State of the Science FACT SHEET

Ocean Acidification

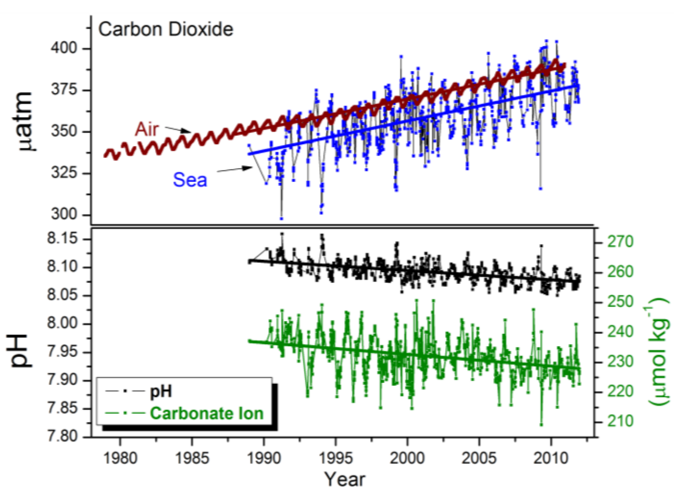
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION • UNITED STATES DEPARTMENT OF COMMERCE

This document represents the state of the science on ocean acidification as developed by NOAA.

What is Ocean Acidification?

Ocean acidification (OA) refers to changes in global ocean carbon chemistry in response to rising levels of atmospheric carbon dioxide (CO_2). When absorbed by ocean and Great Lakes surface waters, CO_2 acidifies them (i.e., reducing pH), increases the carbon content, and causes a decrease in the availability of carbonate ions important to carbonate mineral formation (e.g., shells, reef frameworks, marine sediments). Today's ocean pH has declined by 0.1 globally since the industrial revolution (an increase in acidity of about 30%) and is projected to decline by an additional 0.3 over the next century unless global carbon emissions are significantly curtailed. Such changes are at least ten times faster than at any time over the past 50 million years and can be observed in extended ocean time-series observations. Local factors controlling carbonate chemistry (e.g., upwelling, riverine discharge, nutrient loading, hypoxia, organic carbon remineralization) further modify OA at regional and local scales. Understanding OA and predicting the consequences for marine resources is necessary for informing national and international carbon mitigation discussions and enabling local communities to better prepare and adapt to such changes.

The 'Other' CO_2 Problem



Ocean acidification in the surface ocean near Mauna Loa Observatory in Hawaii. Adapted from Dore et al., 2009. Proc Natl Acad Sci USA 106:12235-12240. As CO_2 increases (top), the ocean's pH and carbonate ion concentrations decline (bottom).

What are the Impacts to Marine Life?

The geological record reveals several acidification events in the distant past which limited the abundance, diversity, and evolution of calcifying organisms throughout the world's oceans. Laboratory and field studies help scientists better understand the implications of modern OA resulting from human activities. These studies demonstrate that many marine species will likely experience adverse effects on health, growth, reproduction, and survival particularly in early life-stages.

An Ecological Challenge

Predicting how OA will impact marine ecosystems and the services they provide demands a multidisciplinary and cross-agency approach.

Most species of coral, calcifying algae, coccolithophores, and molluscs (including some economically important oysters), calcify slower under OA. The effect of OA on marine crustaceans (e.g., copepods, crabs, lobsters, crayfish, shrimp, krill and barnacles) is inconclusive at this time. However, decreases in survival, growth rate, and egg production have been reported for some species. Effects on non-calcifying organisms also have been demonstrated, including on the development of larval stages of some fish and on the ability to detect predators. Reduced survival and growth of sea urchins, sand dollars, seastars, sea cucumbers, and brittlestars may also occur. Some phytoplankton and seagrasses may benefit from OA, likely furthering shifts in community composition.

What Are the Potential Socio-Economic Consequences of Ocean Acidification?

