



Ocean Acidification

Eugene H. Buck

Specialist in Natural Resources Policy

Peter Folger

Specialist in Energy and Natural Resources Policy

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Summary

With increasing concentrations of carbon dioxide (CO₂) in the atmosphere, the extent of effects on the ocean and marine resources is an increasing concern. One aspect of this issue is the potential for seawater to become increasingly acidic (i.e., ocean acidification). Scientists are concerned that increasing acidity could result in reduced growth or even death of shell-forming animals (e.g., molluscs and certain planktonic organisms) as well as disruption of marine food webs and reproductive physiology. Congress is beginning to focus attention on better understanding this issue and determining how it might be addressed.

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What Is Ocean Acidification?

As increasing carbon dioxide (CO₂) from the atmosphere dissolves in seawater, seawater chemistry is altered. The prevailing pH of the ocean is around 8.1, or slightly alkaline.¹ Ocean acidification is the name given to the process whereby pH decreases as seawater becomes more acidic (i.e., less alkaline) when increasing amounts of anthropogenic CO₂ from the atmosphere dissolve in seawater to form carbonic acid. Scientists are concerned that increasing acidity could disrupt physiological processes of marine organisms and detrimentally alter marine ecosystem relationships.

At What Rate Is Ocean Acidification Occurring and What Factors Affect This Rate?

Of the approximately 7 billion metric tons of carbon that all the countries in the world release as CO₂ into the atmosphere each year, the oceans take up about 2 billion tons.² Between pre-industrial times and 1994, average surface ocean pH is estimated to have decreased (i.e., acidity increased) almost 0.1 pH unit.³ That increase sounds small, but it represents an increase of 20% in the concentration of hydrogen ions, because the pH scale is logarithmic (i.e., a pH of 7 is ten times more acidic than a pH of 8, and one hundred times as acidic than a pH of 9). More recent research indicates that the rate of acidification, at least in some locations, may be proceeding much more rapidly.⁴ As long as atmospheric CO₂ continues to increase, many scientists expect the oceans to continue to become more acidic.

Gases, such as CO₂, are generally less soluble in warm water than in cold water. Thus, marine waters near the poles have a much greater capacity for dissolving CO₂ than do ocean waters in the tropics. It follows that the rate of ocean acidification, and the appearance of impacts on physical and biological features, initially may be more likely to occur in marine waters nearer the poles.

Key scientific questions concern which factors may affect the future rate of acidification, especially whether the rate of increase will remain constant in direct relationship to the amount of CO₂ in the atmosphere or whether other factors will result in an acceleration or deceleration of this acidification rate. There is also the question of equilibrium—that is, how long will it take the acidification process of ocean waters to come into equilibrium with the concentration of atmospheric CO₂? An adjunct to this question is how long will it take the rate of ocean

¹ The pH scale is an inverse logarithmic representation of hydrogen proton (H⁺) concentration, indicating the activity of hydrogen ions (or their equivalent) in the solution. A pH of less than 7.0 is considered acidic, while a pH greater than 7.0 is considered basic (alkaline); a pH level of 7.0 is defined as “neutral.”

² Dr. Richard A. Feely, Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, World Ocean Forum, Nov. 13-14, 2006, at http://www.thew2o.net/events/oceans/oa_q_and_a.php.

³ James C. Orr et al., “Anthropogenic Ocean Acidification over the Twenty-First Century and Its Impact on Calcifying Organisms,” *Nature*, vol. 437 (2005): 681-686.

⁴ J. Timothy Wootton, Catherine A. Pfister, and James D. Forester, “Dynamic Patterns and Ecological Impacts of Declining Ocean pH in a High-Resolution Multi-Year Dataset,” *Proceedings of the National Academy of Sciences of the United States of America*, v. 105, no. 48 (Dec. 2, 2008): 18848-18853.

acidification to slow in response to any measures that might be taken to slow or halt the increasing concentration of CO₂ in the atmosphere?

What Are Some of the Potential Effects of Ocean Acidification?⁵

Even with increasing concentrations of atmospheric CO₂, the oceans are not likely to reach pH values of less than 7 (neutral). But as CO₂ dissolves into the ocean's surface waters, it changes the proportions of ions available to marine organisms who make biogenic calcium carbonate to form shells. As more CO₂ dissolves into the surface ocean, not only are some organisms hindered in their ability to make calcium carbonate, but calcium carbonate skeletons of marine organisms may actually start to dissolve at or near the ocean surface in some parts of the globe.

