THE FEDERAL OCEAN ACIDIFICATION RESEARCH AND MONITORING ACT: H.R. 4174

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT

COMMITTEE ON SCIENCE AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED TENTH CONGRESS

SECOND SESSION

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THE FEDERAL OCEAN ACIDIFICATION RESEARCH AND MONITORING ACT: H.R. 4174

THURSDAY, JUNE 5, 2008

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY AND ENVIRONMENT,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC.

The Subcommittee met, pursuant to call, at 10:10 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Nick Lampson [Chairman of the Subcommittee] presiding.

BART GORDON, TENNESSEE
CHAIRMAN

RALPH M. HALL, TEXAS
RANKING MEMBER

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Subcommittee on Energy and Environment

Hearing on

The Federal Ocean Acidification Research and Monitoring Act: H.R. 4174

Thursday, June 5, 2008
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

Witness List

PANEL I

The Honorable Jay Inslee (D-WA)

PANEL II

Dr. Richard A. Feely
Supervisory Chemical Oceanographer, Pacific Marine Environmental Laboratory,
National Oceanic and Atmospheric Administration

Dr. Joan Kleypas
Scientist, Institute for the Study of Society and Environment,
National Center for Atmospheric Research

Dr. Scott Doney
Senior Scientist, Department of Marine Chemistry and Geochemistry,
Woods Hole Oceanographic Institution

Dr. Ken Caldeira
Scientist, Department of Global Ecology, Carnegie Institution for Science of Washington

Mr. Brad Warren
Director, Productive Oceans Partnership Program, Sustainable Fisheries Partnership

HEARING CHARTER

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT COMMITTEE ON SCIENCE AND TECHNOLOGY U.S. HOUSE OF REPRESENTATIVES

The Federal Ocean Acidification Research and Monitoring Act: H.R. 4174

THURSDAY, JUNE 5, 2008
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On Thursday, June 5, 2008 the Subcommittee on Energy and Environment of the Committee on Science and Technology will hold a hearing on H.R. 4174, the *Federal Ocean Acidification Research and Monitoring Act.*

The purpose of the hearing is to receive testimony on H.R. 4174, legislation introduced by Rep. Tom Allen of Maine on November 14, 2007. The Committee will also examine the current status of science on ocean acidification and research and monitoring activities focused on ocean acidification and its potential impacts on marine organisms and marine ecosystems.

Witnesses

Dr. Richard A. Feely, Supervisory Chemical Oceanographer, Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration. Dr. Feely will discuss the quantification of oceanic uptake of carbon dioxide and NOAA's monitoring program; major research issues to be addressed including the relationship between the ocean acidification process and carbon cycling processes in the ocean.

Dr. Joan Kleypas, Scientist, Institute for the Study of Society and Environment, National Center for Atmospheric Research. Dr. Kleypas will discuss the impacts of ocean acidification on marine life and marine ecosystems, particularly on coral reef ecosystems.

Dr. Scott Doney, Senior Scientist, Department of Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution. Dr. Doney will discuss the gaps in our understanding of ocean acidification and the implications of ocean acidification for marine resource management. Dr. Doney will also discuss current interagency efforts and federal programs addressing ocean acidification.

Dr. Ken Caldeira, Scientist, Department of Global Ecology, Carnegie Institution for Science of Washington. Dr. Caldeira will discuss the ongoing changes in the global carbon cycle and its relationship to ocean acidification including the research and modeling efforts needed to better understand ocean acidification and to project its impacts and develop strategies for adaptation and mitigation.

Mr. Brad Warren, Director, Productive Oceans Partnership Program, Sustainable Fisheries Partnership. The Sustainable Fisheries Partnership provides policy and technical guidance to seafood suppliers and producers. The Productive Oceans Partnership Program was formed to address the issue of ocean acidification. Mr. Warren will discuss the potential impacts of ocean acidification on the world seafood industry and the steps the Partnership is recommending to deal with the problem of ocean acidification.

Background

What is Ocean Acidification?

Ocean acidification is the process by which the pH of seawater is being lowered through the absorption of carbon dioxide (CO_2) from the atmosphere. Atmospheric concentrations of CO_2 have increased over the past 200 years from a pre-industrial level of about 280 parts per million to 379 parts per million in 2005.[1] The concentration of CO_2 in the atmosphere would be much higher if not for the absorption of CO_2 by the oceans. The oceans have absorbed about 50 percent of the carbon dioxide (CO_2) released over the past 200 years due to human activities resulting in chemical reactions that release carbonic acid and lower ocean pH. The Royal Society of London released a report in 2005 of the consequences of ocean acidification and indicated that the increase in acidity could be as high as 30 percent over the last 200 years.[2]

Impacts of Ocean Acidification

While oceanic absorption of CO_2 has reduced the atmospheric concentration of CO_2 and therefore limited the greenhouse effect, acidification of the oceans may have negative consequences for sea-life that uses calcium carbonate to grow shells and other physical structures. A growing number of studies have demonstrated adverse impacts on marine organisms, including a decreased rate at which reef-building corals produce their skeletons; reduction in the ability of marine algae and free-swimming zooplankton to maintain protective shells and exoskeletons; and reduced survival of larval marine species, including commercial fish and shellfish. As ocean pH decreases, the amount of available calcium carbonate decreases. Many marine organisms require calcium carbonate to produce their shells and exoskeletons. Calcifying organisms include coral, mollusks, echinoderms and crustaceans.

The U.S. is the third largest seafood consumer in the world—total consumer spending for fish and shellfish is approximately $60 billion per year. Coastal and marine commercial fishing generates as much as $30 billion per year and nearly 70,000 jobs. The organisms likely to be impacted by ocean acidity include both commercially important groups (e.g., clams, oyster, crab, shrimp, and lobster) and organisms that serve as primary food sources for other commercially important species. Healthy coral reefs are the foundation of many of these viable fisheries, as well as the source of tourism and recreation revenues. Changes to the stability of coastal reefs may reduce the protection they offer to coastal communities against storm surges and hurricanes.

Many fisheries are also under stress from over fishing, pollution, diseases, and changes in water temperature.

Changes to the ocean's chemistry can be so long-lasting that they are basically irreversible once begun. According to the Royal Society of London's report,[3] it would take ten thousand years for the oceans' pH to return to their pre-industrial level. Chemical additives to the ocean to restore pH are unproven and could have many unintended consequences to ocean ecology and climate.

Current Federal Research and Monitoring Programs on Ocean Acidification

Although there are projects being funded through several federal agencies and some initial workshops and meetings have been organized to identify key research areas, there is no coordinated plan of research in place with identified funding to ensure that all aspects of ocean acidification are being monitored and explored to provide a comprehensive picture of this phenomenon. H.R. 4174 is intended to provide a statutory structure to ensure ongoing coordination of the relevant agencies to develop a comprehensive federal research, monitoring and assessment program to address the impacts of ocean acidification. A few of the recent activities undertaken by federal agencies are provided below.

NSF, NOAA, NASA, and USGS have been working to develop and coordinate individual agency programs on ocean acidification. These efforts also involve the academic research community and international partners. Japan, Korea, Canada and the European Union are also developing research and monitoring efforts to better understand ocean acidification. The agencies produced a workshop report: *Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research.* NSF supported a workshop convened by Scripps Institution of Oceanography in October 2007 to discuss potential ocean acidification research projects and to identify key gaps in knowledge about ocean acidification and its potential impacts.

Through these efforts the following key research and monitoring needs have been identified: **Monitoring** of the changing ocean chemistry and biological impacts at

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[1] Intergovernmental Panel on Climate Change. 2007. "Working Group I: The Physical Science Basis of Climate Change." Fourth Assessment Report. Chapter 2, p. 137.

[2] The Royal Society 2005, Science Policy Section, "Oceanic acidification due to increasing atmospheric carbon dioxide," *www.royalsoc.ac.uk*

[3] The Royal Society 2005, Science Policy Section, "Oceanic acidification due to increasing atmospheric carbon dioxide," *www.royalsoc.ac.uk*

selected coastal and open-ocean monitoring stations, including satellite-based monitoring to characterize reef habitats and to detect changes in surface ocean chemistry in response to ocean acidification; **Research** to understand the species-specific physiological response of marine organisms to ocean acidification and develop environmental and ecological indices that track marine ecosystem responses to ocean acidification; **Modeling** to predict changes in the ocean carbon cycle as a function of CO_2 and climate-induced changes in temperature, ocean circulation, biogeochemistry, ecosystems and terrestrial input; and to determine impacts on biological systems; **Technology development** and standardization for carbonate chemistry measurements on moorings and autonomous floats; and **Analysis** of social and economic implications of ocean acidification and **development of adaptation strategies** to help society cope with and respond to climate-induced changes in marine ecosystems.

