceanographic patterns such as upwelling or incomplete flushing occur, especially in bays and estuaries.

Mechanisms for this locally-intensified acidification are known: while Hunter et al. (2011) show a negligible effect of deposition of atmospheric NOx and SOx, nitrogen and phosphate runoff from agricultural, industrial, urban and domestic sources causes eutrophication, triggering population spikes of algae or heterotrophic plankton (Cai et al., 2011). When algal blooms are over, the organic matter decays, generating CO2 and acidifying seawater. Understanding and mitigating these secondary causes of acidification is possible at the local and regional scales.

3- IMPACTS OF OCEAN ACIDIFICATION ON MARINE ORGANISMS AND ECOSYSTEMS

Ocean acidification can have a wide range of biological effects, through two main mechanisms. First, pH plays a key role in several physiological processes and many intracellular enzymes that control cellular physiology are pH-sensitive. The pH of body fluids in animals and the intracellular pH of various organs or unicellular organisms are tightly regulated, but regulatory mechanisms are energetically expensive and can be overwhelmed. The second mechanism occurs through changes in the concentration of molecules that are themselves substrates in key physiological processes. For example, carbon dioxide and bicarbonate are used in photosynthesis and carbonate is a building block of shells and skeletons made of calcium carbonate. Hence, ocean acidification can stimulate primary production since the concentrations of both CO2 and HCO3 are larger at lower pH (see Riebesell & Tortell, 2011). It also often decreases calcification (the construction of shells and skeletons; Andersson et al., 2011; Riebesell & Tortell, 2011), and stimulates nitrogen fixation in some cyanobacteria (Riebesell & Tortell, 2011). This suggests that highly calcium-carbonate-dependent ecosystems — such as coral reefs and oyster and mussel beds — could be particularly vulnerable.

However, the magnitude of species-specific physiological effects is highly variable and, in few cases, even the sign of the response may vary (Kroeker et al., 2010, 2013). For example, there is evidence that the same species may differ in sensitivity among life stages (e.g., with enhanced sensitivity among larval stages; Kurihara et al., 2008), among different strains of the same species (Langer et al., 2009; Parker et al., 2011), and dependent on their previous exposure (e.g., carry-over effects; Hettinger et al., 2012; Parker et al., 2012).

A recent analysis of the rapidly expanding body of research on acidification reveals consistent reductions in calcification, growth, and development of a range of calcified marine organisms despite the variability in their biology (e.g., morphology and life history strategies; Kroeker et al., 2013). It also suggests that some taxa may be predictably more resilient to or may benefit from ocean acidification (e.g. brachyuran crustaceans, fish, fleshy algae, and diatoms). The study of Kroeker et al. (2013) did not consider all kind of effects. For example, neurological effects with repercussions for their behavior (Nilsson et al., 2012) or the loss of phenolic compounds used as herbivore deterrents by fleshy algae (Arnold et al., 2012). Furthermore, the potential for acclimation (Evans & Hofmann, 2012) or adaptation (Sunday et al., 2010; Lohbeck et al., 2012) in response to acidification could lessen negative effects. This remains a critical area for future research. While physiological effects on these calcified organisms can result in decreases in their abundance, the higher variability of species responses in multi-species studies indicates that species interactions will also be important determinants of abundance (Fabricius et al., 2011; Kroeker et al., 2011). Furthermore, understanding whether the remaining variation within taxonomic groups and life stages represents real biological differences among species, locally-adapted populations, or acclimatory capacities, or experimental error, remains a critical area for future research. Finally, marine organisms of the future will not be subjected to ocean acidification in isolation, and continued research on the concurrent effects of ocean warming and acidification is necessary to forecast the status of marine organisms and communities in the near-future.

4- KNOWLEDGE GAPS

Despite very active research on ocean acidification and the considerable increase in the number of papers, there are several key knowledge gaps preventing to assess the full extent of the impacts of ocean acidification with reasonable certainty.

— Research needs to be scaled up. Most information available on the impacts of ocean acidification was gained on isolated organisms on short periods of time. Little is known on the responses of whole ecosystems, on the impacts of multiple stressors, and on the potential for evolutionary adaptation. These limitations restrict the level of confidence of future projections.

— Effects of ocean acidification on biogeochemical cycles at a global scale are uncertain. Changing ecosystem composition and the oceans’ carbonate chemistry affects biogeochemical cycles in complex ways. Ocean acidification may also affect production of climate-related gases. We need to understand ecosystem responses to the effects of ocean acidification in order to improve how global models simulate and predict biogeochemical changes.

— Fish and fisheries. It is uncertain how the effects on phytoplankton and zooplankton will propagate through the food web to affect fish and fisheries. Also, very little is known about the direct effects of ocean acidification on fish that are the target of commercial and subsistence fishing.

— Socio-economic impacts are expected but the size of the costs is uncertain.
ACKNOWLEDGEMENTS

This short summary is based largely on the following book and papers: Gattuso & Hansson (2011), Bilé et al. (2013), Kroeger et al. (2013), and IGBP, IOC, SCOR (2013). Interested readers should refer to these references for further information. The support of the BNP Paribas Foundation and the European Community’s Seventh Framework Programme (FP7/2007–2013) through the “Mediterranean Sea acidification in a changing climate” project (MedSeA) is gratefully acknowledged.

REFERENCES


