Statement of

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Chairman Lampsom, Ranking Member Inglis, and Members of the Subcommittee: thank you for the opportunity to provide testimony about the importance of the Federal Ocean Acidification Research and Monitoring (FOARAM) Act. My name is Joan Kleypas. I am a Scientist at the National Center for Atmospheric Research in Boulder, Colorado. My research has focused on the interactions between marine ecosystems and climate change, with particular emphasis on the impacts of climate change on coral reef ecosystems. I have worked on coral reefs for more than 20 years, and on ocean acidification for 10 years. I have authored or co-authored more than 40 peer-reviewed scientific journal articles, book chapters, and technical documents, and have presented more than 40 invited talks worldwide. I have co-organized several international workshops on issues related to climate change and marine ecosystems. I currently serve on three committees related to carbon and the oceans: the Ocean Carbon and Biogeochemistry Scientific Steering Committee, the International advisory boards of the European CarboOcean Program, and the European Program on Ocean Acidification (EPOCA). You have asked me to discuss the potential scope and impacts of ocean acidification on marine organisms and ecosystems, the need for federal research, monitoring and assessment programs to address this phenomenon, and for recommendations for strengthening and improving federal research to do so.

I. Introduction

Ocean acidification is increasingly recognized as an important and potentially dangerous consequence of increasing concentration of atmospheric carbon dioxide in Earth's atmosphere. Because climate change and ocean acidification are both caused by increasing atmospheric carbon dioxide (CO_2), acidification is commonly referred to as the "other CO_2 problem"[1-2]. But compared to climate change, ocean acidification is a more direct and predictable consequence of rising atmospheric carbon dioxide and does not suffer from uncertainties associated with climate change forecasts. Absorption of anthropogenic carbon dioxide, reduced pH, and lower calcium carbonate ($CaCO_3$) saturation in surface waters, where the bulk of oceanic production occurs, are well-verified from models, hydrographic surveys and time series data [3,4,5,6].

Since preindustrial times, atmospheric concentration of atmospheric carbon dioxide has increased from 280 to 385 ppmv (a 38% increase). The increase in atmospheric concentration has driven more CO_2 into the surface ocean that, through a series of carbon and water chemical reactions (e.g., the formation of carbonic acid), has led to a decrease

[1] Henderson C. 2006. Paradise lost. *New Scientist* 5 August 206:29-33
[2] Turley C. 2005. The other CO_2 problem. In *openDemocracy*, http://www.acamedia.info/sciences/sciliterature/globalw/reference/carol_turley.html
[3] Caldeira K, Wickett ME. 2003. Anthropogenic carbon and ocean pH. *Nature* 425:365-
[4] Feely RA, Sabine CL, Lee K, Berelson W, Kleypas J, et al. 2004. Impact of anthropogenic CO_2 on the $CaCO_3$ system in the oceans. *Science* 305:362-6
[5] Orr JC, Fabry VJ, Aumont O, Bopp L, Doney SC, et al. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature* 437:681-6
[6] Solomon S, Qin D, Manning M, Chen Z, Marquis M, et al. 2007. *Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. New York: Cambridge Univ. Press

in average pH of the surface ocean from about 8.2 to 8.1. If atmospheric CO_2 concentrations reach 800 ppmv (the projected end-of-century concentration according to the Intergovernmental Panel on Climate Change (IPCC) business as usual emission scenario), average surface ocean pH will decrease to 7.8–7.9. This change in pH may at first seem small, but it is significant for several important reasons:

1) Because pH measures acidity on a logarithmic scale, a 0.1 decrease in pH represents a 30% increase in ocean acidity.
2) Surface ocean pH is already lower than has occurred in the oceans for at least 800,000 years, and probably many millions of years.
3) The speed of this change is likely to outstrip the ability of many organisms to adapt to the lower pH.

II. Potential scope and impacts of ocean acidification on marine organisms and ecosystems

A. Impacts on Marine Organisms

The fact that increases atmospheric carbon dioxide can cause changes in ocean pH has been known for about a century, but the potential impacts on ocean biota have only recently been appreciated. A general summary of these effects is provided in Table 1.

