Reconstructing Aragonite Saturation State Based on an Empirical Relationship for Northern California

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Abstract
Ocean acidification is a global phenomenon with highly regional spatial and temporal patterns. In order to address the challenges of future ocean acidification at a regional scale, it is necessary to increase the resolution of spatial and temporal monitoring of the inorganic carbon system beyond what is currently available. One approach is to develop empirical regional models thatAuthors enable aragonite saturation state to be estimated from existing hydrographic measurements, for which greater spatial coverage and longer time series exist in addition to higher spatial and temporal resolution. We present such a relationship for aragonite saturation state for waters off Northern California based on in situ bottle sampling and instrumental measurements of temperature, salinity, and dissolved oxygen. Application of this relationship to existing datasets (5 to 200 m depth) demonstrates both seasonal and interannual variability in aragonite saturation state. We document a deeper aragonite saturation horizon and higher near surface aragonite saturation state in the summers of 2014 and 2015 (compared with 2010–2013), associated with anomalous warm conditions and decadal scale oscillations. Application of this model to time

series data reiterates the direct association between low aragonite saturation state and upwelled waters and highlights the extent to which benthic communities on the Northern California shelf are already exposed to aragonite undersaturated waters.

Keywords
Ocean acidification Upwelling California Current System Aragonite saturation
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Chasing the future: how will ocean change affect marine life?

Understanding the potential consequences of rising ocean carbon levels and related ocean changes for marine life and ecosystems is a high priority for the ocean research community and marine resource management. In the mid-1990s, two geoengineering proposals to mitigate global warming by carbon sequestration in the deep sea led to research measuring the effects of increased deep ocean carbon dioxide levels on marine animals. A few years later, ocean acidification and its effects on marine life became an international research priority. Here we provide an overview of several technical developments by scientists and engineers at the Monterey Bay

Aquarium Research Institute (MBARI) that have enabled and enhanced deep-sea exploration and experiments to assess the effects of changing ocean conditions on benthic marine animals. Improvements in remotely operated vehicles (ROVs) have increased the efficiency of dive operations and enabled more complex measurements and experiments at great ocean depths. In situ respirometers and Free Ocean CO_2 Enrichment (FOCE) mesocosms have allowed measurement of physiological and behavioral responses of deep-sea animals to environmental change. A laboratory-based, gas-controlled aquarium system that regulates oxygen and pH in chilled waters was engineered to measure the physiological responses of deep-sea animals and biological communities to expected future environmental conditions. Recently, MBARI engineers and scientists developed an Upwelling Simulator, a lab-based aquarium control system that mimics ocean conditions during coastal upwelling. This system is programmable, allowing independent control of pH, oxygen, and temperature to enable experiments that examine the effects of present-day upwelling conditions, expected future conditions, or other changes in these environmental conditions. In sum, collaboration between the marine operations group, engineers, and scientists at MBARI has advanced methods to explore the ocean and understand the consequences of ocean change for marine organisms and ecosystems.

Barry J. P., Graves D., Kecy C., Lovera C., Okuda C., Boch C. A. & Lord J. P., 2018. Chasing the future: how will ocean change affect marine life? *Oceanography* 30(4): 60-71. Article.

The combined effects of acidification and hypoxia on pH and aragonite saturation in the coastal waters of the California current ecosystem and the northern Gulf of Mexico

Highlights

- In surface waters the percentage change in the carbon parameters due to increasing CO_2 emissions are similar.
- In subsurface waters the changes are enhanced due to changes in the buffer capacity.
- Increased anthropogenic CO_2 concentrations will expose organisms to hypercapnic conditions.

Abstract

Inorganic carbon chemistry data from the surface and subsurface waters of the West Coast of North America have been compared with similar data from the northern Gulf of Mexico to demonstrate how future changes in CO_2 emissions will affect chemical changes in coastal waters affected by respiration-induced hypoxia ($[O_2] \leq \sim 60$ μmol kg^{-1}). In surface waters, the percentage change in the carbon parameters due to increasing CO_2 emissions are very similar for both regions even though the absolute decrease in aragonite saturation is much higher in the warmer waters of the Gulf of Mexico. However, in subsurface waters the changes are enhanced due to differences in the initial oxygen concentration and the changes in the

