WRITTEN TESTIMONY OF
RICHARD A. FEELY, Ph.D.
OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S DEPARTMENT OF COMMERCE

HEARING ON
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Introduction

Chairman Lampson and members of the Subcommittee, thank you for giving me the opportunity to speak with you today on ocean acidification and the Administration's views on H.R. 4174, the *Federal Ocean Acidification Research and Monitoring Act of 2007*. My name is Richard Feely. I am a Supervisory Chemical Oceanographer at the Pacific Marine Environmental Laboratory of the National Oceanic and Atmospheric Administration (NOAA) in Seattle, WA. My personal area of research is the study of the oceanic carbon cycle and ocean acidification processes. I have worked for NOAA for 34 years and have published more than 165 peer-reviewed scientific journal articles, book chapters and technical reports. I serve on the U.S. Carbon Cycle Science Program Scientific Steering Group and I am the co-chair of the U.S. Repeat Hydrography Program Scientific Oversight Committee. I am also on the International Scientific Advisory Panel for the European Program on Ocean Acidification.

What is Ocean Acidification?

As the Committee is aware, and the Intergovernmental Panel on Climate Change (IPCC) has documented, global carbon dioxide (CO_2) emissions to the atmosphere have increased since the start of the industrial age. What happens to all that CO_2 that is put into the atmosphere? Over the past two centuries, the oceans have absorbed approximately 525 billion tons of carbon dioxide from the atmosphere, or about one third of the anthropogenic carbon emissions released during this period (Sabine and Feely, 2007). This natural process of absorption has benefited humankind by significantly reducing the greenhouse gas levels in the atmosphere and mitigating some of the impacts of global warming. However, the ocean's current daily uptake of 22 million tons of carbon dioxide is starting to have a significant impact on the chemistry and biology of the oceans.

Over the last three decades, NOAA, the National Science Foundation and the Department of Energy have co-sponsored repeat hydrographic and chemical surveys of the world oceans, documenting the ocean's response to increasing amounts of carbon dioxide being emitted to the atmosphere by human activities. These surveys have confirmed the oceans are absorbing increasing amounts of carbon dioxide. Both the hydrographic surveys and modeling studies reveal that chemical changes in seawater resulting from absorption of carbon dioxide are increasing the acidity of seawater (or, lowering its pH, the scale used to measure acidity). Scientists have estimated that the pH of our ocean surface waters has already fallen by about 0.11 units from an average of about 8.21 to 8.10 since the beginning of the industrial revolution (a drop in pH indicates an increase in acidity, as on the logarithmic pH scale 7.0 is neutral, with points lower on the scale being "acidic" and points higher on the scale being "basic"; Raven et al, 2005). Further, future predictions indicate that the oceans will continue to absorb CO_2 and become more acidic. Estimates of future atmospheric and oceanic carbon dioxide concentrations, based on the IPCC emission scenarios and numerical circulation models, indicate that by the middle of this century atmospheric carbon dioxide levels could reach more than 500 parts per million (ppm), and near the end of the century they could be over 800 ppm (Orr et al., 2005). This would result in a surface water pH decrease of approximately 0.4 pH units as the ocean becomes more acidic. To put this in historical perspective, the resulting surface ocean pH would be lower than it has been for more than 20 million years (Feely et al., 2004).

Effects of Ocean Acidification on Coral Reefs

Many marine organisms that produce calcium carbonate shells are negatively impacted by increasing carbon dioxide levels in seawater (and the resultant decline in pH). For example, increasing ocean acidification has been shown to significantly reduce the ability of reef-building corals to produce their skeletons, affecting growth of individual corals and making the reef more vulnerable to erosion (Kleypas et al., 2006). Some estimates indicate that, by the end of this century, coral reefs may erode faster than they can be rebuilt. This could compromise the long-term viability of these ecosystems and perhaps impact the thousands of species that depend on the reef habitat. Decreased calcification may also compromise the fitness or success of these organisms and could shift the competitive advantage towards organisms that are not dependent on calcium carbonate. Carbonate structures are likely to be weaker and more susceptible to dissolution and erosion in a more acidic environment. In long-term laboratory and mesocosm experiments corals that have been grown under lower pH conditions for periods longer than one year have not shown any ability to adapt their calcification rates to the low pH levels. In fact, a recent study showed that the projected increase in CO_2 is sufficient to dissolve the calcium carbonate skeletons of some coral species (Fine and Tchernov, 2007).

