State of the Science FACT SHEET

Ocean Acidification

This document represents the state of the science as developed by several NOAA researchers. NOAA's ocean acidification activities include targeted research on changes in the ocean carbon chemistry and pH, impacts on major coastal and pelagic ecosystems and fisheries and socio-economic systems.

What is Ocean Acidification and How Does it Affect Marine Species?

- The oceans have absorbed about 50% of the carbon dioxide (CO_2) released from the burning of fossil fuels, resulting in chemical reactions that lower ocean pH. This has caused an increase in hydrogen ion (acidity) of about 30% since the start of the industrial age through a process known as "ocean acidification." A growing number of studies have demonstrated adverse impacts on marine organisms, including:
- The rate at which reef-building corals produce their skeletons decreases *(Figure 1)*.
- The ability of marine algae and free-swimming zooplankton to maintain protective shells is reduced *(Figure 2)*.
- The survival of larval marine species, including commercial fish and shellfish, is reduced.

$$H_2O + CO_2 + CO_3^{-2} \rightarrow 2HCO_3^-$$

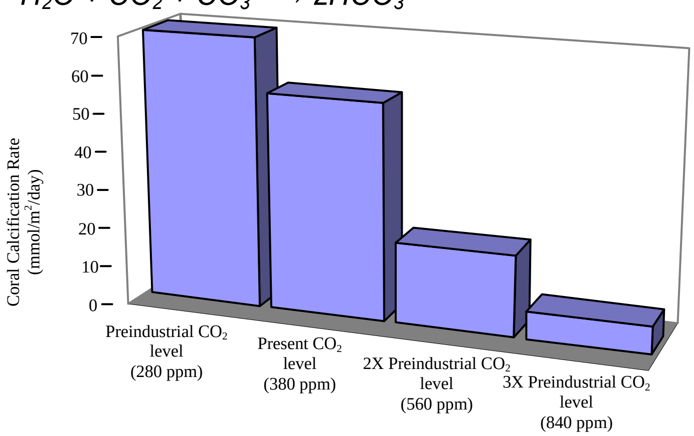

***Figure 1**. Potential impact of rising atmospheric CO_2 on coral reef calcification rate.*

What Are the Broader Impacts of Ocean Acidification?

- The reduced rate of coral reef building could lead to diminished resiliency from bleaching, disease, and coral death at potentially increased frequency as a result of warmer ocean temperature.
- Reef building rates could decrease to levels insufficient to maintain reefs in any oceans when atmospheric CO_2 levels reach ~840ppm *(Figure 1)*, which may be reached by the year 2100.
- Marine plankton is a vital food source for many marine species and their decline could have serious consequences for the marine food web.

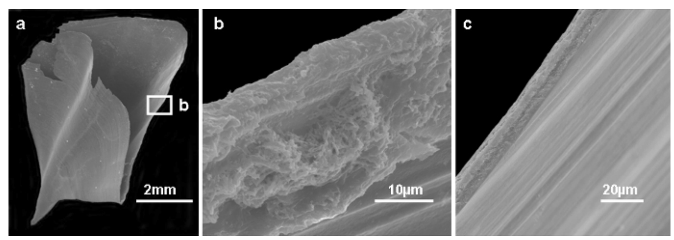

***Figure 2.** Photomicrographs of the shell of the pteropod, Clio pyramidata, collected from the subarctic Pacific. (a) Whole shell from a live pteropod kept in corrosive seawater for 48 hours; the white rectangle indicates the location of the magnified area in (b), which shows advanced dissolution along the leading edge of the shell. (c) No dissolution is observed at the leading edge of shell from Clio pyramidata kept in non-corrosive seawater (photos from V. Fabry).*

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

Ocean acidification will have long-term implications for the global carbon cycle and climate, although the range and magnitude of biogeochemical and biological effects and their socio-economic impacts are currently too uncertain to accurately quantify. However, we do know that such impacts are likely to be substantial.

- The U.S. is the third largest seafood consumer in the world - total consumer spending for fish and shellfish is approximately $60 billion per year. Coastal and marine commercial fishing generates as much as $30 billion per year and nearly 70,000 jobs. Healthy coral reefs are the foundation of many of these viable fisheries, as well as the source of tourism and recreation revenues.
- Approximately half of all federally managed fisheries depend on coral reefs and related habitats for a portion of their life cycles yielding an estimated value to U.S. fish stocks over $250 million.

• Changes to the stability of coastal reefs may reduce the protection they offer to coastal communities against storm surges and hurricanes.

What Are the Key Ocean Acidification Research Goals?