There are several federal monitoring and research projects underway. The National Science Foundation recently awarded a grant through its Biocomplexity in the Environment area to support deployment of the first buoy to monitor ocean acidification in collaboration with scientists at NOAA's Pacific Marine Environmental Laboratory in Washington and scientists at several universities. The buoy was launched in the Gulf of Alaska last year and will measure air-sea exchange of carbon dioxide, oxygen and nitrogen gases and it will measure pH of surface seawater.

In 2005, NSF and NOAA collaborated on a cruise to collect field data on ocean acidification in the Pacific Ocean from the southern to the northern hemispheres as part of a long-term, cooperative hydrographic study. The results indicated decreases in pH and increases in dissolved inorganic carbon, both indicators of ocean acidification.

NSF is also supporting individual extramural academic research projects on ocean acidification topics through several of its directorates and programs. For example, Dr. Victoria Fabry is leading a team to study a species of marine snail to determine how changes in seawater chemistry may impact its ability to extract calcium from seawater to form its shell and other impacts on its physiology.

Chairman LAMPSON. Well, good morning. This hearing will come to order. I welcome to today's hearing all of you on this hearing on the *Federal Ocean Acidification Research and Monitoring Act,* H.R. 4174.

We have heard that climate change will have tremendous consequences for our environment, and today we will learn about one of these in detail, ocean acidification.

The oceans cover over 70 percent of the Earth's surface and have absorbed as much as 50 percent of our carbon emissions during the past 200 years.

As we will hear from our witnesses today, the addition of this excess carbon dioxide has altered the equilibrium between the atmosphere and the ocean, and it is making seawater more acidic.

Ocean acidification poses a threat to many marine organisms and ocean ecosystems. It reduces the ability of shellfish and corals to form their shells and skeletons. It impacts the health and survival of other organisms that are part of the food chain supporting fish and marine mammals.

Coral reefs and many of our fisheries are already compromised by over fishing, disease, pollution, and rising water temperatures. Ocean acidification is yet another stress that could dramatically and permanently alter our ocean environments.

H.R. 4174 introduced by our colleague from Maine, Congressman Tom Allen, and co-sponsored by two Members of this committee, Mr. Baird and Mr. Ehlers, is intended to coordinate and expand the efforts of the Federal Government to expand our knowledge of ocean acidification. Through more comprehensive monitoring and research we can begin to develop strategies to address the impacts of these changes on our fisheries and ocean ecosystems.

We have a distinguished panel of experts here with us today. I look forward to their testimony and your recommendations of what the Federal Government can do to address this serious issue and preserve the productivity and diversity of our oceans.

[The prepared statement of Chairman Lampson follows:]

PREPARED STATEMENT OF CHAIRMAN NICK LAMPSON

Good morning. I want to welcome everyone to today's hearing on *The Federal Ocean Acidification Research and Monitoring Act: H.R. 4174.*

In this committee we have heard that climate change will have tremendous consequences for our environment and today we will learn about one of these in detail—ocean acidification.

Carbon dioxide (CO_2) from the atmosphere dissolves in our oceans causing the pH of the ocean to decrease. Our oceans are our largest environment, covering over seventy percent of the Earth's surface and have absorbed as much as fifty percent of our carbon emissions during the past two hundred years.

Our oceans, however, are not simply a convenient CO_2 storage sink. As we will hear from our witnesses today, too much CO_2 disrupts the healthy equilibrium between our atmosphere and oceans.

The pH of the ocean decreasing poses a threat to the most delicate ocean ecosystems. For example, it reduces the ability of coral, shrimp, lobsters, and crab, to grow their shells and structures.

The changing ocean environment is likely to threaten not only these species, but impact the health of other ecosystems that support the food chain of fish, shrimp and our larger marine organisms. For example, coral reefs, around the world and off the coast of my home State of Texas, are already compromised by rising temperatures and land run off. Ocean acidification is yet another event that could dramatically and permanently alter our ocean environments.

While this committee cannot regulate carbon dioxide emissions, we can aid the science and research to understand our changing world.

I am pleased we are here today to discuss H.R. 4174. The Act was introduced by our colleague from Maine, Congressman Tom Allen, and is sponsored by two Members of this committee from both sides of the aisle, Mr. Baird and Mr. Ehlers, and our guest from Energy and Commerce, Mr. Inslee.

I am looking forward to hearing from our witnesses today on what the Federal Government should be doing to strengthen the research in order to understand the ecological state and consequences of ocean acidification.

Chairman LAMPSON. At this time I would like to yield to my distinguished colleague from South Carolina, our Ranking Member, Mr. Inglis, for an opening statement.

Mr. INGLIS. Thank you, Mr. Chairman. I appreciate you holding this hearing.

On our way to Antarctica this past January, our Science Committee CODEL stopped for a day in Australia to visit the Great Barrier Reef. Scientists there gave us a primer on the effects of ocean acidification on coral reefs. As climate change debate continues, it is essential for us to focus not only on atmospheric effects but also on the oceanic implications as well, understanding that the ocean holds tremendously valuable resources for the world's economy and environment.

The Federal Government is currently working to address ocean acidification on a number of fronts. Programs such as NSF, NOAA, NASA, and USGS all have individual efforts to work to understand the changing ocean chemistry and its biological impacts. H.R. 4174, the *Federal Ocean Acidification Research and Monitoring Act,* would organize and coordinate these efforts into a comprehensive research, monitoring, and assessment program.

The effects of ocean acidification I witnessed first hand in Australia highlight the necessity that this research should also be in a global undertaking. The European Union is launching the "European Project of Ocean Acidification" next week in Paris. This project has been put together to fill in the many gaps of our understanding of the impacts and ramifications of ocean acidification. As we move forward, I would hope that our research agenda reflects the fact that this is an international issue and encourages our scientists to work with their colleagues overseas.

Thank you, again, Mr. Chairman. I look forward to hearing from our witnesses on their perspectives on this legislation and any suggestions they may have to make improvements.

[The prepared statement of Mr. Inglis follows:]

PREPARED STATEMENT OF REPRESENTATIVE BOB INGLIS

Thank you for holding this hearing, Mr. Chairman.

On our way to Antarctica this past January, our CODEL stopped for a day in Australia to visit the Great Barrier Reef. Scientists there gave us a primer on the effects of ocean acidification on coral reefs. As the climate change debate continues, it is essential for us to focus not only on atmospheric effects, but on the oceanic implications as well, understanding that the ocean holds valuable resources for our economy and environment.

The Federal Government is currently working to address ocean acidification on many fronts. Programs such as NSF, NOAA, NASA, and USGS all have individual efforts at work to understand the changing ocean chemistry and its biological impacts. H.R. 4174, the *Federal Ocean Acidification Research and Monitoring Act,* would organize and coordinate these efforts into a comprehensive research, monitoring and assessment program.

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Paris. This project has been put together to fill in the many gaps in our understanding of the impacts and ramifications of ocean acidification. As we move forward, I would hope that our research agenda reflects the fact that this is an international issue and encourages our scientists to work with their colleagues overseas.

Thank you again, Mr. Chairman. I look forward to hearing from our witnesses on their perspectives of this legislation and any suggestions they may have to improve it.

Chairman LAMPSON. Thank you, Mr. Inglis.

I ask unanimous consent that all additional opening statements submitted by the, by Committee Members be included in the record. Without objection, so ordered.

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Thank you, Mr. Chairman, for holding this hearing today, as this is an important opportunity to learn more about the affects of carbon dioxide on our environment and more specifically, our oceans. As Congress considers climate change legislation in the future, this committee will undoubtedly examine the legislative options available to address the affects of global warming. It is important to understand how carbon dioxide affects all aspects of our planet, and I'm pleased that our witnesses are here today to further discuss this issue.

Although government research does exist on the acidification of oceans and the living environment they support, it is clear that we have only scratched the surface. As researchers and as policy-makers, we do not know enough about the effects of CO_2 on our ecosystems.

With the rising energy costs in our country, there is an increasing urgency to find clean, renewable sources of energy that have a zero carbon footprint. With better research and the tools to address this issue, the better prepared we will be to develop technologies that will yield a steady, stable source of energy. During my tenure on this committee and throughout my time in Congress, I have been a strong supporter of Carbon Capture Sequestration technology, so that we can use domestic sources of energy safely, without harm to our ecosystems.

