



# Ocean Acidification

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## Summary

With increasing concentrations of carbon dioxide (CO<sub>2</sub>) 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 less alkaline (i.e., ocean acidification) as more CO<sub>2</sub> dissolves in seawater, causing hydrogen ion concentration in seawater to increase. Scientists are concerned that increasing hydrogen ion concentration could result in reduced growth or even death of shell-forming animals (e.g., corals, 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 ocean acidification and determining how it might be addressed.

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## Introduction

On January 30, 2009, a Monaco Declaration, signed by more than 150 marine scientists from 26 countries, called for immediate action by policymakers to reduce carbon dioxide emissions so as to avoid widespread and severe damage to marine ecosystems from ocean acidification.<sup>1</sup> The Monaco Declaration is based on the *Research Priorities Report* developed by participants in an October 2008 second international symposium on “The Ocean in a High-CO<sub>2</sub> World,”<sup>2</sup> organized by UNESCO’s Intergovernmental Oceanographic Commission, the Scientific Committee on Oceanic Research, the International Atomic Energy Agency, and the International Geosphere Biosphere Programme.

## What Is Ocean Acidification?

As increasing carbon dioxide (CO<sub>2</sub>) from the atmosphere dissolves in seawater, seawater chemistry is altered. The prevailing pH of surface ocean water is around 8.1, or slightly alkaline.<sup>3</sup> 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 CO<sub>2</sub> from the atmosphere dissolve in seawater to form carbonic acid. Scientists are concerned that increasing acidity could alter biogeochemical cycles, disrupt physiological processes of marine organisms, and detrimentally alter marine ecosystems.

## 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 CO<sub>2</sub> into the atmosphere each year, the oceans take up about 2 billion tons.<sup>4</sup> Between pre-industrial times and 1994, average surface ocean pH is estimated to have decreased (i.e., acidity increased) by almost 0.1 pH unit.<sup>5</sup> That increase sounds small, but it represents an increase of 26% in the concentration of hydrogen ions, because the pH scale is logarithmic (i.e., a pH of 7 is 10 times more acidic than a pH of 8, and 100 times more acidic than a pH of 9). Up to a point, as atmospheric CO<sub>2</sub> continues to increase, the oceans will continue to become more acidic; one

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<sup>1</sup> A copy of this declaration is available at <http://scrippsnews.ucsd.edu/Releases/doc/MonacoDeclaration.pdf>.

<sup>2</sup> The full report is available at [http://ioc3.unesco.org/oanet/Symposium2008/ResearchPrioritiesReport\\_OceanHighCO2WorldII.pdf](http://ioc3.unesco.org/oanet/Symposium2008/ResearchPrioritiesReport_OceanHighCO2WorldII.pdf).

<sup>3</sup> The pH scale is an inverse logarithmic representation of hydrogen proton (H<sup>+</sup>) 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.”

<sup>4</sup> 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](http://www.thew2o.net/events/oceans/oa_q_and_a.php).

<sup>5</sup> 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.

estimate suggests that the rate of CO<sub>2</sub> uptake by the oceans could stabilize at around 5 gigatons per year by 2100.<sup>6</sup>

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 CO<sub>2</sub> 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 it might take the acidification process of ocean waters, should the current atmospheric emission rate of CO<sub>2</sub> remain constant, to come into equilibrium with the concentration of atmospheric CO<sub>2</sub>. An adjunct to this question is how long it might take the rate of ocean acidification to slow (or decrease) in response to any measures that might be taken to slow, halt, or even reverse the increasing concentration of CO<sub>2</sub> in the atmosphere. Additional questions relate to how ocean circulation, which eventually controls CO<sub>2</sub> uptake rate, might change in response to rising temperatures caused by greenhouse gas emissions.

All gases, such as CO<sub>2</sub>, are less soluble with increasing water temperature. Thus, marine waters near the poles have a much greater capacity for dissolving CO<sub>2</sub> than do ocean waters in the tropics. In addition, dissolved CO<sub>2</sub> also is transported into ocean depths at these high latitudes (i.e., deep water formation mechanism) since the lower-temperature waters are of higher density, causing greater convection to occur than happens in the more stratified tropical oceans. If temperature were the only factor affecting the rate of ocean acidification and the appearance of impacts on physical and biological features, these impacts might be more likely to occur in marine waters nearer the poles. However, in addition to temperature, other factors modulate the impact of CO<sub>2</sub> on marine waters. Respiration adds CO<sub>2</sub> to seawater, and photosynthesis removes it. Deep oceanic water is enriched in CO<sub>2</sub> due to respiration in the absence of photosynthesis and, when brought to the surface by equatorial currents, can place CO<sub>2</sub>-enriched seawater in contact with the atmosphere where it can absorb even more CO<sub>2</sub>. Hence, the tropics are also vulnerable to near-term effects, most notably tropical reefs. An additional factor is the potential increase in storm activity at higher latitudes as some climate models suggest.<sup>7</sup> CO<sub>2</sub> and other acidic gasses such as nitrogen dioxide are also dissolved in rainwater.<sup>8</sup> An increase in North Atlantic or western North Pacific storms could have significant implications for accelerating acidification of the oceanic surface layer in those regions.