These changes are occurring because of the complex interplay between rising CO₂ levels in the atmosphere and the ocean's chemistry, a process that scientists have recognized for decades. When atmospheric CO₂ dissolves into the ocean, it forms carbonic acid (H₂CO₃). Some of the carbonic acid dissociates in ocean waters producing hydrogen ions (H⁺) and bicarbonate ions (HCO₃⁻). As the number of hydrogen ions increases, the pH of the ocean gets lower, or more acidic. When more CO₂ is added to the atmosphere, more carbonic acid forms in the ocean. Over the past several decades, about half of the CO₂ released by human activities has remained in the atmosphere; of the remainder, about 30% has entered the oceans.⁶ As a result, the additional carbonic acid has increased average ocean acidity by approximately 0.1 pH unit (i.e., an increase of 20% in hydrogen ion concentration).⁷

A lower pH affects marine life in the oceans and is related to other changes in ocean chemistry. For example, the bicarbonate ion (HCO₃⁻) mentioned above further dissociates into H⁺ and carbonate ions (CO₃²⁻), and it is the abundance and availability of carbonate ions that are critical to many shell-forming marine organisms. At current average ocean pH levels (about 8 or above), ocean surface waters have ample carbonate ions to form shells and grow corals. However, as increased amounts of carbonic acid form in the ocean from higher CO₂ levels in the atmosphere, pH gets lower and the amount of carbonate ion in the oceans decreases, resulting in less carbonate ion available for making shells.

Organisms make biogenic calcium carbonate for their shells by combining calcium ions (Ca²⁺)—which are abundant in the oceans—with carbonate ions to form solid calcium carbonate (CaCO₃). Marine organisms such as corals and pteropods use one mineral type of calcium carbonate called aragonite, and other organisms such as foraminifera and coccolithophorids use another type called calcite. Under present conditions of ocean chemistry, both forms of calcium carbonate are

⁵ Since the marine environment is complex and some of the likely changes may be years in the future, the potential effects identified in this section, although many are supported by laboratory experimentation, are primarily conjecture and/or forecasts.

⁶ Richard A. Feely et al., "Impact of Anthropogenic CO₂ on the CaCO₃ System in the Oceans," *Science* (2004), vol. 305, pp. 362-366.

⁷ James C. Orr et al., "Anthropogenic Ocean Acidification over the Twenty-First Century and Its Impact on Calcifying Organisms," *Nature*, vol. 437 (2005): 681-686.

relatively stable in the surface ocean. The surface ocean is deemed saturated with respect to both calcite and aragonite, meaning that organisms can form shells from either mineral type. However, as more carbonic acid is added to the surface ocean from higher levels of CO₂ in the atmosphere, the level of saturation decreases. If the ocean waters become undersaturated, then shells made from aragonite or calcite would tend to dissolve. Shells made from aragonite would tend to dissolve first, at lower concentrations of carbonic acid (and thus at higher pH values) than would shells made from calcite.

Although surface waters currently are more than fully saturated with carbonate, declining carbonate concentrations (caused by increasing acidity) are projected to reduce the ability of organisms to form biogenic calcium carbonate. Some suggest that marine surface waters closer to the poles may become undersaturated within the next 50 years.⁸ Researchers at the Antarctic Climate and Ecosystems Cooperative Research Centre have demonstrated significant reductions in shell mass and thickness of several Southern Ocean marine plants and animals that appear consistent with the projected effects of recent increased acidification of the ocean.⁹

In response to ocean acidification, scientists have projected that mussel and oyster calcification, and thus shell strength, could decrease by 25% and 10%, respectively, by the end of the 21st century, according to the Intergovernmental Panel on Climate Change's IS92a scenario.¹⁰ There is also the concern that increased acidification may cause marine calcium carbonate sediments to dissolve with potential detrimental effects on species and communities residing in and on these sediments.¹¹ Since many of these organisms provide food or modify habitat for other organisms, the well-being of these carbonate-dependent species will affect other species. Because of these interrelationships, the potential indirect effects of acidification on other marine organisms is not well understood. Others raise the concern that ocean acidification, by negatively affecting calcifying plankton species, could shift ecological balances so as to increase populations of noncalcifying species, such as jellyfish.¹²

There are also concerns that increasing acidification of ocean waters could alter the ability of some organisms to conduct essential biochemical and physiological processes. For example, increased CO₂ concentration appears to cause physiological changes that can be detrimental to the relationship between coral and their symbiotic zooxanthellae,¹³ wherein the coral host loses control over the zooxanthellae, resulting in uncontrolled division.¹⁴ Evidence suggests that larval and juvenile fish may be particularly susceptible to changes in ocean pH levels.¹⁵ In addition,

⁸ Orr et al. (2005).