Effects of Ocean Acidification on Fish and Shellfish

Ongoing research is showing that decreasing pH may also have deleterious effects on commercially important fish and shellfish larvae. Both king crab and silver seabream larvae exhibit very high mortality rates in CO_2-enriched waters (Ishimatsu et al., 2004).

Some of the experiments indicated that other physiological stresses were also apparent. Exposure of fish to lower pH levels can cause decreased respiration rates, changes in blood chemistry, and changes in enzymatic activity. The calcification rates of the edible mussel (*Mytilus edulis*) and Pacific oyster (*Crassostrea gigas*) decline linearly with increasing CO_2 levels (Gazeau et al. 2007). Squid are especially sensitive to ocean acidification because it directly impacts their blood oxygen transport and respiration (Pörtner et al., 2005). Sea urchins raised in lower-pH waters show evidence for inhibited growth due to their inability to maintain internal acid-base balance (Kurihara and Shirayama, 2004). The food supply of these commercially valuable species is in jeopardy from ocean acidification. Scientists have also seen a reduced ability of marine algae and free-floating plants and animals to produce protective carbonate shells (Feely et al., 2004; Orr et al., 2005). These organisms are important food sources for other marine species. One type of free-swimming mollusk called a pteropod is eaten by organisms ranging in size from tiny krill to whales. In particular, pteropods are a major food source for North Pacific juvenile salmon, and also serve as food for salmon, mackerel, pollock, herring, and cod. Other marine calcifiers, such as coccolithophores (microscopic algae), foraminifera (microscopic protozoans), coralline algae (benthic algae), echinoderms (sea urchins and starfish), and mollusks (snails, clams, and squid) also exhibit a general decline in their ability to produce their shells with decreasing pH (Kleypas et al., 2006).

Effects on Marine Ecosystems

Since ocean acidification research is still in its infancy, it is impossible to predict exactly how the individual species responses will cascade throughout the marine food chain and impact the overall structure of marine ecosystems. It is clear, however, from both the existing data and from the geologic record that some coral and shellfish species will be negatively impacted in a high-CO_2 ocean. The rapid disappearance of many calcifying species in past extinction events has been attributed, in large part, to ocean acidification events (Zachos et al., 2005; Vernon, 2008). Over the next century, if CO_2 emissions are allowed to increase as predicted by the IPCC CO_2 emissions scenarios, mankind may be responsible for increasing oceanic CO_2 and making the oceans more corrosive to calcifying organisms than at anytime in the last 20 million years. Thus, the decisions we make about carbon dioxide emissions over the next several decades will probably have a profound influence on the makeup of future marine ecosystems for centuries to millennia.

Potential Economic Impacts

The impact of ocean acidification on fisheries and coral reef ecosystems could reverberate through the U.S. and global economy. The U.S. is the third largest seafood consumer in the world with total consumer spending for fish and shellfish around $70 billion per year. Coastal and marine commercial fishing generates upwards of $35 billion per year and employs nearly 70,000 people (NOAA Fisheries Office of Science and Technology; http://www.st.nmfs.gov/st1/fus/fus05/index.html). Increased ocean acidification may directly or indirectly influence the fish stocks because of large-scale changes in the local ecosystem dynamics. It may also cause the dissolution of the newly discovered deepwater corals in the Alaskan Aleutian Island region. Many commercially important fish species in this region depend on this particular habitat for their survival. Healthy coral reefs are the foundation of many viable fisheries, as well as the source of jobs and businesses related to tourism and recreation. In the Florida Keys, coral reefs attract more than $1.2 billion in tourism annually. In Hawaii, reef-related tourism and fishing generate $360 million per year, and their overall worth has been estimated at close to $10 billion. In addition, coral reefs provide vital protection to coastal areas that are vulnerable to storm surges and tsunamis.