Several negative feedback mechanisms also act to moderate the process of acidification. The less alkaline the ocean becomes, the less CO<sub>2</sub> will be taken up by dissolution. In addition, the warmer the seawater becomes, the less CO<sub>2</sub> will dissolve. Speculative questions exist related to what might occur should the oceans reach an equilibrium in their ability to take up CO<sub>2</sub> and atmospheric CO<sub>2</sub> levels continue to increase.

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<sup>6</sup> David Archer, "Fate of Fossil Fuel CO<sub>2</sub> in Geologic Time," *Journal of Geophysical Research*, v. 110 (2005): C09S05, doi:10.1029/2004JC002625.

<sup>7</sup> See the Intergovernmental Panel on Climate Change's *Technical Paper on Climate Change and Water*, available at [http://www.ipcc.ch/meetings/session28/executive\\_summary.pdf](http://www.ipcc.ch/meetings/session28/executive_summary.pdf).

<sup>8</sup> Rainwater is naturally acidic at a pH of around 5.6, and downwind of pollution sources has been measured as low as pH 3.0.

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

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. However, field studies are beginning to provide a more direct view of potential ocean acidification problems.<sup>9</sup>

Even with increasing concentrations of atmospheric CO<sub>2</sub>, the oceans are not likely to reach pH values of less than 7 (neutral). But as CO<sub>2</sub> 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 and skeletons. As more CO<sub>2</sub> 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 CO<sub>2</sub> levels in the atmosphere and the ocean's chemistry, a process that scientists have recognized for decades. When atmospheric CO<sub>2</sub> dissolves into the ocean, it forms carbonic acid (H<sub>2</sub>CO<sub>3</sub>). Some of the carbonic acid dissociates in ocean waters producing hydrogen ions (H<sup>+</sup>) and bicarbonate ions (HCO<sub>3</sub><sup>-</sup>). As the number of hydrogen ions increases, the pH of the ocean gets lower, or more acidic. When more CO<sub>2</sub> is added to the atmosphere, more carbonic acid forms in the ocean. Over the past several decades, about half of the CO<sub>2</sub> released by human activities has remained in the atmosphere; of the remainder, about 30% has entered the oceans.<sup>10</sup> As a result, the additional carbonic acid has decreased average ocean surface water alkalinity as reflected by decreasing ocean pH approximately 0.1 pH unit (i.e., an increase of about 26% in hydrogen ion concentration).<sup>11</sup>

A lower pH affects marine life in the oceans and is related to other changes in ocean chemistry. For example, the bicarbonate ion (HCO<sub>3</sub><sup>-</sup>) mentioned above further dissociates into H<sup>+</sup> and carbonate ions (CO<sub>3</sub><sup>2-</sup>), 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 support shell formation and coral growth. However, as increased amounts of carbonic acid form in the ocean from higher CO<sub>2</sub> 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 (Ca<sup>2+</sup>)—which are abundant in the oceans—with carbonate ions to form solid calcium carbonate (CaCO<sub>3</sub>).

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<sup>9</sup> See, for example, K. K. Yates and R. B. Halley, "Diurnal Variations in Rates of Calcification and Carbonate Sediment Dissolution in Florida Bay," *Estuaries and Coasts*, v. 29 (2006): 24-39; and K. K. Yates and R. B. Halley, "CO<sub>3</sub><sup>2-</sup> Concentration and pCO<sub>2</sub> Thresholds for Calcification and Dissolution on the Molokai Reef Flat, Hawaii," *Biogeosciences*, v. 3 (2006): 357-369.

<sup>10</sup> Richard A. Feely et al., "Impact of Anthropogenic CO<sub>2</sub> on the CaCO<sub>3</sub> System in the Oceans," *Science* (2004), vol. 305, pp. 362-366.

<sup>11</sup> 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.

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 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 CO<sub>2</sub> 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.<sup>12</sup> 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.<sup>13</sup>

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 21<sup>st</sup> century, according to the Intergovernmental Panel on Climate Change's IS92a scenario.<sup>14</sup> 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.<sup>15</sup> 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. While some have raised concerns that ocean acidification, by negatively affecting calcifying plankton species, could shift ecological balances so as to increase populations of some noncalcifying species, there appears to be no significant relationship between jellyfish abundance and acidic conditions, and any role of pH in structuring zooplankton communities is believed to be tenuous.<sup>16</sup>

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, 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.<sup>17</sup> However, larval and juvenile fish were exposed to exceedingly

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<sup>12</sup> Orr et al. (2005).