It is clear from our witnesses today that the scientific community is well-poised to take advantage of this bill. The programs that would begin under H.R. 4174 would finally allow for a federally-directed and federally-funded program to build upon the existing ocean acidification research.

I'm confident that the scientific community would yield results that would prove useful to help create the innovative technology solutions that we will need to help solve the problem of carbon dioxide and global warming. Mr. Chairman, I look forward to our witnesses' testimony today and I yield back.

Panel I:

Chairman LAMPSON. At this time I would like to yield to my distinguished colleague from Washington, Mr. Baird, to introduce our first panel.

Mr. BAIRD. Thank you, Mr. Chairman. I would like to invite my dear friend and colleague, Mr. Inslee, up to the desk there, and I want to introduce him. It is a real pleasure to introduce somebody who had led this Congress in its efforts on global warming and ocean acidification.

As many of us know, this is the shameless plug part, but it is warranted. Mr. Inslee is the author of *"Apollo's Fire,"* which I understand has sold over 10,000 copies, and I am glad that it has. I hope it sells many more, because it is a comprehensive and very positive look at what we can do to reduce ocean acidification. I had the privilege of traveling with Mr. Inglis last year the Great Barrier Reef. We know how important it is there. Mr. Inslee has been involved in following up on some of the studies of the Great Northwest, where we are also having acidification problems, and I see some folks here in the room who are part of the meeting that just kicked off yesterday, Ocean Week, here on the Capitol. It is tremendously appropriate we are having this hearing today.

I think, Mr. Chairman, that at some point people may look back on this hearing and on all the other things that are going on the Capitol today and during the next few months, this hearing may be addressing one of the most grave threats to all of humanity and to our planet, and I am grateful for your leadership and calling it and grateful for Mr. Inslee for his presence as with all the other witnesses here.

Chairman LAMPSON. Congressman Inslee, you are recognized to make your statement.

STATEMENT OF HON. JAY INSLEE, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF WASHINGTON

Mr. INSLEE. Thank you, and I appreciate Mr. Baird's shameless plug for my book. We were going to cast Harrison Ford in the lead of "Apollo's Fire," the movie, but we are now going to cast Congressman Brian Baird as the male lead in the movie.

Mr. BAIRD. If you make it, I want to be in it.

Mr. INSLEE. No, no. We have some roles for everyone. And everyone does have a role in this revolution actually.

I want to thank the Chair and Ranking Member Inglis for holding this hearing. I agree with Mr. Baird that this really could be the largest issue we are going to grapple with in the next several decades. And just on a personal observation how I came to be aware of it, you know, for years I have been doing quite a bit of reading about global warming, back to, you know, mid 1990s, and I have been trying to keep abreast of the science involving global warming. And for years I thought this was a wonderful phenomenon because the oceans were sucking up what I called excess CO_2 out of the atmosphere, and you know, sequestering it in the ocean so we could get it out of that atmosphere and reduce the impact of the climactic system.

So for a long period of time I thought this was a blessing that the oceans were a sponge for carbon dioxide, until May 9, 2006, when Ken Caldeira, another scientist, came to us here in Congress and said, this is great, except it is creating acidic conditions in the ocean, and we have now had a 30 percent increase in ions associated with the acidic and corrosive activities in the ocean.

And the reason I mention this is that this is kind of a tell-tale reason why climactic changes and CO_2 is so dangerous. None of us, at least I did not see this as a problem until just the last year or two, and it shows you how this, when we mess with Mother Nature, it can bite us big time in ways that we do not understand, because we still have such a primitive understanding of the carbon dioxide cycle and what it does throughout these multiple systems, biological and geological and otherwise.

So I think this is a perfect example of the danger associated with CO_2 and the atmosphere that we still don't understand exactly what it is doing.

So obviously this is a problem that we need better scientific knowledge about. We had a hearing in Seattle led by Senator Cantwell on this last week or the week before last, and we are very concerned about this in the Puget Sound region, because we are so intimately involved. You know, the iconic restaurant in Seattle is Ivers Acres of Clams, and Ivers said, when the tide is out, the table is set with clams and oysters. And that may not be the case in Puget Sound in the next century as conditions become so acidic that it can retard the ability to form a calcium carbonate structure which could hurt all the clam and oyster lovers like myself.

But to me, I will just tell you here is what really does terrify me, even on a deeper basis that may cause oyster farms to be in trouble, is that 30 percent of the world's bottom of the food chain, the zooplankton, form some calcium carbonate structure. And at some point it becomes difficult for those little critters to form calcium, and that is the base of the entire food chain, upon which, you know, seven to 10 percent of our protein internationally comes from and which the whales depend on ultimately.

So the whole food chain of the ocean, I believe, is at risk at some level. We don't know exactly where that level is. The biology is very, it is in its very early stages to figure that out, but we had a scientist there in Seattle two weeks ago say she has actually seen a shell dissolve in corrosive water of the types that we will find the next century or so if things do not change. And we have seen the devastation the coral reefs are already experiencing, and the scientists will talk about that.

So in an answer to that I hope that we can move a bill that will try to develop a more, a systematic approach to federal research on how to really tackle this problem. We have been very lucky that some of the scientists today almost volunteered their time to go research this. We were lucky to dodge this bullet. We did not have an organized sentinel on duty for the Federal Government to look for this problem. We need to have an organized federal approach to this, and this bill is one approach on how to do that, and I know there are things we can talk about how to make it perfect, but we need to have some systematic, scientific approach to this, both on a national and ultimately international level. And I think that this bill is one step forward to accomplish this.

So we should not be blind-sided by this or anything else, and we were lucky to have these men and women working for us. They were the minute men and women, but now we need a more organized approach. And I hope that this bill will help move that forward.

So thank you for your farsightedness in holding this hearing. Any questions, happy to oblige.

Discussion

Chairman Lampson. Thank you very much, Mr. Inslee. I don't have questions. Does anyone wish to question?

Yes, sir. You are recognized.

Mr. Akin. Thank you, Mr. Chairman. Let me try and get a little bit of the basic science of the concern.

I assume when you talk about more CO_2 in the atmosphere then as the rain comes down, it picks it up, turns it into carbonic acid, and that goes into the ocean. So it is a form of sort of acid rain. It is not a sulfuric type of stuff, but it is more of a carbonic acid.

And then that changes the pH of the ocean. Is that the basic concern mechanically of what is going on?

Mr. INSLEE. Given my test scores in freshman chemistry, I may not be the proper person to ask that question to, but generally speaking, yes. I actually don't know if it is conveyed through rain or just some partial pressure driving the CO_2 to go into solution, and the chemists behind me will answer that. And I should point out that when we say it becomes more acidic, it actually becomes less base, because the ocean is actually in base conditions, and it reduces the pH, a very small number. On a logarithmic scale that is about a 30 percent increase in those ions that would be, "acidic."

So it is definitely a corrosive, though, for biological, anything forming a calcium-base system, and that is where the real problem is. So I hope that I didn't cloud it too much.

Mr. AKIN. Mr. Chairman, if it is okay, is there somebody else who wanted to go a little further?

Mr. INSLEE. Yes. You better defer to the real scientific——

Chairman LAMPSON. We will have the next panel come up in just a minute.

Mr. AKIN. Thank you, Mr. Inslee.

Chairman LAMPSON. They will be able to get into the details of that.

Dr. Bartlett.

Mr. BARTLETT. Thank you very much.

Carbon dioxide, of course, is very soluble in water, and the colder the water the higher the solubility. We require something like 10 percent oxygen, and we have about almost 21 percent, we can make due at 10 percent, but our plants at the other side of this cycle, they have less than .04 percent CO_2. If you are a rose fan, you are growing them in the greenhouse, you put a tank of CO_2 in there, and you crack the valve because they get starved for CO_2 shortly in the wintertime.

The ocean, of course, has two kinds of plankton, the zooplankton you mentioned, which may be adversely affected by higher CO_2, but the phytoplankton should be happier with high CO_2. The oceans will certainly be different with higher CO_2, and I am wondering what that ultimate balance might be. The phytoplankton is going to do better, it is going to grow faster with higher CO_2 levels. There may be some impediment to the, some of the things that the zooplankton need to do, but it will be a very different world. And I don't know whether it will be a worse world or not, but it will certainly be different, and there is a risk that it could be worse.