NOAA Ocean Acidification Research

Ocean acidification is an important new scientific frontier. NOAA research activities offer significant contributions to improving our understanding and assessing the impacts of this rapidly emerging issue. NOAA research relevant to ocean acidification falls into the categories of ocean observations, studies of the physiological impact on marine species, and support of environmental and ecological modeling efforts.

For example, some on going work includes the following:

- The **Pacific Marine Environmental Laboratory**'s CO_2 shipboard measurements and monitoring buoys provide data that helps NOAA discern seasonal changes in the oceanic carbon system.
- The **Atlantic Oceanographic and Meteorological Laboratory** monitors changes in CO_2 and pH through the use of chemical sensors on ships and moorings.
- The **NOAA Repeat Hydrography Program** provides valuable data on the large-scale changes of carbon system and ocean acidification over decadal time scales.
- **NOAA's Coral Reef Conservation Program** plans to conduct a study starting in FY 2008 and continuing in FY 2009 to determine the impacts of global climate change and coral bleaching on the recreation and tourism industry in the Florida Keys.
- **Sea Grant** supports research on the affects of ocean acidification on coral reefs in Hawaii.
- **The 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 through evaluation and intercomparison.
- **NOAA Fisheries Alaska Fisheries Science Center** has been conducting exposure studies of blue king crab larval survival due to reduced pH.
- **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 necessary information to address the CO_2 and pH changes in the ocean.

NOAA Views on H.R. 4174, the Federal Ocean Acidification Research and Monitoring Act of 2007

As noted in our views letter on S. 1581, the companion bill to H.R. 4174, the Administration supports the intent of the *Federal Ocean Acidification Research and Monitoring Act of 2007*, to develop an ocean acidification research and monitoring plan, and appreciates the interest of the Committee on this area of research. However, the bill creates an interagency committee that is largely redundant with existing government bodies.

In support of well-coordinated programs for climate change and ocean science and technology, the Administration created two interagency bodies under the National Science and Technology Council-- the Climate Change Science Program (CCSP) and the Joint Subcommittee on Ocean Science and Technology (JSOST). Both bodies have been successful in reducing the duplication of efforts in research programs, identifying and addressing programmatic gaps, and synthesizing information for the American public. Their organizational structure supports focused, high-level interaction among Departments and agencies.

As disconcerting as the ramifications of ocean acidification may be, we encourage the Committee to avoid the temptation of creating interagency committees for each potential impact of climate change and rather work within the framework of existing institutions.

The introduction of H.R. 4174 reflects recommendation of the national and international scientific communities for a coordinated scientific research program. The scientific community has identified four major themes for a research program: (1) carbon system monitoring; (2) calcification and physiological response studies under laboratory and field conditions; (3) environmental and ecosystem modeling studies; and (4) socio-economic risk assessments. This research will provide resource managers with the basic information they need to develop strategies for protection of critical species, habitats and ecosystems (similar to what has already been developed for coral reef managers with the publication of *the Reef Manager's Guide* by the U.S. Coral Reef Task Force to help local and regional reef managers reduce the impacts of coral bleaching to coral reef ecosystems).

Ocean acidification is an emerging issue, and research and monitoring are of critical importance to a better understanding of the processes involved. NOAA has a strong foundation in ocean acidification research and as such would be able to provide strong leadership for an interagency effort examining ocean acidification across the federal government. Such an effort would support NOAA's mission, which is to provide information to understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet the nation's economic, social, and environmental needs. NOAA's unique capacity to develop and deploy ocean observation systems can support further examination of ocean acidification.

