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EFFECTS OF CLIMATE CHANGE AND OCEAN ACIDIFICATION ON LIVING MARINE RESOURCES

BEFORE THE
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FISHERIES AND COAST GUARD
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Introduction

Good morning Chairman Cantwell and members of the Subcommittee. Thank you for giving me the opportunity to speak with you today on the short- and long-term impacts of ocean acidification on marine resources. 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 its impact on marine organisms. I have worked for NOAA for more than 32 years and have published more than 160 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. For today, you have asked me to provide my insights on ocean acidification and its effect on living marine ecosystems. Most of my comments below are derived from the Royal Society Report, *"Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide"* (Raven *et al*., 2005) and the recent U.S. report, derived from a workshop held jointly by the National Science Foundation (NSF), NOAA, and the U.S. Geological Survey, entitled *"Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers"* (Kleypas *et al.*, 2006).

Ocean Acidification

Over the past 200 years the release of carbon dioxide (CO_2) from our collective industrial and agricultural activities has resulted in atmospheric CO_2 concentrations that have increased by about 100 parts per million (ppm). The atmospheric concentration of CO_2 is now higher than experienced on Earth for at least the last 800,000 years, and is expected to continue to rise, leading to significant temperature increases in the atmosphere and oceans by the end of this century. 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 minimizing some of the impacts of global warming. However, the ocean's daily uptake of 22 million tons of carbon dioxide is starting to have a significant impact on the chemistry and biology of the oceans. For more than 25 years, NOAA and NSF 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 that the oceans are absorbing increasing amounts of carbon dioxide. Both the hydrographic surveys and modeling studies reveal that the chemical changes in seawater resulting from the absorption of carbon dioxide are lowering seawater pH (Feely *et al.*, 2004; Orr *et al.*, 2005; Caldeira and Wickett, 2005; Feely *et al.*, in press). It is now well established that the pH of our ocean surface waters has already fallen by about 0.1 units from an average of about 8.21 to 8.10 since the beginning of the industrial revolution (on the logarithmic pH scale, 7.0 is neutral (e.g., water), with points higher on the scale being "basic" and points lower being "acidic."). Estimates of future atmospheric and oceanic carbon dioxide concentrations, based on the Intergovernmental Panel on Climate Change (IPCC) CO_2 emission scenarios and general 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. This would result in a surface water pH decrease of approximately 0.4 pH units as the ocean becomes more acidic, and the carbonate ion concentration would decrease almost 50 percent by the end of the century (Orr *et al.*, 2005). To put this in historical perspective, this surface ocean pH decrease would result in a pH that is lower than it has been for more than 20 million years (Feely *et al*., 2004). When CO_2 reacts with seawater, fundamental chemical changes occur that cause a reduction in seawater pH. The interaction between CO_2 and seawater also reduces the availability of carbonate ions, which play an important role in shell formation for a number of marine organisms such as corals, marine plankton, and shellfish. This phenomenon, which is commonly called "ocean acidification," could affect some of the most fundamental biological and geochemical processes of the sea in coming decades. This rapidly emerging issue has created serious concerns across the scientific and fisheries resource management communities.

Effects of Ocean Acidification on Coral Reefs

Many marine organisms that produce calcium carbonate shells studied thus far have shown detrimental effects due to increasing carbon dioxide levels in seawater and the resulting 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 long-term 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 (Litzow *et al*., submitted; 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*., in press). 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). 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 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 the existing data and from the geologic record that some coral and shellfish species will be reduced 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). 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 anytime since the last major extinction, over 65 million years ago. Thus, the decisions we make about our use of fossil-fuels for energy over the next several decades will probably have a profound influence on makeup of future marine ecosystems for centuries to millennia.

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 $60 billion per year. Coastal and marine commercial fishing generates upwards of $30 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). Nearly half of the U.S. fishery is derived from the coastal waters surrounding Alaska. 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.

Conclusions

Ocean acidification may be one of the most significant and far-reaching consequences of the buildup of anthropogenic carbon dioxide in the atmosphere. 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. Corals and other calcifying organisms will be increasingly affected by a decreased capability to produce their shells and skeletons. Other species of fish and shellfish will also be negatively impacted in their physiological responses due to a decrease in pH levels of their cellular fluids. 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. For these reasons, the national and international scientific communities have recommended a coordinated scientific research program with four major themes; (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.

Thank you for giving me this opportunity to address this Subcommittee. I look forward to answering your questions.

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