So thank you very much for your——

Mr. INSLEE. I appreciate that. I think that is a really important point. The answer is obviously we don't know what, you know, the differences will be. One of the scientists at this hearing in Seattle basically said that it is at least a substantial likelihood that there will be species substitution. You will have niches in the food chain that may be filled by different species, but that is not exactly a benign answer, because I don't think my constituents are going to be happy about a fishing season on jellyfish as opposed to a season on salmon.

And that is one of the situations, and by the way, there is, I am told that there is some things going on there right now. There is a profusion of jellyfish going on in the oceans. I don't know what the reason for that it is, but, yes, important point.

Mr. BARTLETT. Thank you very much, Mr. Chairman.

Mr. INSLEE. Thank you.

Chairman LAMPSON. Thank you, Dr. Bartlett.

Mr. BAIRD. Mr. Chair, perhaps one of our later witnesses could comment on the profusion of jellyfish in this institution as well.

Chairman LAMPSON. Thank you for that insight.

Mr. MCNERNEY. Mr. Chairman.

Chairman LAMPSON. Mr. Inslee, thank you——

Mr. MCNERNEY. I just want to say, I have been here for about a year and a half, and I have worked with Mr. Inslee on global warming issues. He has shown a lot of leadership, and I appreciate your coming and testifying before us today. I think you are doing a great job.

Mr. INSLEE. And I am often wrong but never in doubt, as you know.

Chairman LAMPSON. Well, we think that you are doing a tremendous job——

Mr. INSLEE. Thank you, Mr.——

Chairman LAMPSON.—keeping this on our minds and raising the awareness of the world. So, thank you very much, Mr. Inslee.

Ms. WOOLSEY. Mr. Chairman, can I say——

Chairman LAMPSON. Yes.

Ms. WOOLSEY.—nice things about my colleague?

Chairman LAMPSON. Certainly you may, Ms. Woolsey. You are recognized. Just don't say anything too nice.

Ms. WOOLSEY. Jay, I want to say nice things about you.

Mr. INSLEE. Okay. I will listen.

Ms. WOOLSEY. All I can tell you is every time we start talking about our Democratic position on global warming and energy, I say, has anybody asked Jay Inslee. So we need to pay attention to what he is saying. He is a guru, and he is going to be a huge part of what goes right.

Mr. INSLEE. I really appreciate that. Let me just say one thing. I do want to say, though, we are not going to apparently pass the cap and trade system. It would be the first step in an effort to deal with these kind of problems this year. I just want to say that I am optimistic about our ability on a bipartisan, international, multilevel approach to solve this problem.

I do believe it is the largest problem humanity has faced at one time internationally ever. There has never been a problem that people have ever shared all the way around the world other than this one, and we all share this everywhere in the world. And I believe it is going to unite the world eventually. I believe it is going to be a significant cause for economic growth, because the problems we are talking about here have a solution to technologies, which we can create in this country.

And I was just in Napa, California, two weeks ago, meeting with the venture capital community and a bunch of CEOs who are building the technologies today to grow the U.S. economy that will also stop ocean acidification. And I think we should be optimistic and very American and bullish on our ability to solve this, and I look forward to it.

Thank you.

Chairman LAMPSON. Thank you very, very much.

As he leaves and we invite the next panel up, we will just take a breather here without calling it a recess. So we will pause.

Panel II:

Chairman LAMPSON. I want to welcome our second panel of witnesses here. Dr. Richard Feely is the Supervisory Chemical Oceanographer at the Pacific Marine Environmental Laboratory at the National Oceanic and Atmospheric Administration, more commonly known as NOAA. Dr. Joan Kleypas is a Research Scientist at the Institute for the Study of Society and Environment at the National Center for Atmospheric Research. Dr. Scott Doney is a Senior Scientist at the Woods Hole Oceanographic Institution in Woods Hole, Massachusetts. Dr. Ken Caldeira is a Scientist at the Carnegie Institution, Department of Global Ecology at Stanford University, and Mr. Brad Warren is the Director of the Productive Oceans Partnership Program at the Sustainable Fisheries Partnership.

You will each have five minutes in your spoken testimony. Your written testimony will be included in the record for the hearing, and when you all complete your testimony, we will begin with questions. Each Member will have five minutes to question the panel.

Dr. Feely, you may begin.

STATEMENT OF DR. RICHARD A. FEELY, SUPERVISORY CHEMICAL OCEANOGRAPHER, PACIFIC MARINE ENVIRONMENTAL LABORATORY, OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

Dr. FEELY. Good morning, Chairman Lampson, Ranking Member Inglis, and Members of the Subcommittee. Thank you for giving me the opportunity to discuss ocean acidification and the Administration's views on H.R. 4174.

Over the past two centuries the oceans have absorbed approximately 525 billion tons of carbon dioxide from the atmosphere. The ocean's daily uptake of 22 million tons of carbon dioxide is starting to have a significant affect on the chemistry and biology of the oceans. Hydrographic surveys and modeling studies reveal that the chemistry changes in seawater resulting from absorption of carbon dioxide are increasing the acidity of the seawater.

Furthermore, future predictions indicate the oceans will continue to absorb carbon dioxide and become more acidic. It is now well established that our ocean surface waters have increased in acidity by about 30 percent.

Future predictions of atmospheric carbon dioxide concentrations indicate by the middle of the century atmospheric carbon dioxide levels could reach 500 parts per million and near the end of the century could be as high as 800 parts per million. This will result in the ocean becoming approximately 150 percent more acidic.

To this point in historical perspective this increase in surface ocean acidity will result in the oceans being more acidic than it has been for over 20 million years. The increase in ocean acidification has significant affects on many marine ecosystems and species. For example, increased ocean acidification significantly reduces ability of reforming corals to produce their skeletons. This affects the individual coral's growth rates and makes the reefs more vulnerable to erosion.

Ongoing research is showing that the increased ocean acidification may also harm commercially-important fish and shellfish larvae. Scientists have also seen a reduced ability of marine algae and free-flowing plants and animals to produce the protective carbonate shells. The effects of ocean acidification on coral reef ecosystems and fisheries could reverberate throughout the entire U.S. and global economy.

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's ocean acidification research falls into three main categories; observations, physiological effects on marine species, and modeling efforts.

An example I would like to share with some of you, the new research that we have acquired this past year. NOAA's Pacific Marine Environmental Laboratory carries out ocean observations. Their carbon dioxide measurements on ships and monitoring buoys provide data that helps NOAA discern seasonal changes in the ocean carbon system.

Recently we discovered that up along the west coast of North America is drawing corrosive, acidic waters up onto the Continental Shelf. This process happens during the spring and summer months when the winds push surface waters away from the coast and draw CO_2-rich waters on the Continental Shelf in very shallow waters. In fact, we observed some of the coastal waters had actually up-welled all the way to the surface off the northern coast of California.

These findings are quite surprising. No one considered that upwelling of corrosive waters offshore would make the waters on our Continental Shelf so vulnerable to ocean acidification on the timescales that the models have provided thus far. Our findings represent the first evidence that a large section of the North American Continental Shelf is seasonally impacted by ocean acidification. This means that ocean acidification may be seriously impacting marine life on our Continental Shelf right now.

The introduction of H.R. 4174 reflects recommendations from the national scientific community for coordination of scientific research on this issue. The scientific community has identified four major themes for a research program. These include carbon system monitoring, calcification and physiological response studies, environment and ecosystem modeling, and socioeconomic 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.

With support and we support the intent of H.R. 4174 to develop an ocean acidification research and monitoring plan and appreciate the interests of this committee on this research area. As part of our mission NOAA has a strong foundation of ocean acidification research. We will be able to provide strong leadership for federal inter-agency effort examining ocean acidification across the Federal Government.

Because of the very potential for ocean-wide effects of ocean acidification at all levels of the marine ecosystem, we can expect to see significant effects that are of immense importance to humankind. Ocean acidification is an emerging scientific issue, and much research is needed before ecosystem species responses are well understood.

Thank you for giving me this opportunity to address this committee, and I look forward to your questions.

[The prepared statement of Dr. Feely follows:]

PREPARED STATEMENT OF RICHARD A. FEELY

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 deep water 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) socioeconomic 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.