Table 1 illustrates two main points. First, it is clear that changes in ocean chemistry cause important responses in many groups of marine organisms. Experimental studies on corals, for example, which are the best-studied group, indicate that the rate at which they produce their skeletons will decrease 10–50% by the middle of this century (e.g., when atmospheric carbon dioxide levels reach 560 ppmv). Depending on the species of coral, a decrease in this "calcification rate" will either stunt the growth of the colony, or result in a weaker skeleton (similar to osteoporosis in humans).

The second point is that relative to the potential consequences of ocean acidification, we still have very few studies on which to base our predictions about how marine life will change in response to future ocean acidification[7]. Most studies have concentrated on the rather obvious effect of ocean acidification on the ability of marine organisms to grow their shells and skeletons (corals, coccolithophores, mollusks, etc.). Fewer studies have focused on other physiological effects such as photosynthesis, respiration, and reproduction. Even fewer studies have looked at the effects on other important marine processes such as nitrogen fixation, or on the ability of ecosystems to function and provide their normal ecosystem services.

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[7] Fabry VJ, Seibel BA, Feely RA, Orr JC. 2008b. Impacts of ocean acidification on marine fauna and ecosystem processes. *ICES Journal of Marine Science*

Table 1. Summary of organism responses to ocean acidification

Taxon	Response to elevated carbon dioxide *
Cyanobacteria	Some species of cyanobacteria fix elemental nitrogen into a form that is readily available for photosynthesis in other species. An abundant cyanobacterium, *Trichodesmium,* is shown to have higher nitrogen-fixation rates. This has implications for fundamental biological processes in the ocean.
Picocyanobacteria	These ultramicroscopic unicellular organisms are quite possibly the most abundant organisms in the oceans. Two species have been tested. One species had increased growth rates; the other showed no response.
Coccolithophores	These are microscopic algae that secrete calcium carbonate. Several experiments have shown a decrease in calcification, an increase in organic production, and deformation of the calcite liths. Other experiments have shown different results that either reflect experimental artifacts or suggest adaptive capacity in these organisms.
Coralline red algae	One published experiment indicates reduced growth and reduced ability of larvae to colonize surfaces. Experiments in reef communities dominated by coralline red algae also show a significant reduction in calcification rates.
Kelp seaweed	Two species showed slower growth of the microscopic stages.
Planktonic foraminifera	Two species have been studied; both show decreased calcification rate.
Corals	Many studies indicate a decrease in calcification rates in corals, as well as a decrease in entire coral-based communities.
Echinoderms	Studies indicate either a reduction in calcification rate, or an increase in calcification rate at the expense of muscle mass. Larval stages of some species show abnormal development or lower tolerance to temperature.
Mollusks	Several studies show that mollusks experience a reduction in calcification rate, significant changes in blood chemistry, and reduction in reproduction rates. Pteropods, planktonic snails that secrete shells of aragonite, are thought to be particularly vulnerable to ocean acidification.

* only studies with CO_2 changes consistent with future changes are included

B. Impacts on Marine Ecosystems

Almost all ocean acidification studies have been performed on organisms rather than ecosystems, and so far we have had to infer the ultimate effects on ecosystems. For example, we have some understanding of why organisms secrete calcium carbonate shells (e.g., protection, securing to the substrate), but we have only a few examples of how a thinner shell or slower growth rate will affect an organism's fitness or behavior within its ecosystem[8].

[8] Bibby R, Cleall-Harding P, Rundle S, Widdicombe S, Spicer J. 2007. Ocean acidification disrupts induced defences in the intertidal gastropod Littorina littorea. *Biology Letters* 3:699-701

In some cases ocean acidification will directly affect major fishery resources, such as shellfish. In other cases, ocean acidification will indirectly affect fisheries by altering food webs. A well-cited scenario is one where increasing ocean acidity reduces the ranges of pteropods, small planktonic marine snails that are an important food source for some important food fish like salmon[9].