buffer capacity (i.e., increasing Revelle Factor) with increasing respiration from the oxidation of organic matter, with the largest impacts on pH and CO_2 partial pressure (pCO_2) occurring in the colder West Coast waters. As anthropogenic CO_2 concentrations begin to build up in subsurface waters, increased atmospheric CO_2 will expose organisms to hypercapnic conditions (pCO_2 >1000 μatm) within subsurface depths. Since the maintenance of the extracellular pH appears as the first line of defense against external stresses, many biological response studies have been focused on pCO_2-induced hypercapnia. The extent of subsurface exposure will occur sooner and be more widespread in colder waters due to their capacity to hold more dissolved oxygen and the accompanying weaker acid-base buffer capacity. Under present conditions, organisms in the West Coast are exposed to hypercapnic conditions when oxygen concentrations are near 100 μmol kg^{-1} but will experience hypercapnia at oxygen concentrations of 260 μmol kg^{-1} by year 2100 under the highest elevated-CO_2 conditions. Hypercapnia does not occur at present in the Gulf of Mexico but will occur at oxygen concentrations of 170 μmol kg^{-1} by the end of the century under similar conditions. The aragonite saturation horizon is currently above the hypoxic zone in the West Coast. With increasing atmospheric CO_2, it is expected to shoal up close to surface waters under the IPCC Representative Concentration Pathway (RCP) 8.5 in West Coast waters, while aragonite saturation state will exhibit steeper gradients in the Gulf of Mexico. This study demonstrates how different biological thresholds (e.g., hypoxia, $CaCO_3$undersaturation, hypercapnia) will vary asymmetrically because of local initial conditions that are affected differently with increasing atmospheric CO_2. The direction of change in amplitude of hypercapnia will be similar in both ecosystems, exposing both biological communities from the West Coast and Gulf of Mexico to intensification of stressful conditions. However, the region of lower Revelle factors (i.e., the Gulf of Mexico), currently provides an adequate refuge habitat that might no longer be the case under the most severe RCP scenarios.

Feely R. A., Okazaki R. R., Cai W.-J., Bednaršek N., Alin S. R., Byrne R. H. & Fassbender A., 2018. The combined effects of acidification and hypoxia on pH and aragonite saturation in the coastal waters of the California current ecosystem and the northern Gulf of Mexico. *Continental Shelf Research* 152: 50-60. Article (subscription required).

Estuaries may experience accelerated impacts of human-caused CO2

Rising anthropogenic, or human-caused, carbon dioxide in the atmosphere may have up to twice the impact on coastal estuaries as it does in the oceans because the human-caused CO_2 lowers the ecosystem's ability to absorb natural fluctuations of the greenhouse gas, a new study suggests.

Researchers from the U.S. Environmental Protection Agency and Oregon State University found that there was significant daily variability when it comes to harmful indices of CO_2 for many marine organisms in estuaries. At night, for example, water in the estuary had higher carbon dioxide, lower pH levels, and a lower saturation state from the collective "exhale" of the ecosystem.

These night-time harmful conditions are changing about twice as fast as the daily average, the researchers say, meaning the negative impacts on shell-building animals, including oysters, clams and mussels, may manifest more quickly than expected from simply observing the daily average.

Results of the study are being published April 2 in *Proceedings of the National Academy of Sciences*. The study was funded and led by the EPA's Office of Research and Development and Region 10, through a Regional Applied Research Effort grant. The project was coordinated by Stephen Pacella, an EPA scientist who also is a doctoral student in OSU's College of Earth, Ocean, and Atmospheric Sciences.

"In these environments that are dominated by marine plants, photosynthesis and respiration cause large differences in CO_2 concentrations and the addition of anthropogenic carbon make these day-to-night differences even larger than they would be without that extra carbon," said George Waldbusser, an Oregon State marine ecologist and co-author on the study, who serves as Pacella's Ph.D. adviser.

"The continued addition of CO_2 to these waters results in the worst conditions changing twice as fast due to the loss of the system's ability to buffer itself," Waldbusser said.

This is one of the first studies to analyze the dynamics of an estuarine carbonate system on such a fine time scale. Pacella's research focused on an underwater seagrass habitat in Washington state's Puget Sound, which varied between one and four meters in depth. He spent two-and-a-half months monitoring the native eelgrass habitat, which is common to Puget Sound.

The researchers say that although the study focused on a habitat in Puget Sound, the results provide an important framework to evaluate other seagrass and estuarine habitats that tend to have lower inherent buffering capacity and large natural variations in chemistry.

Pacella, who was lead author on the study, used the detailed data he collected to create a model to estimate the daily carbonate chemistry weather during the summer dry season back to the year 1765, and also projected conditions ahead to 2100 altering the amount of anthropogenic carbon in the system.

His measurements and model demonstrates that seagrasses make CO_2 lower during the day, and higher at night, compared to a system without seagrass. The model however predicts that by 2060 atmospheric CO_2 levels will be high enough that harmful nighttime high CO_2levels would actually be more frequent if the seagrass weren't there. So, presently there are relatively more frequent high CO_2 times because of the seagrass, but after 2060 there are relatively fewer high CO_2 times with seagrass than there would be with no seagrass.

"There is tremendous interest in using marine plants to locally mitigate excess CO_2 in coastal waters to the benefit of other sensitive marine species, such as oysters," Waldbusser said. "Steve's very nice work on this topic is among the first in temperate estuaries to demonstrate the potential for this mitigation, while noting that the real benefits may still be a few decades away."