<sup>13</sup> Bruce Mapstone, "Acid Oceans in the Spotlight," *Antarctic Climate and Ecosystem News*, edition 4 (August 2008): 1.

<sup>14</sup> Frederic Gazeau et al., "Impact of Elevated CO<sub>2</sub> on Shellfish Calcification," *Geophysical Research Letters*, v. 34, no. 7 (Apr. 16, 2007): L07603 (5 p.).

<sup>15</sup> M. Gehlen, L. Bopp, and O. Aumont, "Short-term Dissolution Response of Pelagic Carbonate Sediments to the Invasion of Anthropogenic CO<sub>2</sub>: A Model Study," *Geochem. Geophys. Geosyst.*, v. 9 (Feb. 16, 2008): Q02012.

<sup>16</sup> 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.

<sup>17</sup> Jon N. Havenhand, Fenina-Raphaëla Buttler, Michael C. Thorndyke, and Jane E. Williamson, "Near-Future Levels (continued...)"

high CO<sub>2</sub> concentrations (more than 100 times current levels) and suffered little apparent harm,<sup>18</sup> appearing to be among the more tolerant marine animals.<sup>19</sup> These scientists believe that “the relative tolerance of fish may relate to high capacity for internal ion and acid-base regulation via direct proton excretion, and an intracellular respiratory protein that results in a high oxygen-carrying capacity and substantial venous oxygen reserve.”

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.<sup>20</sup> One concern is that increasing levels of atmospheric CO<sub>2</sub> 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 CO<sub>2</sub> 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.<sup>21</sup>

The fossil record indicates that marine organisms may be quite sensitive to ocean acidification—about 55 million years ago, a large injection of CO<sub>2</sub> into the deep ocean, presumably resulting from a massive methane release, was followed by the extinction of some species of benthic foraminifera.<sup>22</sup> Others caution that these paleo-events may be imperfect analogs to current conditions.<sup>23</sup>

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 CO<sub>2</sub> 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 CO<sub>2</sub> concentration, for corals and for phytoplankton.<sup>24</sup> 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

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of Ocean Acidification Reduce Fertilization Success in a Sea Urchin,” *Current Biology*, v. 18, no. 15 (August 2008): 651-652.

<sup>18</sup> A. Ishimatsu et al., “Effects of CO<sub>2</sub> on Marine Fish: Larvae and Adults,” *Journal of Oceanography*, v. 60, no. 4 (2004): 731-741.

<sup>19</sup> V.J. Fabry et al., “Impacts of Ocean Acidification on Marine Fauna and Ecosystem Processes,” *ICES Journal of Marine Science*, v. 65 (2008): 414-432.

<sup>20</sup> 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.

<sup>21</sup> Orr et al. (2005).

<sup>22</sup> J. C. Zachos et al., “Rapid Acidification of the Ocean During the Paleocene-Eocene Thermal Maximum,” *Science*, v. 308 (2005): 1611-1615.

<sup>23</sup> Scott C. Doney et al., “Ocean Acidification: The Other CO<sub>2</sub> Problem,” *Annual Review of Marine Science*, v. 1 (January 2009): 169-192.

<sup>24</sup> Clinton E. Hare et al., “Consequences of Increased Temperature and CO<sub>2</sub> for Phytoplankton Community Structure in the Bering Sea,” *Marine Ecology Progress Series*, v. 352 (2007), p. 14.



were consistent with studies of the synergistic effect of elevated seawater temperatures and CO<sub>2</sub> concentrations on coral calcification.<sup>25</sup>

In support of the ability of certain corals to survive decreasing pH, stony and soft corals have been grown successfully in open systems with water from a saltwater well at a pH between 7.5 and 7.8 since the 1970s.<sup>26</sup> Others have found that certain species of coral survive in the laboratory at a pH 7.3 to 7.6 after their calcified structure dissolves by functioning similar to sea anemones, and retaining the ability to recalcify when pH is increased.<sup>27</sup> However, in the natural marine environment, predation could be a significant factor in limiting the viability of such “naked” corals, and it is unlikely that such organisms could form reefs and attract the diverse community that constitutes a coral reef.

Concern has also arisen that lower ocean water pH will change low-frequency (below 10 KHz) sound absorption in the ocean, increasing noise levels within the auditory range critical for environmental, military, and economic interests.<sup>28</sup> Frequencies dependent decreases to sound absorption related to the current decrease in pH of about 0.1 pH unit may exceed 12%, and an anticipated pH decrease of 0.3 pH units by mid-century may result in an almost 40% decrease in sound absorption. It is unknown how marine mammals might adapt to an ocean increasingly transparent to sound at low frequencies.