In benthic systems, ocean pH and associated carbonate chemistry affect the dissolution rates of calcium carbonate sediments[10,11], and appear to alter the functioning of sediment-dwelling organisms[12]. On coral reefs, even if biological calcification rates did not decline, ocean acidification will decrease reef cementation[13] and cause dissolution rates to increase[14], both of which can shift the reef from one of net growth to net erosion. We know that high biodiversity on reefs is largely due to the reef structure and its complex of holes, substrates, etc., and loss of reef structure leads to loss of biodiversity. However, the erosion of coral reefs that act as breakwaters also increases the exposure of adjacent low-lying coastal areas to storms and other erosive forces. Another benthic example is deep-sea corals, recently discovered but widespread communities that live in deeper waters; these are limited by the aragonite saturation depth in the oceans and so are directly threatened as the aragonite saturation depth shallows in response to ocean acidification[15]. It is unknown how the loss of these communities will affect the fisheries that they support, but it is certain that degradation of both coral reefs and deep water coral communities will impact the fisheries that are associated with them.

Not all organisms will be affected by ocean acidification, and we can expect both winners and losers. Two species of very abundant picoplankton (very small microorganism in the ocean) were cultured in elevated carbon dioxide conditions; one species exhibited a 4-times increase in photosynthesis but the other showed little response[16], which suggests that open ocean food-web structures could substantially change in the future. Such basic changes in our ocean ecosystems are of particular concern because of the repercussions to marine biogeochemistry, food webs, fisheries,

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[9] Orr JC, Fabry VJ, Aumont O, Bopp L, Doney SC, et al. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature* 437:681-6

[10] Andersson AJ, Mackenzie FT, Lerman A. 2006. Coastal ocean and carbonate ecosystems in the high CO_2 world of the Anthropocene. *American Journal Of Science*

[11] Andersson AJ, Bates NR, Mackenzie FT. 2007. Dissolution of carbonate sediments under rising pCO(2) and ocean acidification: Observations from Devil's Hole, Bermuda. *Aquatic Geochemistry* 13:237-64

[12] Widdicombe S, Needham HR. 2007. Impact of CO_2-induced seawater acidification on the burrowing activity of Nereis virens and sediment nutrient flux. *Marine Ecology-Progress Series* 341:111-22

[13] Manzello DP, Kleypas JA, Budd DA, Eakin CM, Glynn PW, Langdon C. in press. Poorly cemented coral reefs of the eastern tropical Pacific: possible insights into reef development in a high CO_2 world. *Proceedings of the National Academy of Sciences of the United States of America*

[14] Kleypas JA, Buddemeier RW, Gattuso JP. 2001. The future of coral reefs in an age of global change. *International Journal of Earth Sciences* 90:426-37

[15] Guinotte JM, Orr J, Cairns S, Freiwald A, Morgan L, George R. 2006. Will human-induced changes in seawater chemistry alter the distribution of deep-sea scleractinian corals? *Frontiers in Ecology and the Environment* 4:141-6

[16] Fu FX, Warner ME, Zhang YH, Feng YY, Hutchins DA. 2007. Effects of increased temperature and CO_2 on photosynthesis, growth, and elemental ratios in marine *Synechococcus* and *Prochlorococcus* (Cyanobacteria). *Journal of Phycology* 43:485-96

and other ocean resources. These needs are the basis for the call from the oceanographic community to establish a national coordinated program on ocean acidification.

A small-scale example of how we might view future changes in our ocean ecosystems is to imagine the typical sequence of events in establishing a marine aquarium. One of the most important lessons in keeping marine aquaria is to maintain the seawater chemistry within very precise limits of pH, nutrients, temperature, and alkalinity. Many hobbyists launch their aquaria with all of the necessary ingredients, including the sand substrate, clean seawater, water circulation, and of course, a collection of beautiful fish and invertebrates. Unfortunately, many hobbyists do not maintain the seawater chemistry adequately, and nutrient levels increase and most notably, the acidity of the water increases. As the seawater chemistry changes, so does the ecosystem, with undesirable species (winners) displacing the desirable ones (losers) until the original ecosystem has been entirely replaced by another. As ocean acidification progresses in our oceans, we can imagine a similar course of ecosystem changes, albeit more slowly and perhaps not as pronounced. In fact, a recent study of ecosystem shifts around underwater volcanic carbon dioxide vents confirm that calcifying organisms, in particular, are progressively displaced by algae and other non-calcifying organisms along the gradient of decreasing pH[17].