⁹ Bruce Mapstone, "Acid Oceans in the Spotlight," *Antarctic Climate and Ecosystem News*, edition 4 (August 2008): 1.

¹⁰ Frederic Gazeau et al., "Impact of Elevated CO₂ on Shellfish Calcification," *Geophysical Research Letters*, v. 34, no. 7 (Apr. 16, 2007): L07603 (5 p.).

¹¹ M. Gehlen, L. Bopp, and O. Aumont, "Short-term Dissolution Response of Pelagic Carbonate Sediments to the Invasion of Anthropogenic CO₂: A Model Study," *Geochem. Geophys. Geosyst.*, v. 9 (Feb. 16, 2008): Q02012.

¹² A. J. Richardson and M. J. Gibbons, "Are Jellyfish Increasing in Response to Ocean Acidification?," *Limnology and Oceanography*, v. 53, no. 5 (2008):2040-2045.

¹³ Algae that live in the tissues of a variety of invertebrate groups (e.g., corals). Under lighted conditions, zooxanthellae use the CO₂ and waste materials produced by corals, providing oxygen and food substances that may be used by the coral.

¹⁴ J. Ravindran and Chandralata Raghukumar, "Pink-Line Syndrome, a Physiological Crisis in the Scleractinian Coral *Porites lutea*," *Marine Biology*, v. 149, no. 2 (2006): 347-356.

¹⁵ A. Ishimatsu et al., "Effects of CO₂ on Marine Fish: Larvae and Adults," *Journal of Oceanography*, v. 60, no. 4 (2004): 731-741.

scientists have found that, when exposed to water of pH 7.7, roughly equivalent to acidity levels predicted for the year 2100, sea urchin sperm swam much more slowly. Overall, fertilization fell by 25%, and in almost 26% of cases where the eggs were fertilized, they did not survive long enough to develop into larvae.¹⁶

In nature, the ocean waters at depths of hundreds or thousands of feet become undersaturated with respect to aragonite and calcite, which is why most of the shells from dead organisms that “rain” down from the ocean surface dissolve before reaching the ocean floor.¹⁷ One concern is that increasing levels of atmospheric CO₂ entering the ocean and mixing with deeper waters will result in a shoaling of undersaturated conditions, which could reach shallow levels where most of the shell-forming organisms live. Under those conditions, some plankton and corals may have difficulty maintaining their calcium carbonate skeletons. This is likely to occur first in colder waters near the poles, which tend to have higher levels of dissolved CO₂ than warmer waters near the equator. Recent research suggests that some areas, such as the Southern Ocean, could become undersaturated with respect to aragonite by 2050 or sooner.¹⁸

The fossil record indicates that marine organisms may be quite sensitive to ocean acidification—about 55 million years ago, a large injection of CO₂ into the deep ocean, presumably resulting from a massive methane release, was followed by the extinction of some species of benthic foraminifera.¹⁹ Others caution that these paleo-events may be imperfect analogs to current conditions.²⁰

Some have raised questions downplaying the potential harm to coral reefs from ocean acidification. Differences of opinion exist on the relative effects of climate change as expressed in increased CO₂ when compared to increased ocean temperature. Opinion has been expressed that, in marine systems, increased temperature may have detrimental effects comparable to or larger than those seen from increased CO₂ concentration, for corals and for phytoplankton.²¹ Although calcification rates in massive *Porites* coral were reported to have declined over a 16-year study period by approximately 21% in two regions on Australia’s Great Barrier Reef, these findings were consistent with studies of the synergistic effect of elevated seawater temperatures and CO₂ concentrations on coral calcification.²²

As noted above in relation to corals, scientists point out that CO₂ is far less soluble in warm water than in cold water. Thus the cold polar and deeper waters will likely be the first to be affected by

¹⁶ Jon N. Havenhand, Fenina-Raphaëla Buttler, Michael C. Thorndyke, and Jane E. Williamson, “Near-Future Levels of Ocean Acidification Reduce Fertilization Success in a Sea Urchin,” *Current Biology*, v. 18, no. 15 (August 2008): 651-652.

