State of the Science FACT SHEET

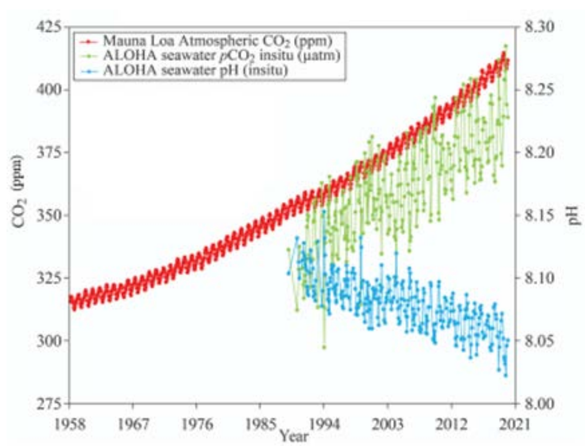
Ocean Acidification

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION • UNITED STATES DEPARTMENT OF COMMERCE

This document describes the state of the science on ocean acidification, including effects on marine life and ecosystems, and its socio-economic consequences.

What is Ocean Acidification?

Ocean acidification (OA) refers to a decline in pH accompanied by other changes in ocean chemistry over extended periods, primarily due to rising levels of atmospheric carbon dioxide (CO_2) as it is absorbed by the ocean and the Great Lakes. The rise in atmospheric CO_2 is primarily due to the burning of fossil fuels (such as coal, petroleum, and natural gas), cement production, and land use change. Increased OA slows the formation and promotes the erosion of shells, crustacean exoskeletons, and coral reef frameworks, and may alter the growth and behavior of a broad range of marine species in ways not yet fully understood.

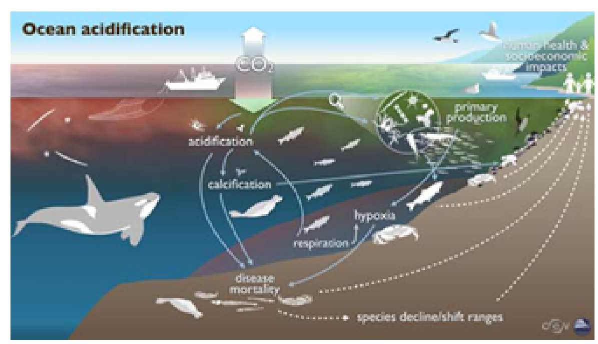


As CO2 increases (red), the ocean's pH (blue) declines. Measurements near Mauna Loa Observatory in Hawaii. (Figure credit: NOAA PMEL Carbon Group)

Global surface ocean pH has declined on average by approximately 0.1 since the Industrial Revolution, an increase in acidity of about 30%. These changes can be observed in extended ocean time-series and are at least ten times faster than any period over the past 50 million years. Ocean pH is projected to decline an additional 0.39 units over the next century unless global carbon emissions are significantly curtailed. Within the coastal zones, acidification can be further exacerbated by local factors such as upwelling, nutrient loading, and biological respiration and is termed coastal acidification. Coastal acidification can be episodic and event driven while ocean acidification generally refers to the multidecadal decline in pH driven by the supply of anthropogenic carbon from the atmosphere. To marine organisms, ocean and coastal acidification are often entangled and indistinguishable. While this document refers to OA, coastal acidification is implied as a co-occurring factor within coastal and near-shore environments. Understanding OA and predicting the consequences for marine resources and services is necessary for informing national and international carbon mitigation discussions, and enabling local communities to better prepare for and adapt to such changes.

What are the Impacts to Marine Life?

Laboratory and field studies improve our understanding of the biological implications of OA. Species vary in their sensitivity, with some responding positively, some negatively, and others not at all. Overall, studies suggest that many marine species will experience adverse effects on health, growth, reproduction, and survival, particularly in early life-stages.



