

Acidification of the Coastal Ocean: Are deep waters of the Gulf of Maine already corrosive to pteropods?

Z. Aleck Wang, Gareth Lawson, and Amy Maas

Final Report

Background and Objectives – As a result of increases in atmospheric carbon dioxide (CO_2), the ocean is taking up extra CO_2 and becoming more acidic, in a process referred to as ocean acidification (OA, Fig. 1). Certain coastal regions, such as the upwelling system along the U.S. West Coast, are more susceptible to the effects of ocean acidification than others, because their waters are naturally low in pH and saturation of aragonite, but higher in CO_2 concentration, at least at some times of year. Aragonite is a mineral type of calcium carbonate, and its level in seawater (measured by its saturation state) is an important indicator for shellfish growth of their shells. Recent evidence has suggested that the US northeast coastal waters, including the Middle Atlantic Bight (MAB) and Gulf of Maine (GoME), are more susceptible to ocean acidification than has previously been thought. Aragonite saturation state (Ω_A) in the US Northeast coastal waters on average is close to a border line value of 1, below which seawater chemical conditions would favor dissolution of aragonite shell (corrosive to aragonite, Fig. 1). If ocean acidification continues, US northeast coastal waters may be the first along the East Coast that experience corrosive condition to aragonite, thus the first to ‘feel’ OA effects.

Thecosome pteropods are a group of aragonite shell-forming zooplankton that may be among the first pelagic organisms to experience the consequences of Ω_A under-saturation in the GoME (Fig. 1). *Limacina retroversa* is an important pteropod species in temperate latitudes of the North Atlantic and is by far the most common pteropod species in the Gulf of Maine, where it is a food item for a number of important fisheries species and other higher predators.

This interdisciplinary project aimed to assess seasonal variations of the CO_2 system in the deep GoME and the associated impacts on thecosome pteropods. The main objectives

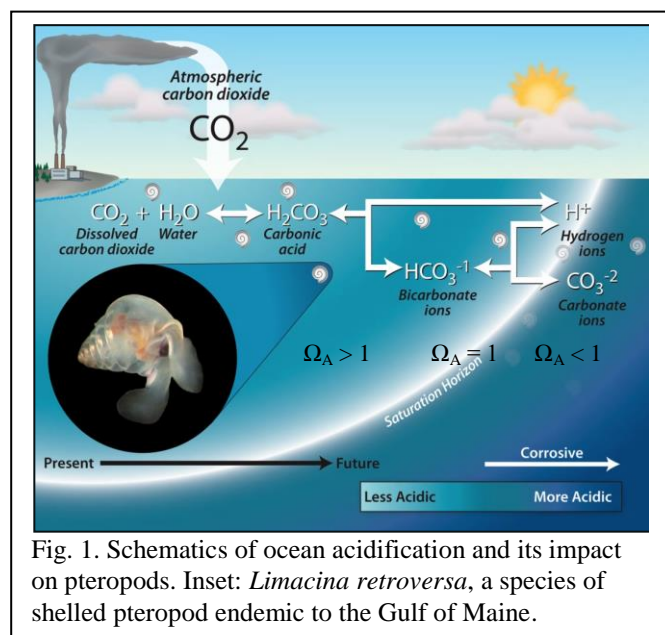


Fig. 1. Schematics of ocean acidification and its impact on pteropods. Inset: *Limacina retroversa*, a species of shelled pteropod endemic to the Gulf of Maine.

of this project were to: (1) investigate if deep waters of the GoME are already seasonally under-saturated with respect to aragonite saturation state and (2) quantify seasonal patterns in the abundance of the most common thecosome pteropod in the GoME, *Limacina retroversa*, and examine the impacts of potential under-saturation of aragonite on its vertical distribution.

Results – To achieve the objectives of the project, we conducted a series of seasonal research cruises in May, August, and October of 2013 and January and April of 2014 on the R/V *Tioga* to the deep portions of Wilkinson Basin (~300m) in the GoME (Fig. 2). At each station, we collected water samples for measurements of the seawater CO_2 chemistry, determined pteropod vertical distributions using depth-stratified nets, and captured live pteropods for physiological experiments (as part of other funded work). The first two cruises were conducted with COI support. Initial findings from those two

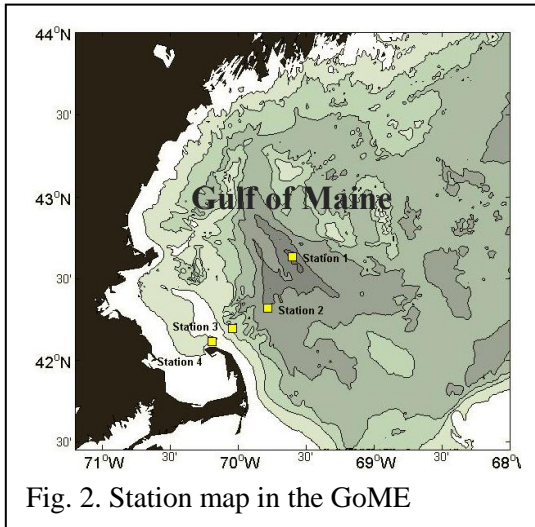


Fig. 2. Station map in the GoME

cruises led to additional funding from the Pickman Foundation to support carbonate chemistry sampling and analysis on three additional cruises conducted as part of an NSF-funded project examining pteropod physiology.