C. Other Impacts

The effects of ocean acidification reach beyond the impacts on organisms. pH is a fundamental property of seawater that governs innumerable chemical reactions and equilibria. Acidity and oxidation state are the two phenomena that modulate all of ocean chemistry and biochemistry. The speciation (the chemical form) of many elements and nutrients in seawater changes in response to pH. These include many common elements (e.g., iron, copper, zinc) and nutrients such as phosphate, silicate and ammonia, all of which are essential to biological processes. Very few studies have looked into the biogeochemical consequences of changing pH on nutrients, although changes in the speciation of phosphate, silicate, iron and ammonium will be significant in response to the expected ocean acidification conditions of this century[18]. For example, in regions with high nutrient concentrations, a decrease in pH from 8.1 to 7.8 causes the proportion of ammonium (NH_4^+) to ammonia (NH_3) to increase[19], and can potentially affect important metabolic processes like nitrification (the conversion of ammonium and ammonia to nitrate, the form of nitrogen that is used in photosynthesis).

Ultimately, ocean acidification will affect the global ocean carbon cycle. Future changes in calcium carbonate production and dissolution alone will almost certainly have impacts on the ocean's capacity to store carbon. If ocean acidification causes shifts in

[17] Hall-Spencer JM, Fodolfo-Metalpa R, Martin S, Ransome E, Fine M, et al. 2008. Volcanic carbon dioxide vents show ecosystem effects of ocean acidification. *Nature* doi:10.1038/nature07051
[18] Royal Society. 2005. Ocean acidification due to increasing atmospheric carbon dioxide, The Royal Society, London
[19] Raven JA. 1986. Physiological consequences of extremely small size for autotrophic organisms in the sea. In *Photosynthetic Picoplankton* ed. T Platt, WKW Li, pp. 1-70. Ottawa: Can. Bull. Fish. Aquat. Sci.

ecosystems, particularly in microbial communities, then we can expect additional changes in marine biogeochemistry. The interplay and feedbacks between marine biogeochemistry, ecosystem shifts, and feedbacks to the Earth system are complex, and our ability to predict how these processes will be impacted by ocean acidification, particularly in combination with other global climate changes, is a formidable task.

III. The need for federal research, monitoring, and assessment programs on ocean acidification

In 2006, a report jointly sponsored by the National Science Foundation, the National Oceanic and Atmospheric Administration, and U.S. Geological Survey[20] entitled "Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research." This report was borne out of a workshop held in St Petersburg, Florida, and represents the consensus of more than 60 experts in the fields of marine chemistry, physics, biology, geology and remote sensing. Following this report, the scientific steering committee of the Ocean Carbon and Biogeochemistry Program (OCB; a NSF-NOAA-NASA interagency group with the mission to: *establish the evolving role of the ocean in the global carbon cycle, in the face of environmental change, through studies of marine biogeochemical cycles and associated ecosystems*), identified ocean acidification as one of its top research priorities, and sponsored a workshop to further recommend research strategies to investigate the effects of ocean acidification on not only calcification, but other marine biological and biogeochemical processes as well. That workshop convened at the Scripps Institute of Oceanography in October 2007, and with the input of more than 90 scientists in the field, produced priorities and timelines for ocean acidification research in four major ocean environments: warm-water coral reefs, coastal margins, subtropical/tropical pelagic regions, and high latitude regions[21].

The remaining testimony draws heavily from these two workshops and reports, because they represent several years of work to synthesize existing knowledge on how ocean acidification affects marine ecosystems, as well as a consensus of the many scientists who produced that research and attended the workshops.