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BIOGRAPHY FOR RICHARD A. FEELY

Dr. Richard A. Feely's major research areas are carbon cycling in the oceans and ocean acidification processes. He received a B.A. in chemistry from the University of St. Thomas, in St. Paul, Minnesota in 1969. He then went on to Texas A&M University where he received both an M.S. degree in 1971 and a Ph.D. degree in 1974. Both of his post-graduate degrees were in chemical oceanography. He is a member of the U.S. Science Steering Committees for the U.S. Carbon Cycle Science Program, the U.S. Ocean Carbon and Climate Change Program, and the U.S. Carbon and Biochemistry Program. Dr. Feely has authored more than 150 refereed research publications.

Visit Dr. Feely's website for more information on his research activities and publications (http://www.pmel.noaa.gov/co2/personnel/feely.html).

Chairman LAMPSON. Thank you, Dr. Feely.

And Dr. Kleypas, with whom I share an alma mater, Lamar University in Beaumont, Texas. You are recognized for five minutes.

STATEMENT OF DR. JOAN A. KLEYPAS, SCIENTIST, INSTITUTE FOR THE STUDY OF SOCIETY AND ENVIRONMENT, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Dr. KLEYPAS. Thank you, Chairman Lampson, also Ranking Member Inglis, Members of the Subcommittee. I am very grateful for being able to provide testimony about the effects of ocean acidification on marine life and to provide recommendations on the *Federal Ocean Acidification Research and Monitoring Act.*

Representative Inslee may have not done so well in the Stanford Chemistry, but he got an A-plus today in his description of ocean acidification, and as he and Dr. Feely has described, ocean acidification is proceeding, and it will continue for as long as carbon dioxide remains unstabilized in our atmosphere.

Over the last decade we have gathered a lot of information to confidently say that ocean acidification is a major threat to marine life, and here are some of the effects.

Ocean acidification has been shown to affect a wide variety of organisms from the tiniest microscopic single-celled bacteria in the oceans, all the way up through coral reef ecosystems, and it is likely to alter our food webs as well.

Ocean acidification can affect photosynthesis, respiration, reproduction, and growth, and as described already, it also affects the ability of many marine organisms to secrete their calcium carbonate skeletons or shells. These, we often think of the common things like corals, shellfish, and starfish, but it also affects many lesser-known microscopic organisms that are pervasive in, throughout the oceans.

As the oceans become more acidic, it simply is harder for these organisms to secrete their calcium carbonate shells, and as an example, you might recall that experiment when you were a kid where you take an egg and you put it in household vinegar. After a few days that calcium carbonate has dissolved away, and that eggshell is soft, and it is no longer protective. So that experiment is really a dramatic example of what acid can do to calcium carbonate skeletons, but the principle is really the same.

So shells and skeletons are very important for the survival of marine organisms. They produce those shells for a reason, and those reasons are things like protection and for competition of space. In corals, for example, we estimate that the growth rates of their skeletons will decline by 10 to 50 percent within the next 40 to 50 years. That means they will have to grow much more slowly or less densely, like osteoporosis, and you know, if our bones grew 10 to 50 percent less, that would be a pretty big deal. We would either be much shorter or our bones would be a lot weaker.

Ocean acidification affects coral reefs in other ways, too. Reefs exist because corals and other organisms build them faster than they are eroded away. Even if corals are able to maintain their growth, ocean acidification will still cause reefs to erode away more quickly, and if they do erode away, we are going to lose a lot of those services that reefs provide like fisheries, biodiversity, and coastline protection.

Right now we really can't predict exactly what will happen to marine ecosystems if ocean acidification continues, but another example would be like an aquarium, and a lot of us started aquariums when we were little, and we did everything just right. We got the salinity right, the temperature, the organisms, but one of the most important things to do in an aquarium is to get the pH just right, to keep it within a very narrow range. If you don't do that and the pH declines, the first thing to go are the corals. They stop growing, and then what happens is the algae tend to take over. And so what you have witnessed there on a small scale is the replacement of that very desirable ecosystem with one which we don't desire.

So across the entire ocean as acidification proceeds, we expect to see similar changes in our ecosystems. So what do we do about this? Well, first, we need to take actions to reduce carbon dioxide emissions, but second, given that we are already experiencing ocean acidification and that we expect it to continue in the next two, you know, next few decades, we need studies to tell us what impacts will be and how to manage ecosystems underneath this additional stress.

So the *Federal Ocean Acidification Research and Monitoring* (FOARAM) *Act* is, really is a good bill, and it addresses the major research needs, but I have two recommendations to strengthen it. One is a stronger commitment of funds. The appropriations are really quite modest when we consider the scope of the problem and the cost of comparable ocean programs in the past. In order to do this research quickly and to provide good advice to managers and decision-makers, we have estimated that the minimum costs to do this research is about $50 to $55 million a year.

The other point is this. Ocean acidification is a big, emerging issue, and there is the potential for many new discoveries, things that we just don't know about yet. So we need not only applied research, but we need very basic research as well.

Through our previous workshops and planning efforts we have already identified the strengths that both federal and academic agencies will bring to ocean acidification program, and to build on those efforts I recommend that the bill explicitly delineate the roles of each of those relevant agencies and allocate resources directly to them.

Thank you again for this opportunity to take, to make the case for ocean acidification as an urgent and important issue and to comment on the FOARAM Act.

[The prepared statement of Dr. Kleypas follows:]

PREPARED STATEMENT OF JOAN A. KLEYPAS[1]

Chairman Lampson, 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."[2,3] 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.[4,5,6,7]

Since pre-industrial times, atmospheric concentration of atmospheric carbon dioxide has increased from 280 to 385 ppmv (a 38 percent increase). The increase in at-

[1] Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author and do not necessarily reflect those of the National Science Foundation.

[1] Henderson C. 2006. Paradise lost. *New Scientist* 5 August 206:29–33.

[3] Turley C. 2005. The other CO_2 problem. In "openDemocracy," *http://www.acamedia.info/sciences/sciliterature/globalw/reference/carol_turley.html*

[4] Caldeira K, Wickett ME. 2003. Anthropogenic carbon and ocean pH. *Nature* 425:365–365.

[5] 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* 305:362–366.

[6] 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* 437:681–686.

[7] 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.

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

[9] 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.

[10] 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* 437:681–686.

mospheric 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 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 percent 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 percent 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.[8] 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.

[8] 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.[9]

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.[10]

In benthic systems, ocean pH and associated carbonate chemistry affect the dissolution rates of calcium carbonate sediments,[11,12] and appear to alter the functioning of sediment-dwelling organisms.[13] On coral reefs, even if biological calcifi-

[9] 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.

[10] 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* 437:681–686.

[11] 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.*

[12] 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* 13:237–264.

[13] 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* 341:111–122.

cation rates did not decline, ocean acidification will decrease reef cementation[14] and cause dissolution rates to increase,[15] 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.[16] 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 four-times increase in photosynthesis but the other showed little response,[17] 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, 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.[18]

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 cen-

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[14] 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.*

[15] Kleypas JA, Buddemeier RW, Gattuso JP. 2001. The future of coral reefs in an age of global change. *International Journal of Earth Sciences* 90:426–437.

[16] 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* 4:141–146.

[17] 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* 43:485–496.

[18] 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.

tury.[19] 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,[20] 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 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[21] 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.[22]

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[23] 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:

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;

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[19] Royal Society. 2005. Ocean acidification due to increasing atmospheric carbon dioxide, The Royal Society, London.

[20] 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.

[21] Kleypas JA, Feely RA, Fabry VJ, C. Langdon CL, Sabine CL, Robbins LL. 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/*

[22] 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* 89:143–144.

[23] 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.

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[24]), 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 coordi-

[24] 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.

nate 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. 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.[25] 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[26] 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

[25] 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."

[26] 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.

of ocean acidification. I therefore recommend that H.R. 4174 more explicitly delineate the roles of the relevant agencies and allocate resources accordingly.

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[27] (NOPP) Broad Agency Announcement provides an example of how to design such a mechanism). Establishing an interagency funding mechanism builds on the interagency 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 interagency 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 interagency 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[28] 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 two to three years, 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 acidifica-

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

tion 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.

BIOGRAPHY FOR JOAN A. KLEYPAS

Education

1992—Ph.D., Tropical Marine Studies, James Cook University of North Queensland, Australia, Thesis: "Geological development of fringing coral reefs in the southern Great Barrier Reef, Australia." Thesis Advisor: Professor David Hopley.

1980—M.S., Marine Science, University of South Carolina, Thesis: "Migrations and feeding of predatory fish in an intertidal creek, with special reference to the silver perch (*Bairdiella chrysura* L.)." Thesis Advisor: Professor John Mark Dean.

1978—B.S., Oceanography/Marine Biology, Lamar University, TX.