The results analyzed so far indicate that near bottom waters of the Wilkinson Basin in the GoME are already experiencing seasonal corrosive condition with respect to aragonite at the end of May (Fig. 3). In other words aragonite shells of pteropods and other shell-bearing organisms can dissolve in these waters, in the absence of any physiological compensation mechanisms. This region of aragonite undersaturation corresponded to the bottom nepheloid layer, which has the maximum particle concentration in the water column that may result from resuspension of sediment.

This condition occurs at the end of spring phytoplankton bloom, where a pronounced subsurface primary production maximum occurred (Fig. 3). It suggests that aragonite undersaturation near bottom may be a result of decomposition of freshly settled dead materials from surface and subsurface phytoplankton bloom. Organic matter is broken down by microbial activity which consume oxygen, release CO₂, and lower pH and hence aragonite saturation.

Interestingly, such a corrosive condition did not occur during the other three seasonal sampling cruises, especially for August and October when primary production was high near surface. Previous studies on bioparticles in the Wilkinson Basin suggests that aragonite shells are missing from sediment traps and aragonite particles in the water column decrease rapidly with depth, all of which seems to provide the evidence that near bottom waters should be corrosive to aragonite shells for much of the annual cycle. This project thus finds an interesting research question that warrants future studies.

Depth-stratified net sampling found that thecosome pteropods were most abundant in near-surface waters and absent from the deepest portions of the water column where aragonite saturation states were lowest (e.g., Figure 4). It is noteworthy that maximum abundance was found at shallow depths given that sampling occurred during the daytime, when many zooplankton, including pteropod species in other regions, tend to migrate to large depths in order to avoid visual predators. *Limacina retroversa* being found near the surface suggests it may avoid any deleterious consequences of under-saturation at depth, but as a consequence may be exposed to greater predation threat.

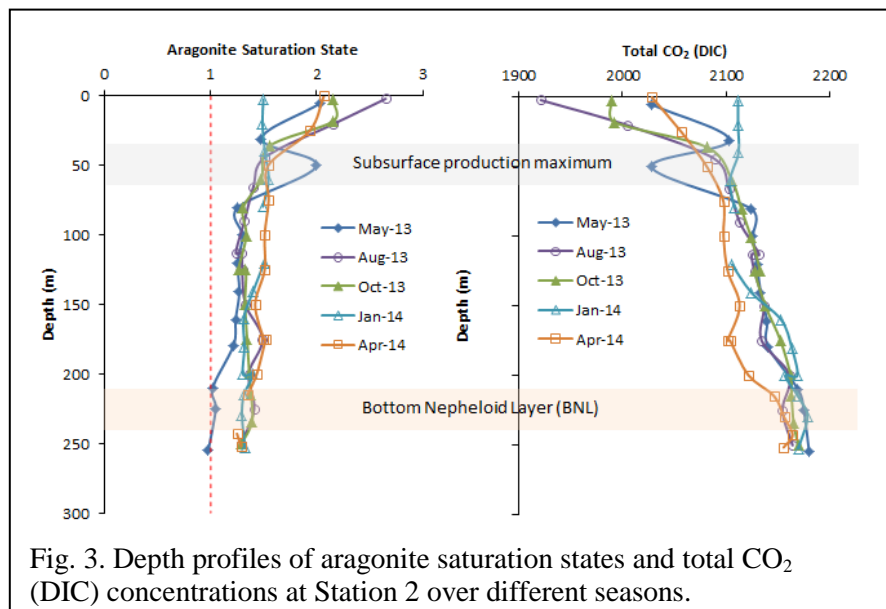


Fig. 3. Depth profiles of aragonite saturation states and total CO₂ (DIC) concentrations at Station 2 over different seasons.