OA is expected to impact organisms and cause changes to the marine food web. These changes lead to socio-economic consequences. Predicting how it will impact marine ecosystems and the services they provide demands a multidisciplinary and cross-agency approach (Figure credit: Simone Alin, NOAA PMEL, and Hunter Hadaway, University of Washington Center for Environmental Visualization)

Organisms that produce calcium carbonate structures, like corals, shellfish, coralline algae, pteropods, and urchins, are generally most sensitive because OA compromises their ability to build and maintain their structure. Reduced growth and faster dissolution puts highly valued habitats like oyster beds and coral reefs at risk, potentially disrupting ecosystem function and food web dynamics. OA may hinder the ability for reefs to recover from acute mortality events due to thermal stress (i.e. bleaching), disease, storms and local disturbances.

Non-calcifying organisms have also demonstrated negative health effects with OA affecting the nervous system function of some fish, impacting their ability to navigate and detect predators. Predators could experience indirect effects from food web interactions (e.g., loss of their food source). On the other hand, some seagrasses and phytoplankton may benefit from the CO_2 enrichment which accompanies OA, further shifting community composition and the food webs on which we are dependent.

OA does not occur in isolation as species are often simultaneously exposed to other stressors, such as low oxygen and increased temperatures. These co-occurring stresses can have complex effects on species, sometimes amplifying one another, but other times reducing overall species response. NOAA is conducting laboratory and field studies on the impact of multiple stressors on marine organisms to better predict future implications of a high CO_2 world.

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

Globally, marine ecosystem services may be impacted; thus socio-economic modeling represents an important aim of the NOAA OA research strategy. Substantial revenue declines, job losses, and indirect economic costs could occur should marine habitats be broadly impacted and marine resource availability altered[1]. Many valuable fisheries are based on shellfish, which are susceptible to OA[2]. Human communities could also be affected by impacts to culturally significant species, coral and oyster reef ecosystem services, and species important for subsistence harvesting. See the following examples:

- Coral reefs provide habitat for an estimated one million species and offer food, income and coastal protection to about 500 million people globally. NOAA has identified OA as a contributing threat to coral reefs in the Endangered Species Act listings. OA serves as an additional stress to an already challenged ecosystem threatened by warming seas and pollution. The Environmental Protection Agency estimates a $140 billion loss in reef-based recreation in Hawaii, South Florida, and Puerto Rico from global Change effects[3].
- In 2019, total U.S. shellfish landings were valued at $3.5 billion[4]. Failures at Pacific oyster hatcheries beginning in 2007 with large economic consequences have been linked to OA[5]. In response, states and regions around the U.S. have developed task forces and action plans to evaluate and combat problems of OA in local waters. Further, some shellfish hatcheries in Washington State have adapted to acidifying conditions through buffering their seawater during production, while other have relocated operations to other more resilient locations. These techniques represent a pathway towards resilience and adaption for the shellfish aquaculture industry[6].

NOAA's Research on Ocean Acidification

Regional differences in OA rates and variable species sensitivity[7] contribute to large uncertainties in predicting impacts to the Blue Economy (economic sectors tied to oceans and coasts), and more research is needed to answer numerous questions related to the consequences on marine biology. NOAA works to reduce uncertainty through OA monitoring, data management, data quality control and synthesis activities[8], modeling, species response research, and examining potential socio-economic impacts. NOAA collects long-term, high-quality OA observations within ocean, coastal, and coral reef environments to identify temporal changes in carbon chemistry, making these data and derived products available to the international science community and decision makers. Knowledge of how local processes can alter the dynamics of OA is needed to inform local management actions to prevent, mitigate, or adapt to OA. NOAA observations are guiding experiments conducted on commercially, ecologically, and culturally significant organisms to better predict how OA may impact ecosystems and the services they provide. NOAA also continues to develop state-of-the-art global and regional oceanographic models that simulate historical changes and project future OA conditions for use by scientific and resource management communities. Finally, informing society about the growing concerns of OA through education and outreach resources is an important part of all NOAA efforts

Additional resources, including the 2020 NOAA OA Research Plan are available from the NOAA Ocean Acidification Program at: www.oceanacidification.noaa.gov

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3 EPA. 2017. Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment. U.S. Environmental Protection Agency, 430-R-17-001.

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6 Clements, Jeff C., and Thierry Chopin. "Ocean acidification and marine aquaculture in North America: potential impacts and mitigation strategies." Reviews in Aquaculture 9.4 (2017): 326-341.

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