However, the researchers point out that seagrass should be looked at holistically, not just through a carbon budget lens, because it also offers ecological benefits including habitat to marine organisms.

Waldbusser has called these changing daily CO_2 conditions "carbonate weather" because changes in the chemistry are so dramatic depending on the time of the day – much like the difference and interaction between weather and climate.

"Organisms, including us, experience the weather – and climate is what causes changes to the weather," Waldbusser said. "However, we can't really 'feel' the gradual change in global temperature. We do, though, experience the extreme weather events or flooding, which are predicted to get worse due to gradual increases in sea level.

"In this case, the carbonate chemistry history is changing more rapidly than we anticipated. As with sea level rise, the graduate increase becomes more important during events that amplify those otherwise naturally occurring cycles."

The researchers say they are still working to better understand how these events – versus changes in average conditions – affect the long-term health of species that are sensitive to ocean acidification. There also are implications for how water quality criteria are set.

"If, as we tend to believe, extreme events matter to marine organisms, the research suggests that more work is needed to define water quality criteria that incorporate daily changes in the highs and lows of CO_2 rather than just utilizing average daily or annual conditions," Waldbusser said.

Journal Reference:

1. Stephen R. Pacella, Cheryl A. Brown, George G. Waldbusser, Rochelle G. Labiosa and Burke Hales. **Seagrass habitat metabolism increases short-term extremes and long-term offset of CO2 under future ocean acidification**. *PNAS*, April 2, 2018 DOI: 10.1073/pnas.1703445115

Oregon State University (via ScienceDaily), 2 April 2018. Press release.

Biologists discover that female purple sea urchins prime their progeny to succeed in the face of stress

Source: University of California – Santa Barbara

Summary: This story begins in the kelp forest and ends with a very important climate change message: All is not lost – at least not for purple sea urchins.

Eggs released from a female purple sea urchin. *Credit: Marie Strader*

This story begins in the kelp forest and ends with a very important climate change message: All is not lost – at least not for purple sea urchins.

A new study by UC Santa Barbara marine biologists demonstrates that for females of the species (*Strongylocentrotus purpuratus*), exposure to stressful climate conditions such as low pH levels often makes for hardier, larger offspring. The group's findings appear in the journal *Molecular Ecology.*

"We've known that these things go on in fish and other species, but we've never studied this in the context of climate change in the marine ecology of kelp forests," said co-author Gretchen Hofmann, chair of UCSB's Department of Ecology, Evolution, and Marine Biology. "This project looked for evidence of rapid adaptation in organisms in response to a changing ocean — and we found it."

Inspired by dynamic shifts in pH due to upwelling — the movement of nutrient-rich water toward the ocean surface — the researchers took urchins from the Santa Barbara Channel and brought them into the lab. The animals were held for about four months while the females made ripe eggs — a process called gametogenesis. When they spawned and were fertilized, the investigators tested the embryos.

Two groups of urchins were held at different pH levels — one that was low pH, akin to ocean acidification conditions, and another that mimicked normal non-upwelling pH conditions. The researchers then compared the progeny of the two groups.

"It was more dramatic than we expected," Hofmann said. "It's almost like the female could sense that her progeny were about to be released into some challenging conditions for early-stage development. In response, she primed her offspring and gave them tools to face stressful conditions. It's like she packed them a backpack of tools, including extra lipids."

Using next-generation sequencing technology, the scientists examined the transcriptome — every gene activated in the embryo — to create a snapshot of how baby urchins responded physiologically.

"The two groups were radically different," said lead author Juliet Wong, a graduate student in the Hofmann Lab. "Urchin larvae from females exposed to low pH conditions had more genes turned on and were better prepared to handle stress. We were pretty surprised to see that."

One of the mechanisms driving alterations in gene expression is epigenetic change, where the female is able to change her offspring's genome to cause certain genes to be expressed differently.

"This work shows that a rapid adaptation response is likely possible in many organisms," Hofmann explained. "We just haven't looked at these transgenerational or maternal effects in a climate change context before. Because purple sea urchin females can condition their progeny to experience future stress, the urchins have tools at hand to respond to changes like ocean acidification."

Researchers worldwide are studying how these types of mechanisms might work in other marine organisms such as tropical corals threatened by ocean warming. For Hofmann's team, the next step is more closely examining the genome-to-phenotype transition and attempting to replicate these new findings in the ocean.

Members of the lab are already starting field experiments to test whether or not these epigenetics play out in local kelp forests, as part of research within the Santa Barbara Coastal Long Term Ecological Research project.

"For now," Hofmann said, "we know that female urchins are able to prepare their offspring to experience harsher conditions — more so than we ever thought — so our results are somewhat hopeful."

"This important study tests the mechanisms that determine how organisms are likely to respond to ocean acidification in natural settings," said David Garrison, program director in the National Science Foundation's Division of Ocean Sciences, which funded the research.

Original post: https://www.sciencedaily.com/