NOAA has already begun identifying key issues related to the potential impacts of ocean acidification on fisheries and ecosystems, and we are working with the National Academy of Science's Ocean Studies Board (OSB) to prioritize future research and monitoring efforts. Science planning workshops and a university office to foster academic research in ocean acidification (among other responsibilities) has also been jointly funded by the National Science Foundation, National Aeronautics and Space Administration, and NOAA. It is important that NOAA and other agencies coordinate laboratory studies and collaborate in the design of appropriate field investigations. This will allow us to better assess the threat and more precisely forecast the impacts of ocean acidification on marine ecosystems, and the associated socioeconomic consequences.

NOAA believes that the National Academy can provide an important bridge between the academic community and federal agencies in designing and implementing appropriate long-term cooperative studies and experiments to determine how marine ecosystems may respond to ocean acidification. A planned National Academy study, to be conducted through its OSB, will be used to help design long term monitoring studies to monitor changes in carbonate chemistry in vulnerable marine ecosystems of the United States, and as a method to collaborate internationally. The OSB will provide guidance regarding methods, frequency, and placement of monitoring sensors and oceanographic sensing to track ocean acidification over time, and in relation to changes in atmospheric carbon dioxide. This work will be important in influencing the interagency committee on ocean acidification as outlined in H.R. 4174.

We note that many of the timelines established by H.R. 4174 for production of plans and reports appear ambitious. If NOAA is to consider input from other committees and panels (e.g., the National Research Council, the Ocean Research and Resources Advisory Panel, the Joint Subcommittee on Ocean, Science, and Technology of the National Science and Technology Council, the Joint Ocean Commission Initiative, and other expert scientific bodies) before it establishes a national program on ocean acidification, it will require at least two years to coordinate. Each of the committees and panels must be allowed some time to perform their work before they can provide meaningful input back to NOAA, and the Committee will require additional time to evaluate the different input provided by each of the committees and panels before a final recommendation to Congress can be made.

The Administration recommends that H.R. 4174 be modified to place greater emphasis on changing ocean carbon chemistry, rather than limiting the scope to pH. In particular, the impacts of the changing levels of various forms of dissolved inorganic carbon and alkalinity offer more comprehensive information on how changes in atmospheric carbon dioxide concentrations are impacting our oceans. It is the changes in the carbon system parameters that are at the heart of the ocean acidification issue. In addition to atmospheric carbon dioxide, there are secondary processes (such as changes in land use, continental weathering, and emissions of other acidic compounds) that will also influence carbonate chemistry and will thus need to be considered in any research program.

Conclusion

In conclusion, it has been recently discovered that ocean acidification, caused by the buildup of carbon dioxide and other acidic compounds in the atmosphere, may have significant impacts on marine ecosystems. Results from laboratory, field and modeling studies, as well as evidence from the geological record, clearly indicate that marine ecosystems are highly susceptible to the increases in oceanic CO_2 and the corresponding decreases in pH. Because of the very clear potential for ocean-wide impacts of ocean acidification at all levels of the marine ecosystem, from the tiniest phytoplankton to zooplankton to fish and shellfish, we can expect to see significant impacts that are of immense importance to mankind. Ocean acidification is an emerging scientific issue and much research is needed before all of the ecosystems responses are well understood. However, to the limit that the scientific community understands this issue right now, the potential for environmental, economic and societal risk is also quite high, hence demanding serious and immediate attention. Thank you for giving me this opportunity to address this Subcommittee. I look forward to answering your questions.

References and Additional Sources

Caldeira, K., and M.E. Wickett (2005). Ocean model predictions of chemistry changes from carbon dioxide emissions to the atmosphere and ocean. Journal of Geophysical Research (Oceans) 110, C09S04, doi:10.1029/2004JC002671.