A. Priorities in Ocean Acidification Research – A Scientific Consensus

The St. Petersburg Report[22] identified the state of the current scientific knowledge (Chapters 1-3); the urgent gaps in that knowledge (Chapter 3) and how to tackle them (Chapters 3-6); and recommended an overall phased scientific strategy for the next 5-10 years (Chapter 7). The major scientific needs identified in this report were to:

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[20] Kleypas JA, Feely RA, Fabry VJ, C. Langdon CL, Sabine CL, L.L. Robbins. 2006. *Impacts of Increasing Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research*: NSF, NOAA, and the U.S. Geological Survey. 88 pp. http://www.isse.ucar.edu/florida/
[21] Fabry VJ, C. L, Balch WM, Dickson AG, Feely RA, et al. 2008a. Ocean acidification's effects on marine ecosystems and biogeochemistry. *Eos, Transactions of the American Geophysical Union* 89:143-4
[22] Kleypas JA, Feely RA, Fabry VJ, C. Langdon CL, Sabine CL, L.L. Robbins. 2006. *Impacts of Increasing Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research*: NSF, NOAA, and the U.S. Geological Survey. 88 pp.

1. Determine the calcification response of benthic calcifiers such as corals (including cold-water corals), coralline algae, foraminifera, mollusks, and echinoderms to elevated carbon dioxide; and in planktonic calcifiers such as coccolithophores, foraminifera, and shelled pteropods;
2. Discriminate the various mechanisms of calcification within calcifying groups, through physiological experiments, to better understand the cross-taxa range of responses to changing seawater chemistry;
3. Determine the interactive effects of multiple variables that affect calcification and dissolution in organisms (saturation state, light, temperature, nutrients) through continued experimental studies on an suite of calcifying groups;
4. Establish clear links between laboratory experiments and the natural environment, by combining laboratory experiments with field studies;
5. Characterize the diurnal and seasonal cycles of the carbonate system on coral reefs, including commitment to long-term monitoring of the system response to increases in carbon dioxide;
6. In concert with above, monitor in situ calcification and dissolution in planktonic and benthic organisms, with better characterization of the key environmental controls on calcification;
7. Incorporate ecological questions into observations and experiments; e.g., How does a change in calcification rate affect the ecology and survivorship of an organism? How will ecosystem functions differ between communities with and without calcifying species?
8. Improve the accounting of coral reef and open ocean carbonate budgets through combined measurements of seawater chemistry; calcium carbonate production, dissolution and accumulation, and bioerosion and off-shelf export;
9. Quantify and parameterize the mechanisms that contribute to the carbonate system, through biogeochemical and ecological modeling, and apply such modeling to guide future sampling and experimental efforts;
10. Develop protocols for the various methodologies used in seawater chemistry and calcification measurements.

The recommendations from the Scripps workshop expanded on the major points listed above, but also included non-calcifying organisms and ecosystems, and focused on four major environments: warm-water coral reefs, coastal margins, subtropical/tropical pelagic regions, and high-latitude regions. In addition to establishing research plans in each of these environments, overall recommendations from this workshop were to:

1. Quantify the distributions and abundances of calcareous organisms, particularly in regions projected to undergo substantial changes in carbonate chemistry over the next decades;
2. Develop autonomous systems for measurement of the seawater CO_2 system (pH, pCO_2, total dissolved inorganic carbon, alkalinity);
3. Establish a U.S. national program on ocean acidification that will coordinate research activities among federal agencies, and leverage existing infrastructure and programs, as well as establish sites for monitoring and process studies aimed explicitly at ocean acidification; and

4. Develop a coordinated, global network of ocean observations and studies through close partnerships with our international colleagues.

B. The Need for a Federal Program on Ocean Acidification

Ocean acidification is an emerging scientific issue; the issue is of high uncertainty but also high risk. Evidence from multiple scientific disciplines indicate that ocean acidification will cause changes in marine organisms, ecosystems and biogeochemistry, as well in the overall functioning of the ocean and global carbon cycles. However, our ability to forecast these changes is severely limited by a lack of data and scientific understanding of oceanic and ecosystem processes. Given that so much of the U.S. economy draws from ocean and coastal resources (e.g., the value of U.S. commercial fisheries is more than $35 billion per year[23]), the establishment of a federal program to research the potential impacts of ocean acidification is a sound economic investment.

The need for this understanding has prompted scientists both nationally and internationally to accelerate ocean acidification research. Many U.S.-based and international workshops on ocean acidification have highlighted the need to coordinate this research at both the national and international levels. The coordination is necessary to avoid duplication of efforts, and have the international community join forces in ways that are both necessary to answer the most pressing scientific and management questions, and to improve the efficiency of translating research results to support decision-makers. Some of the U.S.'s international colleagues have already established their own government-funded programs (e.g., European Program on Ocean Acidification) or are in the process of doing so (Australian Institute of Marine Science).