## **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 CO<sub>2</sub>, 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. Other measures might include habitat restoration/creation, such as planting seagrass. 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 CO<sub>2</sub> emissions to the atmosphere and/or removing CO<sub>2</sub> 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 CO<sub>2</sub> levels in the atmosphere, and its residence time there, acidification of the oceans will likely continue for a long time. Even if atmospheric CO<sub>2</sub> were to return to pre-industrial levels, it would

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<sup>25</sup> 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.

<sup>26</sup> 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.

<sup>27</sup> Maoz Fine and Dan Tchernov, “Scleractinian Coral Species Survive and Recover from Decalcification,” *Science*, v. 315, no. 5820 (March 30, 2007): 1811.

<sup>28</sup> Keith C. Hester et al., “Unanticipated Consequences of Ocean Acidification: A Noisier Ocean at Lower pH,” *Geophysical Research Letters*, v. 35 (2008): L19601, doi:10.1029/2008FL034913.

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.<sup>29</sup>

## 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.

The National Science Foundation (NSF) was the first federal agency to become involved in research related to ocean acidification. The modern surveys of CO<sub>2</sub> status in the oceans can be traced to the NSF-sponsored Joint Global Ocean Flux Study (JGOFS), which originated in recommendations from a National Academy of Sciences workshop in 1984.<sup>30</sup> The more modern concerns over ocean acidification arose from a May 2004 Paris workshop chaired by the now-president of the National Academy of Sciences, Ralph Cicerone.<sup>31</sup> 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 CO<sub>2</sub> emissions absorbed into the oceans may be altering fisheries, marine mammals, coral reefs, and other natural resources.<sup>32</sup> This study was required by Section 701 of P.L. 109-479.<sup>33</sup>

A variety of programs conducted within the National Oceanic and Atmospheric Administration (NOAA) help to gain a better understanding of ocean acidification.<sup>34</sup> The Pacific Marine Environmental Laboratory's CO<sub>2</sub> 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 CO<sub>2</sub> and pH through the use of chemical sensors on ships and moorings. NOAA's Repeat Hydrography Program provides data on the large-scale 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.<sup>35</sup> NOAA Fisheries Southwest Fisheries Science Center has been

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<sup>29</sup> The Royal Society, *Ocean Acidification due to Increasing Atmospheric Carbon Dioxide*, Policy Document 12/05 (June 2005), 60 p.

<sup>30</sup> For additional background, see <http://www1.whoi.edu/jgofMission.html>.

<sup>31</sup> Ralph Cicerone, "The Ocean in a High CO<sub>2</sub> World," *Eos*, v. 85, no. 37 (September 14, 2004): 351, 353.

<sup>32</sup> See [http://www.noaanews.noaa.gov/stories2008/20081020\\_oceanacid.html](http://www.noaanews.noaa.gov/stories2008/20081020_oceanacid.html).

<sup>33</sup> 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.

<sup>34</sup> 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.

<sup>35</sup> 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.

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 CO<sub>2</sub> 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.<sup>36</sup>

The National Aeronautics and Space Administration (NASA) has a number of space projects that contribute to a better understanding of ocean acidification.<sup>37</sup>

## What Is the Congressional Interest in Ocean Acidification?

Congressional attention is focused primarily on addressing the cause of ocean acidification—increasing atmospheric CO<sub>2</sub>.<sup>38</sup> 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 the 111<sup>th</sup> Congress, the Federal Ocean Acidification Research And Monitoring Act of 2009 (H.R. 14, S. 173, and Title XII, Subtitle D of S. 22) would direct the Secretary of Commerce to establish an ocean acidification program within NOAA, establish an interagency committee to develop an ocean acidification research and monitoring plan, and authorize appropriations through FY2012 for NOAA and the National Science Foundation. The Senate passed S. 22, the Omnibus Public Land Management Act of 2009 (amended) on January 15, 2009.

In comparison to previous sessions of Congress, legislative interest in ocean acidification expanded significantly in the 110<sup>th</sup> Congress. In the 110<sup>th</sup> 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, 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.

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<sup>36</sup> Personal communication from Jonathan Kelsey, Congressional Affairs Specialist, Office of Legislative Affairs, NOAA, (202) 482-0809, Dec. 11, 2008.

<sup>37</sup> 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>.

<sup>38</sup> 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](http://apps.crs.gov/cli/cli.aspx?PRDS_CLI_ITEM_ID=2645&from=3&fromId=2522).

More than a dozen other bills containing provisions on this issue did not receive any floor action in the 110<sup>th</sup> Congress.<sup>39</sup>

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<sup>39</sup> For more details on ocean acidification legislation in the 110<sup>th</sup> Congress, see the section “Climate Change” in CRS Report RL33813, *Fishery, Aquaculture, and Marine Mammal Legislation in the 110<sup>th</sup> Congress*, by Eugene H. Buck.