Work History (post-Master's degree)

Scientist III, NCAR, 2008–present; Institute for the Study of Society and Environment

Scientist II, NCAR, 2004–present; Institute for the Study of Society and Environment

Scientist I, NCAR, 2003–2004; Environmental and Societal Impacts Group (now Institute for the Study of Society and Environment)

Associate Scientist, NCAR, 1998–2003; U.S. JGOFS Synthesis & Modeling Project

Visiting Scientist, NCAR, 1996–1998; Climate and Global Dynamics

Visiting Assistant Professor, Geosciences, Colorado College, 1995–1996; (also taught courses in 1997, 1998, 2005)

Postdoctoral Research Scientist, NCAR, 1993–1995; Advanced Study Program

Senior Scientist, Walsh & Associates, Boulder, CO, 1992–1993; Environmental consulting; marine impact assessments

Research Assistant and Fulbright Scholar, Australia; James Cook University, 1987–1991; Ph.D. research on Great Barrier Reef

Research and Teaching Assistant, Texas A&M University, Oceanography and Geology Departments, College Station, TX 1984–1987 (Ph.D. program in Geology)

Research Scientist, TerEco Corporation, College Station, TX 1982–1984; EPA contracts to determine marine biological distributions of deep-sea fauna, and impacts of oil drilling, brine disposal, etc., in the Gulf of Mexico

Honors and Awards

- Aldo Leopold Leadership Fellow, 2008
- Best Paper Award, Coral Reefs, 2003
- Advanced Study Program Fellowship, NCAR, 1993–95
- Jerald J, Cook Memorial Award for best Paper, *8th Thematic Conf. Geol. Remote Sensing,* 1991
- Fulbright Scholarships, 1987, 1988
- Getty Oil Co. Scholarship, 1984
- Texas A&M Univ. Faculty Scholarships, 1982, 1983
- *Undergraduate awards:* Summa cum laude, 1978; Merit Scholarship, 1977; Phi Beta Honor Society; Sigma Xi Honor Society; Sigma Gamma Epsilon Geological Honor Society

Research Grants

- NSF grant "A Workshop on Impacts of Increasing Atmospheric CO_2 on Marine Calcifiers," 2005, lead PI: Kleypas, Amount: $34,904 (Co-PIs: Vicki Fabry, Chris Langdon, Richard Feely, Chris Sabine)
- NCAR Opportunity Fund "Implementing seawater chemistry measurements within the NOAA Coral Reef Early Warning System," 2004, main PI: Kleypas, Amount: $54,865 (Co-PIs: James Hendee, Rik Wanninkhof, Chris Langdon)
- Australian Science Society "Geological Development of coral reefs in the southern Great Barrier Reef," 1990, $65,000 (Co-PI with lead PI: David Hopley)

Professional Affiliations

American Geophysical Union; Geological Society of America; AAAS; ASLO; International Society for Reef Studies; Australian Coral Reef Society; Fulbright Association

Publications

Theses

MS thesis title: Kleypas, JA 1980. Migration and feeding of predatory fish in an intertidal creek, with special reference to the silver perch (*Bairdiella chrysura* L.), Marine Science Program, University of South Carolina. (Advisor: Professor John Mark Dean)

Ph.D. thesis title: Kleypas, JA 1992. Geological development of fringing coral reefs in the southern Great Barrier Reef, Australia, James Cook University of North Queensland, Australia.

Peer-Reviewed Journal Publications

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Buddemeier, RW, J–P Gattuso and JA Kleypas, 1998: Rising CO_2 and marine calcification. *LOICZ (Land-Ocean Interactions in the Coastal Zone) Newsletter* 8: 1–3.

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Chairman LAMPSON. Thank you, Dr. Kleypas.

Dr. Doney, you are recognized.

STATEMENT OF DR. SCOTT C. DONEY, SENIOR SCIENTIST, DEPARTMENT OF MARINE CHEMISTRY AND GEOCHEMISTRY, WOODS HOLE OCEANOGRAPHIC INSTITUTION

Dr. DONEY. Thank you, Chairman Lampson, Ranking Member Inglis, and Subcommittee Members. Thank you for giving me the opportunity today to talk about the *Federal Ocean Acidification Research and Monitoring Act.*

The rapid rise in atmospheric carbon dioxide levels due to deforestation and fossil fuel burning is fundamentally changing the chemistry of the sea, pushing surface waters towards more acidic conditions. The physics and chemistry of this process are well understood, and ocean acidification is now confirmed by real-world observations.

Unless carbon dioxide emissions are curbed, acidification will accelerate over the next several decades. Laboratory experiments show that acidification directly harms many marine plants and animals by reducing calcium carbonate shell and skeleton formation, slowing growth rates, and hindering reproduction.

Acidification thus directly threatens a wide range of marine organisms, from microscopic plankton and shellfish to massive coral reefs. Acidification will affect the food webs that depend upon those shell-forming organisms for both food and habitat, as well as the oceanic economic and ecosystem functions that we depend upon.

About half the dollar value of U.S. fishery landings comes from species that are directly sensitive to ocean acidification. The present national investment in ocean acidification research is inadequate to address these challenges. As a result, the U.S. research community is not providing the information needed by stakeholders and policy-makers and is falling behind our European and Japanese colleagues.

Major gaps exist in our current scientific understanding, limiting our ability to forecast the consequences of ocean acidification and hindering the development of adaptation approaches for marine resource managers.

Rising carbon dioxide will affect many ocean processes beyond just shell formation. And recent results suggest that there may be biological winners as well as losers as some organisms benefit from elevated carbon dioxide levels. Expanded ocean and satellite-based observations are needed to monitor ocean acidification and its biological impacts, particularly in our coastal waters, where acidification is already occurring as Dr. Feely has mentioned, in very important ecosystems.

Innovative ecosystem scale field experiments are required to characterize ocean acidification and the changes they have, it has on marine food webs. The science must also be better connected with stakeholder needs with more applied research targeting resource management, conservation, and the socioeconomic impacts from damaged fisheries and coral reefs.

The FOARAM Act is an important step towards a comprehensive U.S. ocean research program on acidification. The proposed funding level ramping up to $30 million in fiscal year 2012 will greatly enhance U.S. research capabilities, but as mentioned by Dr. Kleypas, even this level may fall short of the true needs, which we have estimated at closer to $50 to $55 million a year.

There is much that we don't know about acidification, and the research program should leave wide latitude for exploratory and discovery-based science investigations, such as those supported by the National Science Foundation and NASA. The bill should also include a substantial portion of funding that is not just competitive but also extramural to harness the tremendous capacity of our academic research community. Considering the scope of the ocean acidification problem, we need to bring all available resources to bear on developing the science quickly and efficiently.

Direct authorizations of funds to NASA and NSF rather than directing it through NOAA would streamline the distribution and the planning effort and take better advantage of the new capabilities of our main ocean agencies on science, NASA and remote sensing, NSF on process studies and chemical and biological dynamics, and NOAA on ocean monitoring and fisheries.

The bill should support a strong interagency consultative process on the science of ocean acidification, but this may be best accomplished through successful existing and often informal partnerships among the agencies rather than creating a new interagency committee specifically directed on ocean acidification.

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

[The prepared statement of Dr. Doney follows:]

PREPARED STATEMENT OF SCOTT C. DONEY[1]

Introduction

Good morning Chairman Lampson, Ranking Member Inglis and Members of the Subcommittee. Thank you for giving me the opportunity to speak with you today on ocean acidification and the proposed *Federal Ocean Acidification Research and Monitoring Act,* H.R. 4174. My name is Scott Doney, and I am a Senior Scientist at the Woods Hole Oceanographic Institution in Woods Hole MA. My research focuses on interactions among climate, the ocean and global carbon cycles, and marine ecosystems. I have published more than 110 peer-reviewed scientific journal articles and book chapters on these and related subjects. I serve on the U.S. Carbon Cycle Science Program (CCSP) Scientific Steering Group and the U.S. Community Climate System Model (CCSM) Scientific Steering Committee. Currently I am the Chair of the U.S. Ocean Carbon and Climate Change (OCCC) Scientific Steering Group and the U.S. Ocean Carbon and Biogeochemistry (OCB) Scientific Steering Committee.

For today's hearing, you have asked me to discuss the strengths and weaknesses of the current interagency effort to monitor and research ocean acidification and to assess its potential impacts on marine organisms and marine ecosystems, and in addition, to provide recommendations for strengthening individual programs of the federal agencies participating in the interagency committees focusing on ocean issues.