One of the reasons for an integrated and coordinated federal program supporting ocean acidification research is that no single federal agency can adequately tackle the breadth of the research needed to understand ocean acidification, its impacts, and its feedbacks on the Earth. Four federal agencies have so far been actively engaged in planning discussions for ocean acidification research: NOAA, NSF, NASA, and USGS. Each agency brings different and valuable expertise to address the problems and questions on ocean acidification, and is an essential component of a federally funded research program. NOAA primarily brings expertise in terms of ocean observing systems and physiological responses of commercially important fish and shellfish species. NSF supports academic, hypothesis-driven research in ocean chemistry, the physiology of ocean organisms and understanding of ecological systems, fostered around the world in field settings or in the laboratories of American institutions. NASA provides the capacity to remotely sense the effects of ocean acidification on ocean biology and chemistry, and/or scale up from in-water measurements to regional and global scales to address appropriate research questions. The USGS has the history and expertise in examining the interactions between coastal marine ecosystems and seawater carbonate chemistry.

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[23] Andrews, R., D. Bullock, R. Curtis, L. Dolinger Few, et al., 2007. Fisheries of the United States, 2006. National Marine Fisheries Service Office of Science and Technology, Fisheries Statistics Division, National Oceanographic and Atmospheric Administration.

Together these agency areas of expertise fit together to form the foundation of an integrated and coordinated research program to understand a changing ocean system.

H.R. 4174 (FOARAM Act) addresses the above recommendations to establish as U.S. research program on ocean acidification that includes monitoring; laboratory and field investigations of ocean acidification impacts on organism, ecosystems, and biogeochemistry; studies on the interactions with other environmental changes in the ocean; environmental and ecosystem modeling; and studies on the socioeconomic impacts. I have encouraged the passing of H.R. 4174 in recent testimony to the House Select Committee on Energy and the Environment[24]. I continue to support the passage of this bill, with several recommended changes.

IV. Recommendations for strengthening and improving federal research on ocean acidification

A. Coordination among federal agencies and with international partners

The Ocean Research Priorities Plan (ORPP) and Implementation Strategy[25] lists 20 national ocean research priorities for the coming decade, and ocean acidification is an issue that cuts across many of these priorities. The ORPP Implementation Strategy established a strong basis for carrying out these priorities by including: 1) use of existing mechanisms to address ocean research priorities, 2) partnerships (local, tribal, state, federal, international, etc.), 3) peer-review, 4) balancing sustained effort with new initiatives, and 5) accounting for different scales of research efforts and needs. A new governance structure established under the Committee on Ocean Policy expands the capacity for coordinating efforts across various federal agencies.

H.R. 4174 currently authorizes the allocation of funds to one agency (NOAA), which must then allocate to other departments and agencies. A more prudent approach is to directly allocate federal funds to each agency partner, and to take advantage of existing cross-agency groups to coordinate and manage activities between agencies. Given that ocean acidification was recognized as an important issue only within the last several years, there is still considerable basic research to be done on the impacts of changing chemistry on the oceans and its ecosystems. Ocean acidification is proving to be a far-reaching issue, and one that will almost certainly yield new discoveries, which calls for supporting unsolicited research proposals on ocean acidification that are unconstrained by questions predefined by federal agencies. This is the very heart of basic research and of discovery of the unknown dimensions of ocean acidification. I therefore recommend that H.R. 4174 more explicitly delineate the roles of the relevant agencies and allocate resources accordingly.

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[24] U.S. House of Representatives Select Committee on Energy Independence and Global Warming, 29 April 2008 Hearing on "Global Warming's Impact on the Oceans."

[25] NSTC Joint Subcommittee on Ocean Science and Technology (2007) Charting the Course for Ocean Science in the United States for the Next Decade, An Ocean Research Priorities Plan and Implementation Strategy, January 26, 2007, 84 pp.