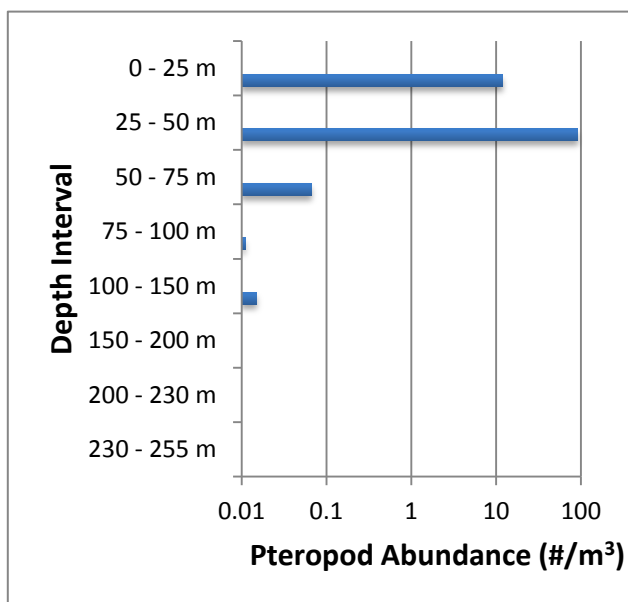
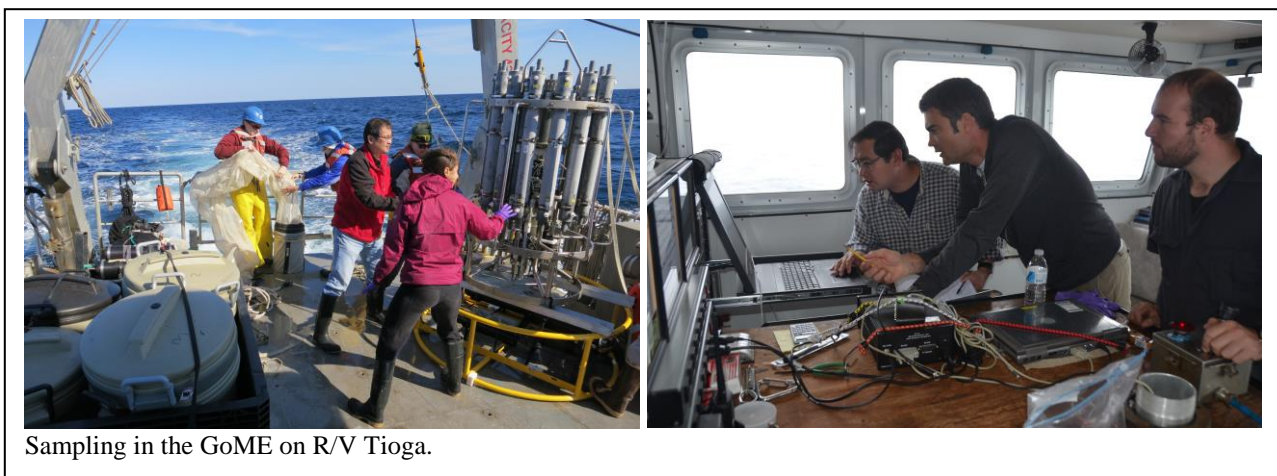


Fig. 4. Vertical distribution of *Limacina retroversa* from depth-stratified net sampling at Station 2 in May, 2013.

The current study so far demonstrates that undersaturation of aragonite does occur near bottom waters in the Wilkinson Basin of the GoME. However, we still have limited knowledge on the controlling mechanisms of such undersaturation, as well as the likely biological consequences to pteropods (and pteropod predators) and other calcifying organisms. We do not know how widespread the undersaturation is in the GoME. As the region is famous for its profitable shellfish industry, the implication for our finding is significant not only to biology and the ecosystem but to regional socio-economics. It is expected that undersaturation of aragonite in the GoME would become more prevalent as ocean acidification continues.

Leverage, Education, and Outreach – This project has generated important results that allowed us to secure another grant from the New Hampshire Charitable Foundation to continue seasonal sampling in Wilkinson Basin. We are planning to submit another proposal to the National Science Foundation (NSF) to study the mechanisms of controlling the aragonite saturation state in the region. The importance of this project is also reflected in several aspects: (1) The results described here on seasonality in carbonate chemistry are providing key insight into the acclimation of pteropods to seasonality that is studied by a related NSF project; (2) This project has provided training and research opportunities for two postdoctoral scholars, three WHOI-MIT Joint Program graduate students, and multiple student interns; (3) Lawson and Wang are featured in an exhibit on pteropods and OA at the Sant Ocean Hall of the Smithsonian’s National Museum of Natural History and Lawson participated in the Museum’s “The Scientist Is In” program; (4) Project-related materials have been communicated to a K-12 audience and the general public via the WHOI “Image of the Day” site. The Lawson lab also contributed multimedia for the PBS Learning Media by KCTS in Seattle: <https://www.youtube.com/watch?v=MzpmUHdwLr0>.



Sampling in the GoME on R/V Tioga.