Current Scientific Understanding

My comments on our state of knowledge about ocean acidification are based on a broad scientific consensus as represented in the current scientific literature and

[1] The views expressed here do not necessarily represent those of the Woods Hole Oceanographic Institution.

recent in scientific assessments compiled by the scientific community, in particular the United Kingdom Royal Society (Royal Society, 2005), the German Advisory Council on Global Change (WBGU) (Schuster et al., 2006), and a U.S. science workshop sponsored by the National Science Foundation, National Oceanic and Atmospheric Administration and the United States Geological Survey (Kleypas et al., 2006).

The current rapid rise in atmospheric carbon dioxide levels, due to our intensive burning of fossil fuels for energy, is fundamentally changing the chemistry of the sea, pushing surface waters toward more acidic conditions. Greater acidity slows the growth or even dissolves ocean plant and animal shells built from calcium carbonate, the same mineral as in chalk and limestone. Acidification thus threatens a wide-range of marine organisms, from microscopic plankton and shellfish to massive coral reefs, as well as the food webs that depend upon these shell-forming species. Rising CO_2 levels will also alter a host of other marine biological and geochemical processes, often in ways we do not yet understand. Ocean acidification is a critical issue for the 21st century impacting on the health of the ocean, the productivity of fisheries, and the conservation and preservation of unique marine environments such as coral reefs.

Over the last 250 years, atmospheric carbon dioxide (CO_2) increased by nearly 40 percent, from pre-industrial levels of about 280 ppmv (parts per million volume) to nearly 384 ppmv in 2007 (Solomon et al., 2007). This rate of increase, driven by human fossil fuel combustion and deforestation, is at least an order of magnitude faster than has occurred for millions of years, and the current concentration is higher than experienced on Earth for at least the last 800,000 years and likely the last several tens of millions of years (Doney and Schimel, 2007). About one-third of this excess, anthropogenic carbon dioxide dissolves in the ocean, where it forms carbonic acid and a series of dissociation products. The release of hydrogen ions from the breakdown of carbonic acid lowers the pH of seawater, shifting the normally somewhat alkaline seawater (surface pH about 8.2) toward more acidic conditions. As important for many organisms is the simultaneous reduction in carbonate ion concentration, which is used in the construction of calcium carbonate ($CaCO_3$) shells. Ocean acidification is a predictable consequence of rising atmospheric CO_2 and does not suffer from uncertainties associated with climate change forecasts. Absorption of anthropogenic CO_2, reduced pH, and lower calcium carbonate saturation in surface waters, where the bulk of oceanic production occurs, are well-verified from models, hydrographic surveys and time series data (Feely et al., 2004; Orr et al., 2005).

Since preindustrial times, the average ocean surface water pH has fallen by about 0.1 units, from about 8.21 to 8.10 (Royal Society, 2005), and is expected to decrease a further 0.3–0.4 pH units (Orr et al., 2005) 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; Solomon et al., 2007). The most sensitive areas may be the sub-polar North Pacific, the Southern Ocean, and along the Pacific continental shelf and margin where waters are already near or at corrosive levels for some carbonate shells (Feely et al., 2008). The problem of ocean acidification will be with us for a long time because it takes centuries to thousands of years for natural processes, primarily mixing into the deep-sea and increased dissolution of marine carbonate sediments, to remove excess carbon dioxide from the air.

Ocean acidification appears to have a significant, and often negative impact on many ocean plant and animal species. The magnitude and even the sign of the biological effects, however, differ from organism group to group and on the specific biological processes involved. Rising atmospheric CO_2 alters seawater chemistry in several different ways—reducing pH, increasing the partial pressure of dissolved CO_2 gas (pCO_2), increasing total dissolved inorganic carbon, and reducing carbonate ion and the saturation state of calcium carbonate minerals. Because of the reduction in calcium carbonate saturation state, much of the research emphasis has been on shell-forming plants and animals that use calcium carbonate including some plankton (coccolithophorids, foramaniferia, and pteropods), benthic mollusks (clams, oysters and mussels), echinoderms (sea urchins), corals and coralline algae. Laboratory experiments show that ocean acidification and changes in ocean carbonate chemistry directly harms many of these calcifying species by reducing shell formation, slowing growth rates and hindering reproduction (Fabry et al., 2008a). The degree of sensitivity varies among species, however, and some organisms may show enhanced calcification at CO_2 levels projected to occur over the 21st century (Iglesias-Rodríguez et al., 2008). However, calcification-CO_2 response studies exist for a limited number of species in many calcifying groups, and currently, we lack sufficient understanding of calcification mechanisms to explain species-specific differences observed in manipulative experiments.

The consequences of acidification will extend well beyond the fate of any particular marine species. Acidification impacts on processes fundamental to the overall structure and function of marine ecosystems. Any significant changes could have far reaching impacts for the future of ocean food-webs. Many marine animals prey on calcifying organisms or utilize their skeletons for habitat. Tropical corals are the backdrop for rich and diverse reef environments, and many fish species would disappear along with the corals. Others such as clams, scallops, oysters and sea urchins are important sources of seafood. Less familiar are the many shell-forming planktonic organisms, including plants like coccolithophores and marine snails called pteropods, which are an important food source for salmon and whales. Recent discoveries indicate the presence of extensive deep-water coral reefs around the edge of continents and on seamounts, which may decline before we fully understand their contribution as a habitat for fish. Some preliminary experiments suggest that larval and juvenile fish may also be at risk.

Human and Economic Dimensions of Ocean Acidification

Ocean acidification will also impacts the millions of people that depend on its food and other resources for their livelihoods. Fish and marine organisms provided, on average, 15.5 percent of the world's protein in 2003 (FAO, 2007); losses of crustaceans, bivalves, their predators, and their habitat (in the case of reef-associated fish communities) would particularly injure societies that depend heavily on consumption, export, and tourism of marine resources. Reef losses would also expose low-lying settlements and biologically diverse regions to storm and wave damage, multiplying economic hardships (Anderson et al., 2006).

U.S. commercial fisheries depend on calcifying species and their predators, making economic effects from ocean acidification a likelihood over the next several decades. Acidification effects likely will be most directly felt on mollusk fisheries (e.g., clams, scallops, oysters and mussels), which provide 18 percent of total revenue (Figure 1, red tones). Crustaceans (e.g., lobsters, crabs, shrimp) may also be sensitive and contribute an additional 32 percent of total revenue. The possible indirect impacts through reduced food supply for commercial fish species is not well understood yet. For scale, in 2006 the total landing value (what is paid for a boat's catch at the dock) of the U.S. commercial fisheries was about $4 billion, and subsequent seafood processing, wholesale and retail activities added a net $35.1 billion to the gross national product (Andrews et al., 2007). Domestic commercial marine fisheries directly support a larger number of jobs in the fishing fleet, the exact number not well reported because many fishers are self-employed; wholesaling and seafood processing generates an additional nearly 70,000 jobs nationwide; including seafood retailing and food services expands that number substantially. Meanwhile, U.S. recreational saltwater fishing generated $12 billion of direct, indirect, and induced income (Steinback et al., 2004) and supported 350,000 jobs in 2004, many of them related to recreational boat sales and maintenance.

Scientific Knowledge Gaps and Future Research Directions

The U.S. research community has recently hosted two major scientific meetings to identify knowledge gaps and discuss future research needs in ocean acidification. The first meeting of 60 experts in the field was held in 2005 in St. Petersburg, FL and sponsored by National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA) and the United States Geological Survey (USGS); the workshop developed a consensus set of recommendations related to ocean acidification and calcifying organisms (Kleypas et al., 2006). Building on that report, the U.S. Ocean Carbon and Biogeochemistry (OCB) Program (*http://us-ocb.org/*), supported NSF, NASA, and NOAA, hosted a planning workshop for 90 U.S. and international ocean scientists in La Jolla, CA in the Fall of 2007. The recommendations from the OCB workshop were similar to those of the St. Petersburg meeting but extended as well more broadly to acidification impacts on non-calcifying organisms and ocean biogeochemistry (Fabry et al., 2008b).

Major gaps exist in our current scientific understanding, limiting our ability to forecast the consequences of ocean acidification and hindering the development of adaptation approaches for marine resource managers. Thus far, most of the elevated CO_2 response studies on marine biota, whether for calcification, photosynthesis or some other physiological measure, have been short-term laboratory or mesocosm experiments ranging in length from hours to weeks. Chronic exposure to increased CO_2 may have complex effects on the growth and reproductive success of calcareous and non-calcareous plants and animals and could induce possible adaptations that are not observed in short-term experiments. Our present understanding also stems largely from experiments on individual organisms or a species in isolation; consequently, the response of populations and communities to more realistic gradual changes is largely unknown.