However, there is a need for interagency coordination. To ensure that basic as well as applied research is carried out in a prompt and timely way, there must be a funding mechanism that entrains the academic research community in a competitive, peer-reviewed program of extramural funding (the National Ocean Partnership Program[26] (NOPP) Broad Agency Announcement provides an example of how to design such a mechanism). Establishing an inter-agency funding mechanism builds on the inter-agency cooperation on science funding and workshop support that led to the recognition that ocean acidification is an urgent issue and merits further research. The same inter-agency cooperation led to the establishment of the Ocean Carbon and Biogeochemistry (OCB) office to facilitate sustained science planning on ocean acidification and other pressing ocean research priorities. To sustain significant progress on the basic and applied research outlined above I recommend that this legislation establish a consultative inter-agency body focused on the science of ocean acidification.

For scientific oversight, a scientific steering committee that includes scientists funded from each of the participating agencies would oversee the scientific decisions, similar to how the scientific steering committee oversaw the U.S. Joint Global Ocean Flux Study (U.S. JGOFS) Program. (OCB) Scientific Steering Committee, for example, which is jointly supported by NSF, NOAA, and NASA, is already well informed and supportive of ocean acidification research, and could naturally take on the scientific guidance of an ocean acidification research program.

Finally, the objectives to understand the effects of ocean acidification are universal with our international colleagues, and much good will has been forged between scientists in the last few years toward maintaining international partnerships. The EPOCA program, for example, includes several U.S. scientists on its external advisory board. The global nature of ocean acidification certainly calls for increasing mechanisms to increase coordination of research with our international colleagues.

B. Costs

The authorization of appropriations in H.R. 4174 for fiscal years 2009, 2010, and 2011, is $6 million, $8 million, and $11 million, respectively, and $30 million per year for each year thereafter. It is useful to compare this appropriation to that of similarly tasked interagency ocean research programs in the late 1990s. For example, the NSF (only) contributions to JGOFS and GLOBEC[27] totaled about $17–22 million per year. The broad nature of an ocean acidification program will require both a biogeochemical emphasis (similar to U.S. JGOFS) as well as the effects on high-order organisms and ecosystems (similar to U.S. GLOBEC). The additional contributions from NOAA, NASA, and DOE to these programs are estimated to have doubled the total funding to around $40–45 million per year. The FOARAM Act appropriations are therefore quite modest compared to similarly sized programs of 10 years ago. In order to obtain timely information relevant to managers and decision-makers, we realistically need $50-55 million per year. The $30 million per year may be appropriate for the first 2-3 years,

[26] http://www.nopp.org/
[27] GLOBal Ocean ECosystem Dynamics http://www.usglobec.org/

while large-scale efforts are still being planned, but once the program is fully engaged, $50-55 million is considered the minimum if scientists are to provide useful information regarding how the oceans are responding to acidification, and how we should change our mitigation and adaptation policies.

Summary

Ocean acidification is an emerging scientific issue, and one of high uncertainty but high risk. Evidence from multiple scientific disciplines indicate that ocean acidification will cause changes in marine organisms, ecosystems and biogeochemistry, as well as in the overall functioning of the ocean and global carbon cycles. However, our ability to forecast these changes is severely limited by a lack of data and scientific understanding of oceanic and ecosystem processes. Two important U.S.-led workshops on ocean acidification have already identified the major gaps in our understanding of the consequences of ocean acidification for marine life, and have set priorities to guide a national research program on this topic.

H.R. 4174 (the Federal Ocean Acidification Research and Monitoring Act) enables such a national research program through the establishment of an interagency committee to oversee the planning, establishment, and coordination of ocean acidification research; the establishment of reporting procedures; the development of a strategic research and implementation plan; and an authorization of appropriations to carry out the plan.

I have recommended a few important changes to H.R. 4174, but otherwise fully support this bill that is so urgently needed to ensure proper stewardship of our oceans and protection of the abundant natural resources they provide.

Chairman Lampsom, Ranking Member Inglis, and Members of the Subcommittee: thank you once again for the opportunity to provide this testimony about ocean acidification, and to provide recommendations toward accelerating the scientific process of understanding its impacts quickly and in ways that will help inform future policy and management decisions.