

2010 Sendai Ocean Acidification Workshop

by Kenneth Denman, Yukihiro Nojiri and Hans-Otto Pörtner

The oceans are becoming acidified as carbon dioxide from fossil fuel emissions enters surface ocean waters from the atmosphere. Global surface pH has already decreased by more than 0.1 units, (IPCC WG1 AR4 Report, Chapter 5, 2007), and may decrease by another 0.4 units by the end of this century under the high CO₂ emission scenario. Some regions of the ocean may have a significant decrease in the CaCO₃ saturation state even with the same atmospheric CO₂ change. The key question that should be addressed in future studies on the effects of increasing P_{CO₂} in the ocean may be stated as: What will be the responses and adaptive capacities of individual species and whole ecosystems to a multi-decadal decrease in pH of 0.1–0.5 units?

A 1-day workshop on “Potential impacts of ocean acidification on marine ecosystems and fisheries”, co-convened by the authors of this article, was held immediately prior (April 25, 2010) to the International Symposium on “Climate change effects on fish and fisheries” in Sendai, Japan. Talks and posters presented at the workshop reported on manipulation experiments and observations on the effects of elevated CO₂ on organisms at all trophic levels of fisheries foodwebs, and modelling approaches to predict the impact of continuing increases in atmospheric CO₂.

The first talk (Denman *et al.*) presented observational evidence of open ocean increases in P_{CO₂} and decreases in pH, followed by model projections of global mean and spatial patterns of the decrease in pH until the end of this century. Several talks and posters reported on studies of organisms with calcium carbonate skeletal structures subjected to various experimental exposures to low pH (high P_{CO₂}) waters in controlled laboratory or field situations. Other

talks and posters described physiological and behavioural responses of animals to elevated CO₂ conditions. One poster evaluated the adequacy of a number of ecosystem models to simulate adaptation over long time scales to changes in CO₂ (and other related variables) associated with climate change.

Nakamura *et al.* reported on a depression of metabolism and growth in coral larvae with elevated CO₂ levels. Similiary, Lartey-Antwi and Anderson found decreased growth rates of flat-tree oysters. Suwa and Shirayama presented data obtained with a system precisely mimicking constant and fluctuating CO₂ levels, where the fluctuating levels showed less impact on the growth and skeletal structures of echinoderm larvae than CO₂ levels set permanently high. Kurihara provided an overview on different levels of CO₂ sensitivities according to taxon and in early life stages. Ishimatsu *et al.*, Munday *et al.* and Dissanayake *et al.* reported on changes in various processes indicating tolerance limits, decreased aerobic scope and behavioural changes in shrimp and young fish in response to elevated CO₂ levels, with species-specific differences even among closely related fish species. Salau introduced a model of reduced carrying capacity for pteropods as pH decreases, and the feedback effects on pink salmon: as a result, even and odd year differences in salmon stock size will increase over time with management implications for repeating strong and weak returns in alternating years. Rumrill *et al.* (poster) presented long-term observations of an estuary showing decreasing pH and effects on oysters in the outer saline estuary and increasing pH probably resulting from changes in precipitation and freshwater runoff. Takami *et al.* demonstrated how elevated CO₂ levels