¹⁷ Recent research suggests that no more than about 30% of the calcium carbonate produced in the surface ocean each year is buried in shallow or deep sea sediments; the rest dissolves on its way down the water column. See Feely et al. (2004), p. 365.

¹⁸ Orr et al. (2005).

¹⁹ J. C. Zachos et al., “Rapid Acidification of the Ocean During the Paleocene-Eocene Thermal Maximum,” *Science*, v. 308 (2005): 1611-1615.

²⁰ Scott C. Doney et al., “Ocean Acidification: The Other CO₂ Problem,” *Annual Review of Marine Science*, v. 1 (January 2009): 169-192.

²¹ Clinton E. Hare et al., “Consequences of Increased Temperature and CO₂ for Phytoplankton Community Structure in the Bering Sea,” *Marine Ecology Progress Series*, v. 352 (2007), p. 14.

²² T. F. Cooper et al., “Declining Coral Calcification in Massive *Porites* in Two Nearshore Regions of the Northern Great Barrier Reef,” *Global Change Biology*, v. 14 (2008): 529-538.

ocean acidification,²³ while the tropical surface waters and coral reefs may be among the last places to be threatened by the effects of ocean acidification. Also supportive of the ability of certain corals to survive decreasing pH, stony and soft corals have been grown successfully in open systems with low pH water from a saltwater well since the 1970s.²⁴

What Are the Natural and Human Responses That Might Limit or Reduce Ocean Acidification?

Our ability to reduce ocean acidification through artificial means is unproven. Proposals have suggested the addition of chemicals to the ocean, such as (1) using iron compounds to stimulate planktonic algae growth whereby the increased photosynthesis might capture/remove dissolved CO₂, or (2) using limestone to neutralize (i.e., buffer) the more acidic streams and rivers near where they enter oceans and close to sources of limestone. Unless a massive global effort is mounted, these techniques will at best be effective only on a very local scale. In addition, manipulation of ocean chemistry has the potential to damage or otherwise alter the marine environment and ecosystems. Reducing CO₂ emissions to the atmosphere and/or removing CO₂ from the atmosphere (i.e., carbon sequestration) currently appear to be the only practical ways to minimize the risk of large-scale and long-term changes to the acidity of marine waters. Because of the continuing increase in CO₂ levels in the atmosphere, and its residence time there, acidification of the oceans will likely continue for a long time. Even if atmospheric CO₂ were to return to pre-industrial levels, it would likely take tens of thousands of years for ocean chemistry to return to a condition similar to that occurring at pre-industrial times more than 200 years ago.²⁵

What Is the Federal Government Doing About Ocean Acidification?

Much of the current federal attention to ocean acidification focuses on research to better understand the chemical processes involved and to become better able to predict how ocean ecosystems might respond to increasing acidification.

A variety of programs conducted within the National Oceanic and Atmospheric Administration (NOAA) help to gain a better understanding of ocean acidification.²⁶ The Pacific Marine Environmental Laboratory's CO₂ shipboard measurements and monitoring buoys provide data that help discern seasonal changes in the oceanic carbon system. The Atlantic Oceanographic and Meteorological Laboratory monitors changes in CO₂ and pH through the use of chemical sensors on ships and moorings. NOAA's Repeat Hydrography Program provides data on the large-scale

²³ Bruce Mapstone, "Acid Oceans in the Spotlight," *Antarctic Climate and Ecosystem News*, edition 4 (August 2008): 1.

²⁴ M. J. Atkinson, B. Carlson, and G. L. Crow, "Coral growth in high nutrient, low-pH seawater: a case study of corals cultured at the Waikiki Aquarium, Honolulu, Hawaii," *Coral Reefs*, v. 14, no. 4 (1995): 215-223.

²⁵ The Royal Society, *Ocean Acidification due to Increasing Atmospheric Carbon Dioxide*, Policy Document 12/05 (June 2005), 60 p.

