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Contribution to Special Issue: 'Towards a Broader Perspective on Ocean Acidification Research Part 2'

Food for Thought

CO_2 sensitivity experiments are not sufficient to show an effect of ocean acidification

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The ocean acidification (OA) literature is replete with laboratory studies that report species sensitivity to seawater carbonate chemistry in experimental treatments as an "effect of OA". I argue that this is unintentionally misleading, since these studies do not actually demonstrate an effect of OA but rather show sensitivity to CO_2. Documenting an effect of OA involves showing a change in a species (e.g. population abundance or distribution) as a consequence of anthropogenic changes in marine carbonate chemistry. To date, there have been no unambiguous demonstrations of a population level effect of anthropogenic OA, as that term is defined by the IPCC.

Keywords: climate change, CO_2 sensitivity experiments, ocean acidification.

Ocean acidification (OA) can be defined as the reduction in ocean pH caused primarily (but not exclusively) by the uptake of CO_2 from the atmosphere (IPCC, 2011). Anthropogenic OA refers to the human-caused reduction in ocean pH and is the primary focus of nearly all articles on this topic. Demonstrating an effect of anthropogenic OA on a species or in a single long-lived individual requires demonstrating a change in the species living in the wild in response to the changes that have occurred and are occurring in ocean carbonate chemistry. This criterion for demonstrating a biological effect of OA raises three key issues: (i) can a laboratory study show an effect of OA, (ii) what evidence is needed to directly show an effect of OA, and (iii) has an effect of OA already been observed. This comment primarily addresses the first issue and its implications, with a brief foray into the other two topics.

Laboratory experiments testing species sensitivity to increased CO_2 are a common way to assess the potential effects of OA on marine organisms. It is common in the literature to refer to these experiments as studying the "effect of OA". A review of 393 papers describing CO_2 sensitivity experiments found that ~40% include some variation of the phrase "effect of OA" in the title (database by Busch and McElhany, in review), and the majority of presentations at the American Fisheries Society 2015 Annual Meeting OA Symposium included some variation of that phrase in the title. I contend that applying the phrase "effect of OA" to experiments purportedly documenting the sensitivity of organisms to increased CO_2 is unintentionally misleading because the phrase implies that the changes in ocean chemistry that have already occurred have affected the species in the wild. Laboratory exposure experiments do not show that the species has been affected by a change in ocean chemistry – they simply show sensitivity, in a laboratory setting, to the chemistry changes that occur in seawater with increased CO_2. Likewise, snapshot studies showing different biological performance in locations with different contemporary carbonate chemistry do not directly demonstrate the effect of changing ocean chemistry (e.g. Bednaršek *et al.*, 2014). Although laboratory experiments and spatial observations are essential approaches for predicting potential effects of OA, they are not sufficient to demonstrate an effect of OA.

Demonstrating an effect of OA can most directly be accomplished by correlating a time series of abundance or other species attribute with a time series of changes in ocean carbonate chemistry and simultaneously demonstrating that the change in the species (or long-lived individual) was caused by the change in carbonate chemistry. I am not aware of any studies that correlate

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contemporary biological and chemical time series to directly and unambiguously demonstrate an effect caused by anthropogenic OA. The lack of correlative time series is not a surprise to OA researchers – carbonate chemistry and biological data sets are noisy and short. Attributing a biological change exclusively to OA as opposed to other confounding variables, like temperature or biological interactions, is difficult, especially given the strong correlations between carbonate chemistry and other important biological drivers in the field (e.g. Juranek *et al.*, 2009; Reum *et al.*, 2014). In addition, modelling of historical and projected marine carbonate chemistry indicates that the greatest biological impacts of OA will be in the future rather than in the recent past (Bopp *et al.*, 2013). Studies that potentially provide a baseline for evaluating an effect of OA are starting to accumulate for a few species such as Pacific oysters (Barton *et al.*, 2012), pteropods (Bednaršek *et al.*, 2014), and some corals (Manzello *et al.*, 2014; coral reef example in Alin *et al.*, 2015), but longer time series and additional data are needed to clearly show a change in the population of these species driven by OA.

In some ways, the issue of how we describe laboratory studies is semantic quibbling. After all, the papers and presentations noted above are intended to discuss *potential* effects of OA. However, use of the phrase "the effect of OA" without qualification has important implications for how we interpret our studies and how current knowledge about the risks of OA is communicated. Implying that laboratory sensitivity studies demonstrate an effect of OA overstates the information we have about OA's impact on contemporary natural ecosystems. This contrasts with studies examining the temperature effects of climate change. There is a large literature describing laboratory studies that measure species sensitivity to temperature (e.g. Freitas *et al.*, 2010). These temperature sensitivity studies are generally not described as demonstrating "the effect of climate change". Studies documenting the effect of climate change seek to show (and sometimes succeed in showing) that a change in a species in the wild was caused by a change in the earth's climate (e.g. Johnston *et al.*, 2013; see Parmesan *et al.*, 2013 for discussion of methods).

Although it is necessary to approach claims of "ocean calamity" with scepticism (Duarte *et al.*, 2015), there is substantial evidence that OA poses a threat to many marine ecosystems (e.g. see Hoegh-Guldberg *et al.*, 2014). However, it is important to acknowledge that there are no studies that directly demonstrate modern day effects of OA on marine species. We can look again to the climate change-temperature analogy. Decades ago, when atmospheric scientists first projected likely temperature changes from increased anthropogenic CO_2, biologists predicted substantial ecological changes based on results from laboratory studies and field correlations of species performance with spatial variability in temperature. However, in those early days, there were no studies directly documenting the effect of anthropogenic (CO_2-driven) climate change on ecosystems. Now, decades later, there are many studies showing the effects of climate change on ecosystems (e.g. ocean evidence reviewed in Hoegh-Guldberg *et al.*, 2014).

Ocean acidification research is still in the early stages of development. To advance this development, we should support establishment of co-located biological and carbonate chemistry monitoring in targeted systems, as well as re-examination of existing time series with a focus on detecting the signature of OA. Creative experimental approaches, such as Albright *et al.* (2016), can also provide information about possible recent effects of OA. The evidence is clear that the ocean is acidifying and studies directly documenting the biological effects of OA are no doubt coming. In the meantime, it is important to use language that clearly communicates the status of OA research. Our terminology can be improved by using the phrase "sensitivity to CO_2" to describe results from manipulative experiments or static field observations.

Disclosure

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