- *Monitor* the changing ocean chemistry and biological impacts at selected coastal and open-ocean monitoring stations.
- *Support research* addressing the species-specific physiological response of marine organisms to ocean acidification and develop environmental and ecological indices that track marine ecosystem responses to ocean acidification.
- *Expand NOAA modeling efforts* to predict changes in the ocean carbon cycle as a function of CO_2 and climate-induced changes in temperature, ocean circulation, biogeochemistry, ecosystems and terrestrial input; and model ocean acidification impacts on biological cycling.
- *Advance technology development and standardization* for carbonate chemistry measurements on moorings and autonomous floats.
- *Promote satellite monitoring* in terms of both characterizing reef habitats and modeling changes in surface ocean chemistry in response to ocean acidification.
- *Advance the analysis of social and economic implications* of ocean acidification and study the potential adaptation strategies to help society cope with and respond to climate-induced changes in marine ecosystems.

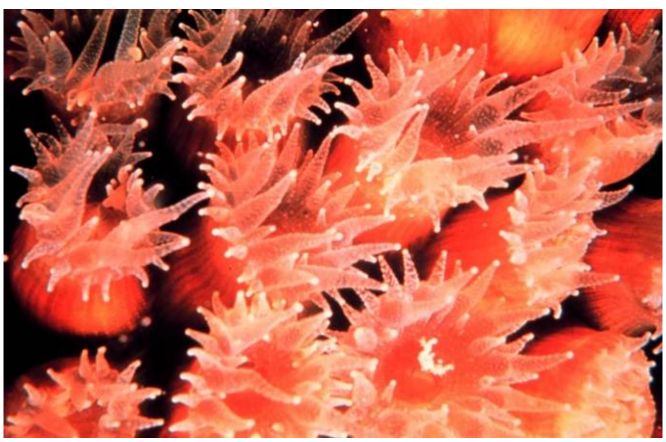

***Figure 3**. Cavernous Star Coral (Montastrea cavernosa) in the Florida Keys National Marine Sanctuary. Photo: Florida Keys National Marine Sanctuary Staff.*

Resources for Additional Information

NOAA laboratories contribute to several international and national research programs that study ocean acidification.

NOAA Office of Oceanic and Atmospheric Research Pacific Marine Environmental Laboratory/Ocean Climate Research Division: Physical and chemical understanding of the impacts of climate on marine ecosystems through use of physical and chemical sensors on ships, moorings, and floats, etc; monitoring of changing ocean CO_2 and pH; and monitoring of changing calcification of coral reef ecosystems. PMEL and AOML contributions to the joint NOAA/NSF CLIVAR/ CO_2 Repeat Hydrography Program, and the NOAA Global Carbon Cycle (GCC) Program have documented the spatial and temporal changes in carbon and pH distributions of the global oceans. http://www.pmel.noaa.gov/co2/OA

Atlantic Oceanographic and Meteorological Laboratory Ocean Chemistry Division: Chemical and biological understanding of coral reef ecosystems; monitoring of changing ocean CO_2 and pH through use of chemical sensors on ships, and moorings. AOML and the University of Miami have deployed commercially available CO_2 sensors on NOAA Integrated Coral Observing Network stations (ICON) at two reefs in the Caribbean. http://www.aoml.noaa.gov/ocd

Geophysical Fluid Dynamics Laboratory: Studies of climate variability and change; development and use of the required climate models; development of biogeochemical and ecosystem models used for ocean acidification projections. GFDL works cooperatively in NOAA to advance the assessment of global climate through modeling elevated CO_2 on the ocean. http://www.gfdl.noaa.gov

Climate Program Office: Intramural and extramural support for development of a predictive understanding of the climate system, the required observational capabilities, delivery of climate services. http://www.climate.noaa.gov

National Environmental Satellite, Data and Information Service (NESDIS). Coral Reef Watch: Near real-time and long term monitoring, modeling and reporting of environmental conditions impacting coral reef ecosystems; modeling sea surface ocean carbon chemistry from satellite remote sensing and coupled in situ observations tailored for management. http://coralreefwatch.noaa.gov

NOAA National Marine Fisheries Service: The Marine Ecosystems Division of the Office of Science and Technology serves as the focal point for science issues related to biology, ecology, fisheries oceanography, climate coastal ecosystems, ecosystem science for living marine resource management required to fulfill NOAA fisheries science and management mandates. NOAA's Alaska Fisheries Science Center (AFSC) researches the effects of decreased pH on king crab larval growth and survival and forecasts fishery impacts. NOAA's Northwest Fisheries Science Center (NWFSC) uses food web ecosystem models to address the fate of other marine species in response to a decline in pH-susceptible species. NOAA's Southwest Fisheries Science Center (SWFSC) is analyzing samples of pteropods taken from 1955-1995 for changes that may have occurred over the past 40 years in the California Current. http://www.nwfsc.noaa.gov