Feely, R. A., C. L. Sabine, K. Lee, W. Berrelson, J. Kleypas, V. J. Fabry, and F. J. Millero (2004). Impact of anthropogenic CO_2 on the $CaCO_3$ system in the oceans, Science, 305(5682): 362-366.

Feely, R.A., J. Orr, V.J. Fabry, J.A. Kleypas, C.L. Sabine, and C. Landgon (in press): Present and future changes in seawater chemistry due to ocean acidification. AGU Monograph on "The Science and Technology of Carbon Sequestration".

Fine, M. and D. Tchernov (2007). Scleractinian coral species survive and recover from decalcification, Science (315): 1811.

Gazeau, F., Quiblier, C., Jeroen M. Jansen, J. M. Jean-Pierre Gattuso, J.-P., Middelburg, J. J., and C. H.R. Heip (2007). Impact of elevated CO_2 on shellfish calcification, Geophysical Research Letters, 34, L07603, doi:10.1029/2006GL028554.

Ishimatsu, A., Kikkawa, T., Hayashi, M., Lee, K.-S., and . J. Kita (2004). Effects of CO_2 on marine fish: Larvae and adults, Journal of Oceanography, Vol. 60, pp. 731 – 741.

Kleypas, J.A., R.A. Feely, V.J. Fabry, C. Langdon, C.L. Sabine, and L.L. Robbins (2006). Impacts of ocean acidification on coral reefs and other marine calcifiers: A guide to future research. Report of a workshop held 18–20 April 2005, St. Petersburg, FL, sponsored by NSF, NOAA, and the U.S. Geological Survey, 88 pp.

Kurihara, K. and Shirayama, Y. (2004). Impacts of increased atmospheric CO_2 on sea urchin early development, Mar. Ecol;. Prog. Ser., 274, 161-169.

Marshall, P. and H. Schuttenberg (2006): A Reef Manager’s Guide to Coral Bleaching, Great Barrier Ref Marine Park Authority, Townsville, Australia, 139pp.

Orr, J. C., V. J. Fabry, O. Aumont, L. Bopp, S. C. Doney, R. A. Feely, A. Gnanadesikan, N. Fruber, A. Ishida, F. Joos, R. M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet. R. G. Najjar, G.-K. Plattner, K. B. Rodgers, C. L. Sabine, J. L. Sarmiento, R. Schlitzer, R. D. Slater, I. J. Totterdel, M.-F. Weirig, Y. Yamanaka, and A. Yool (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms, Nature, 437: 681-686.

Pörtner, H.O., M. Langenbuch, and B. Michaelidis (2005) Synergistic effects of temperature extremes, hypoxia, and increases in CO2 on marine animals: From Earth history to global change, J. Geophys. Res. 110, C09S10, doi:10.1029/2004JC002561.

Raven, J. Caldeira, K. Elderfield, H. Hoegh-Guldberg, O. Liss, P. Riebesell, U. Shepherd, J. Turley, C. Watson, A. (2005). Acidification due to increasing carbon dioxide. In Report 12/05. London , T.R.S.o. (ed.) London : The Royal Society, pp. vii + 60.

Sabine, C.L., and R.A. Feely (2007). The oceanic sink for carbon dioxide. In Greenhouse Gas Sinks, D. Reay, N. Hewitt, J. Grace, and K. Smith (eds.), CABI Publishing, Oxfordshire, UK.

Vernon, J.E.N. (2008). A reef in time: the Great Barrier Reef from beginning to end, The Belknap Press, Cambridge, MA, 289pp.

Zachos, J. C., U. Röhl, S. A. Schellenberg, A. Sluijs, D. A. Hodell, D. C. Keely, E. Thomas, M. Nicolo, I. Raffi, L. J. Lourens, H. McCarren, and D. Kroon (2005). Rapid acidification of the ocean during the Paleocene-Eocene thermal maximum, Science, 308: 1611-16.