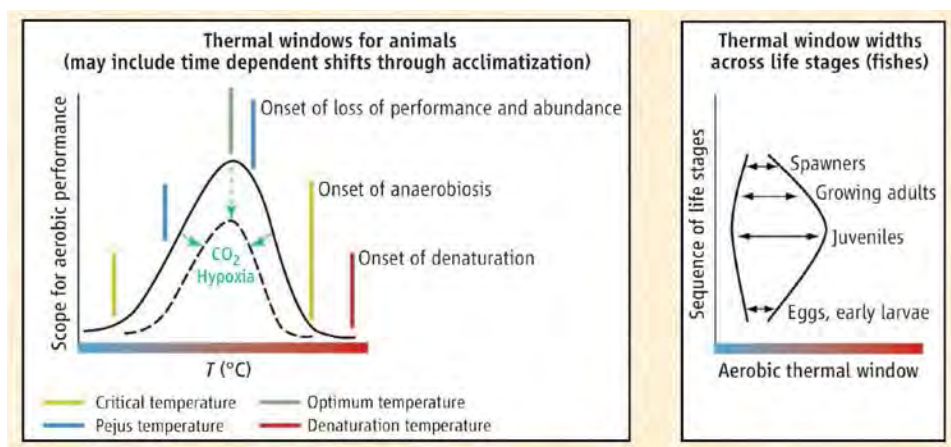


Fig. 1 Animal physiology and climate change showing (left panel) how the ‘thermal window’ for normal activity by marine animals may shrink with decreasing oxygen concentrations and increasing CO₂ concentrations, and (right panel) how the thermal window changes with life stage (from Pörtner and Farrell, 2008, *Science*, 322, 690–692) [see page 31].

slow and disturb development in abalone, and Sugie *et al.* (poster) found enhanced drawdown in Si/N by Bering Sea phytoplankton as pH fell and Fe was limited. Kim and Kim (poster) used brine shrimp as a model for identifying changes in the expression of individual genes during exposure to low pH. Finally, Le Quesne and Pinnegar (poster) analyzed several ecosystem models, emphasizing that parameterizations of various physiological processes would be needed to support the evaluation of responses to changing pH.

Noteworthy findings can be summarized as follows:

- Overall, investigators are observing different sensitivity levels among investigated organisms (some closely related), ranging from calcification and growth to development, behaviours and ecosystem level responses. The consideration and introduction of environmental variability changes the pattern and level of response. In light of the complexity and diversity of responses observed, it is thus too early to draw general conclusions regarding the responses of ecosystems to elevated CO₂.
- The inclusion of pre-industrial levels (around 280 ppm CO₂) in experimental protocols, as well as the precise

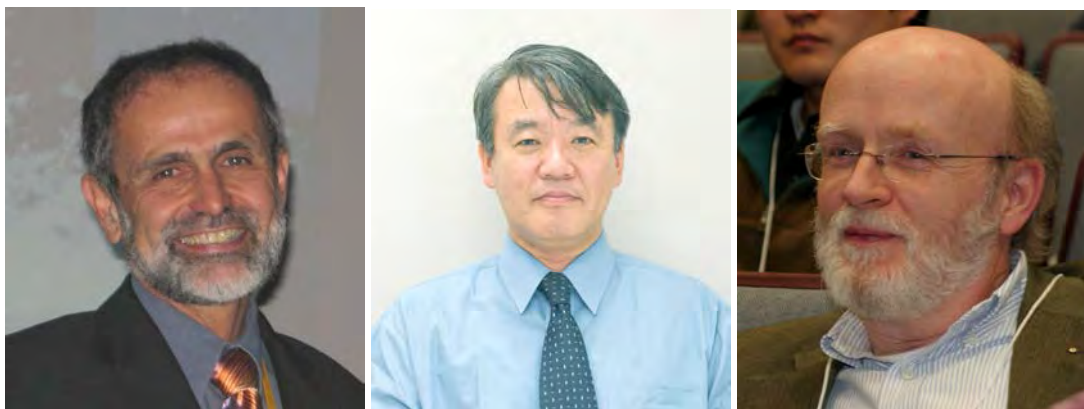
control of diel CO₂ cycling, was considered highly valuable in studying the impact of ocean acidification. In fact, one study reported improvement in calcified structures in echinoderm larvae under pre-industrial compared with present-day levels of ambient CO₂. Investigations of mechanisms under high PCO₂ need be complemented by testing the role of such responses under expectable PCO₂ according to ocean acidification scenarios.

- Studies of behavioural and physiological responses to elevated CO₂ levels for organisms that are not necessarily calcifiers are less mature, but are exciting because so little is known.

Recommendations and Key Questions from the workshop include:

- Pre-industrial control runs should be done more often, since organisms have already adapted from that point.
- Experiments often include current day PCO₂ (~380 ppm) and an elevated CO₂ level of ~1000 ppm. If emissions are controlled to try to achieve <3°C global warming, then intermediate levels of, say, 450, 550, and 700 ppm, have to be considered. Both these recommendations require precise PCO₂ (pH) control.

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