²⁶ Testimony by Dr. Richard A. Feely, NOAA Office of Oceanic and Atmospheric Research, before the House Committee on Science and Technology, Subcommittee on Energy and Environment, June 5, 2008.

changes of carbon system and ocean acidification over decadal time scales. Sea Grant supports research on the effects of ocean acidification on coral reefs in Hawaii. NOAA's Geophysical Fluid Dynamics Laboratory participated in the Ocean-Carbon Cycle Model Intercomparison Project (OCMIP2) to develop an international collaboration to improve the predictive capacity of carbon cycle models. NOAA Fisheries Alaska Fisheries Science Center has been conducting exposure studies of blue king crab larval survival due to reduced pH and has developed an ocean acidification research plan.²⁷ NOAA Fisheries Southwest Fisheries Science Center has been evaluating the long-term impacts of low pH on marine plankton in the California Current and off Antarctica. Projects funded by NOAA Global Carbon Cycle program at NOAA laboratories and universities provide information to address the CO₂ and pH changes in the ocean. NOAA estimates that its annual expenditures for these ocean acidification research and related programs in FY2008 were about \$4.3 million; for FY2009, NOAA has requested \$4.06 million.²⁸

In October 2008, NOAA and the National Science Foundation commissioned an 18-month comprehensive national study by the National Research Council of the National Academy of Sciences of how CO₂ emissions absorbed into the oceans may be altering fisheries, marine mammals, coral reefs, and other natural resources.²⁹ This study was required by Section 701 of P.L. 109-479.³⁰

The National Aeronautics and Space Administration (NASA) has a number of space projects that contribute to a better understanding of ocean acidification.³¹

What Is the Congressional Interest in Ocean Acidification?

Congressional attention is focused primarily on addressing the cause of ocean acidification—increasing atmospheric CO₂.³² Legislative attention to ocean acidification focuses on authorizing and funding research to increase knowledge about ocean acidification and its potential effects on marine ecosystems.

In comparison to previous sessions of Congress, legislative interest in ocean acidification expanded significantly in the 110th Congress. In the 110th Congress, the Senate Commerce, Science, and Transportation Subcommittee on Oceans, Atmosphere, Fisheries, and Coast Guard held a hearing on the effects of climate change and ocean acidification on living marine resources. In the House, the Committee on Science and Technology held a hearing on H.R. 4174,

²⁷ Alaska Fisheries Science Center, *Forecast Fish, Shellfish, and Coral Population Responses to Ocean Acidification in the North Pacific Ocean and Bering Sea*, National Marine Fisheries Service (Juneau, AK: August 2008), AFSC Processed Report 2008-7, 35 p.

²⁸ Personal communication from Jonathan Kelsey, Congressional Affairs Specialist, Office of Legislative Affairs, NOAA, (202) 482-0809, Dec. 11, 2008.

²⁹ See http://www.noaanews.noaa.gov/stories2008/20081020_oceanacid.html.

³⁰ This measure requires the Secretary of Commerce to request that the National Research Council study acidification of the oceans and how this process affects the United States.

³¹ See <http://oco.jpl.nasa.gov/>, <http://modis.gsfc.nasa.gov/about/>, <http://oceancolor.gsfc.nasa.gov/SeaWiFS/>, and <http://so-gasex.org/media.html>.

³² See CRS Current Legislative Issue “Climate Change”, available at http://apps.crs.gov/cli/cli.aspx?PRDS_CLI_ITEM_ID=2645&from=3&fromId=2522.

the Federal Ocean Acidification Research and Monitoring Act (establishing an interagency committee to develop an ocean acidification research and monitoring plan and establishing an ocean acidification program within NOAA). The House later passed this measure, but it was not considered in the Senate. In addition, the House passed H.R. 3221 (amended), wherein Section 7471 would have directed the Secretary of Commerce to develop a national strategy to predict, plan for, and mitigate climate change effects, including ocean acidification, on ocean and coastal ecosystems to ensure the recovery, resiliency, and health of these systems. The Senate did not consider this measure. The Senate did pass H.R. 3093, after inserting language that would have specified NOAA funds to initiate the study of ocean acidification and its effects, required by Section 701 of P.L. 109-479; however, this language was deleted in conference on this measure. More than a dozen other bills containing provisions on this issue did not receive any floor action in the 110th Congress.³³

Author Contact Information

Eugene H. Buck
Specialist in Natural Resources Policy
gbuck@crs.loc.gov, 7-7262

Peter Folger
Specialist in Energy and Natural Resources Policy
pfolger@crs.loc.gov, 7-1517

³³ For more details on ocean acidification legislation in the 110th Congress, see the section “Climate Change” in CRS Report RL33813, *Fishery, Aquaculture, and Marine Mammal Legislation in the 110th Congress*, by Eugene H. Buck.