Global marine ecosystem services, many of which are likely to be impacted by OA, have been estimated at a total annual value of US$20 trillion[1]. Socioeconomic modeling efforts represent an important aim of the NOAA OA research strategy. Should OA broadly impact marine habitats and alter marine resource availability as anticipated, substantial revenue declines, job losses, and indirect economic costs would occur[2]. Effects to human communities would include changes in shellfish harvest, coral and oyster reef ecoservices, and indirect impacts across marine food webs. A few examples are:

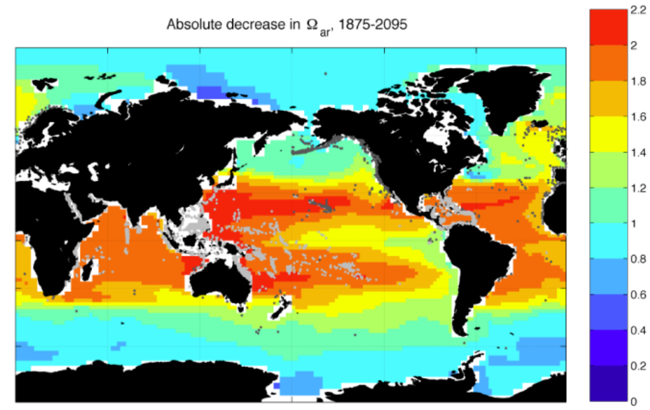
- Coral reefs provide habitat for an estimated one million species, and offer food, income, and coastal protection for about 500 million people globally. NOAA has identified OA as a contributing threat to coral reefs in the recently proposed Endangered Species Act (ESA) listings. OA serves as an additional stress to an already challenged ecosystem threatened by unsustainable fishing, warming seas and pollution.

- In 2009, U.S. shellfish represented about half the total seafood revenue estimated at $3.9 billion. OA already has been identified as affecting key sectors of this industry along the Pacific Northwest. Failures at oyster hatcheries beginning in 2007 have been linked to OA. Washington's seafood industry is estimated to contribute to over 42,000 jobs and at least $1.7 billion to the gross state product through profits and employment at businesses such as restaurants, distributors, and retailers. A Blue Ribbon Panel was convened in 2012 by Washington State Governor Gregoire, uniting scientists, decision makers, industry stakeholders, tribal representatives, and conservation representatives to address the issue. The panel produced a set of 42 recommendations to guide Washington's response[3].

NOAA's Research on Ocean Acidification

NOAA works to improve understanding of OA and impacts to marine resources. A global network of ship surveys and time-series stations monitoring atmospheric and oceanic CO_2 have provided a strong foundation to understand OA globally. Characterizing OA at regional and local scales, particularly within coastal margins and estuaries, remains a key challenge. Knowledge of how local processes can alter the dynamics of OA is needed to inform management actions to prevent, mitigate, or adapt to OA. NOAA is working to establish long-term high quality OA observations within ocean, coastal, and coral reef environments using a network of targeted and volunteer ship surveys, fixed mooring observations, and advanced technologies. This information is guiding experiments conducted on commercially and ecologically significant organisms to better advance eco-forecasting and socioeconomic modeling efforts. NOAA also continues to develop state of the art Earth System Models of OA projections for use by scientific and resource management communities. Improving our understanding of how OA occurs regionally and teasing out the broad range of vulnerabilities will aid in developing local management and adaptation practices. Finally, informing society about the growing concerns of OA through education and outreach resources is an important part of all NOAA efforts.

A Sea of Change



Shown here is the projected decline in aragonite saturation state (Ω) in response to OA as adapted from Feely et al., 2009[4]. OA is projected to differ between regions whereby tropical waters housing coral reefs will experience the greatest overall change but polar waters will actually become corrosive by 2100.

NOAA laboratories contribute to several international and national research programs studying OA. National coordination is organized through the Interagency Working Group on OA and the Ocean Carbon and Biogeochemistry Program, among others. The International Coordination Centre on OA is further expected to facilitate information sharing between researchers and policymakers across the globe. Additional resources are available from the NOAA Ocean Acidification Program at www.oceanacidification.noaa.gov.

[1] Costanza, R., et al., 1997. The value of the world's ecosystem services and natural capital. *Ecol. Econom*. 25 (1), 3–15.

[2] Cooley, S. R. and S. C. Doney, 2009. Anticipating ocean acidification's economic consequences for commercial fisheries. *Environmental Research Letters* 4(2): 024007.

[3] Washington State Blue Ribbon Panel on Ocean Acidification (2012): *Ocean Acidification: From Knowledge to Action, Washington State's Strategic Response*. H. Adelsman and L. Whitely Binder (eds). Washington Department of Ecology, Olympia, Washington. Publication no. 12-01-015. www.ecy.wa.gov

[4] R.A. Feely, S.C. Doney, and S.R. Cooley. 2009. Ocean Acidification: Present Conditions and Future Changes in a High-CO2 World . *Oceanography* 22(4):36–47, doi:10.5670/oceanog.2009.95.