Other aspects of ocean biogeochemistry may be strongly influenced by rising CO_2 levels. Recent experiments with one of the most abundant types of phytoplankton, Synechococcus, showed significantly elevated photosynthesis rates under warmer, high CO_2 conditions. Elevated CO_2 also enhanced nitrogen fixation rates (production of biologically useful nutrients from dissolved nitrogen gas) for a key tropical marine cyanobacteria, which would in effect fertilize the surface ocean and offset predicted reductions in tropical biological production due to climate warming and stratification. Further, a major but under-appreciated consequence of ocean acidification will be broad alterations of inorganic and organic seawater chemistry beyond the carbonate system. Acidification will affect the biogeochemical dynamics of calcium carbonate, organic carbon, nitrogen, and phosphorus in the ocean as well as the seawater chemical speciation of trace metals, trace elements and dissolved organic matter.

A fully-integrated research program with in-water and remote sensing observing systems on multiple-scales, laboratory, mesocosm (large volumes of seawater either in tanks or plastic bags), and field process studies, and modeling approaches is required to provide policy-makers with informed management strategies that address how humans might best mitigate or adapt to these long-term changes. This program should emphasize how changes in the metabolic processes at the cellular level will be manifested within the ecosystem or community structure, and how they will influence future climate feedbacks. A program should include the following components:

- Systematic monitoring system with high resolution measurements in time and space of atmospheric and surface water carbon dioxide partial pressure (pCO_2), total dissolved inorganic carbon, alkalinity, and pH to validate model predictions and provide the foundations for interpreting the impacts of acidification on ecosystems;
- In regions projected to undergo substantial changes in carbonate chemistry, tracking of abundances and depth distributions of key calcifying and non-calcifying species at appropriate temporal and spatial scales to be able to detect possible shifts and distinguish between natural variability and anthropogenic forced changes;
- Standardized protocols and data reporting guidelines for carbonate system perturbation and calcification experiments;
- Manipulative laboratory experiments to quantify physiological responses including calcification and dissolution, photosynthesis, respiration, and other sensitive indices useful in predicting CO_2 tolerance of ecologically and economically important species;
- New approaches to investigate address long-term subtle changes that more realistically simulate natural conditions;
- Manipulative mesocosm and field experiments to investigate community and ecosystem responses (i.e., shifts in species composition, food web structure, biogeochemical cycling and feedback mechanisms) to elevated CO_2 and potential interactions with nutrients, light and other environmental variables;
- Integrated modeling approach to determine the likely implications of ocean acidification processes on marine ecosystems and fisheries including nested models of biogeochemical processes and higher trophic-level responses to address ecosystem-wide dynamics such as competition, predation, reproduction, migration, and spatial population structure;
- Robust and cost effective methods for measuring pH, pCO_2, and dissolved total alkalinity on moored buoys, ships of opportunity, and research vessels, floats and gliders;
- Studies on the human dimensions of ocean acidification including the socioeconomic impacts due to damaged fisheries and coral reefs;
- Assessment of potential adaptation strategies needed by resource managers including reducing other human stresses (over-fishing, habitat destruction, pollution) to increase ecosystem resiliency as well as local-scale mitigation efforts.

Current National Research Effort on Ocean Acidification

Over the last several years, a growing U.S. research effort on ocean acidification has emerged. The research is supported by several federal science agencies and builds from two major oceanographic research programs one on ocean biogeochemistry, the U.S. Joint Global Ocean Flux Study (JGOFS; *http://www1.whoi.edu/*), which ran from the late 1980s through the mid-2000s, and one of marine plankton ecology, U.S. Global Ocean Ecosystems Dynamics (GLOBEC; *www.usglobec.org*), which is in it's concluding synthesis phase. Each of the federal science agencies involved brings a specific approach and research emphasis to the problem of ocean acidification.

The National Oceanic and Atmospheric Administration (NOAA) supports observational networks for ocean CO_2, pH and seawater carbonate system through a combination research ship based surveys (CLIVAR/CO_2 Repeat Hydrography Program; *ushydro.ucsd.edu*) and autonomous instruments on volunteer merchant vessels and moorings (*http://www.aoml.noaa.gov/ocd/gcc/index.php*). NOAA also is involved in biological impact assessment of acidification on corals and coral reefs and more recently fish and invertebrates. Most of NOAA funding supports scientists internal to NOAA, though there is some extramural funding of university researcher through the Climate Program Office and Sea Grant.

The National Science Foundation (NSF) supports unsolicited, hypothesis driven research on a wide range of relevant topics, from ocean chemistry and physics to organism biology and genomics. NSF and NASA jointly fund, along with NOAA, the CLIVAR/CO_2 Repeat Hydrography Program, which is directly documenting the decrease in ocean pH and changes in seawater carbonate chemistry. NSF has also supported the two longest running, continuous ocean carbon time-series, one off of Hawaii (*http://hahana.soest.hawaii.edu/hot/hot_jgofs.html*) and the other off of Bermuda, (*http://bats.bios.edu*). These sustained time-series were begun in 1988 under the JGOFS program and are key elements in directly demonstrating acidification trends. All NSF funding is extramural to the university academic community. As the only non-mission science agency, NSF has built in flexibility to adapt rapidly to new ideas as they arise from the research community and to fund higher risk, discovery driven investigations.

The National Aeronautics and Space Administration supports satellite and airborne remote sensing, ship-based process studies and field validation and numerical modeling relevant to ocean ecology and biogeochemistry. Much of the research is extramural and hypothesis driven. Satellite ocean color data from NASA's MODIS sensor and from GeoEYE and NASA's Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) (*http://oceancolor.gsfc.nasa.gov/*) have been used to characterize the global distributions calcareous plankton and coral reefs. NASA will also launch the Orbiting Carbon Observatory (OCO; *http://oco.jpl.nasa.gov*) this December, a two-year exploratory mission to measure the vertical average atmospheric CO_2 concentration; this data can be combined with numerical models to estimate global patterns of the exchange of carbon dioxide from the ocean and atmosphere. Much of the NASA funded ocean ecology and biogeochemistry research is relevant to ocean acidification, and the funding specifically focused on acidification it is expected to grow in the future.

The Department of Energy (DOE) does not have an active ocean biogeochemical research program at the moment; in the past, it has supported relevant work on measuring and modeling ocean CO_2 uptake, methods of deliberate ocean carbon sequestration, and ocean environmental genomics. The United States Geological Survey (USGS) co-sponsored a recent major ocean acidification workshop and report (Kleypas et al., 2006) that has expertise on ocean carbonate systems and coastal ecosystems, and is supporting currently a limited research effort on acidification effects on coral reefs. Other federal science agencies with potential interest and expertise relevant to the acidification problem and its biological repercussions include the National Park Service, U.S. Fish and Wildlife and the Environmental Protection Agency.

Strengths and Weaknesses of Present Interagency Effort

Despite some prominent successes, the present national investment in ocean acidification research is inadequate to address the research challenges described above and is not creating the required comprehensive research program integrating the chemical, biological and human dimension aspects of the acidification problem. There are issues involving the direction and funding level for both basic science, which provides information on the extent of ocean acidification, and applied science, which addresses adaptation strategies and solutions. Research and training go hand in hand, and more resources need to be devoted to undergraduate and graduate student training to ensure and strong scientific base for the future. Further, basic science efforts within the U.S. are often poorly connected with stakeholders and more applied research targeting coral reef and fisheries management and conservation. As a result, the U.S. research community is falling behind our European and

Japanese colleagues, who are already moving forward on coordinated ocean acidification initiatives.

The current funding level for ocean acidification research does not support the deployment of sufficient ocean monitoring capabilities, particularly in coastal waters where economically important ecosystems are at risk. New findings just released last week in *Science* magazine (Feely et al., 2008) of corrosive, acidified ocean waters on the continental shelf along the U.S. west coast indicate that acidification is a problem we face now, not decades in the future. But these results from the first systematic survey of seawater CO_2 and acidification in North American coastal waters also highlight the difficulties in monitoring ocean chemistry from slow moving and expensive ships. New robust chemical sensor technologies exist or are being developed, and an ocean acidification observing system needs to be deployed combining instrumented autonomous platforms (moorings, gliders, floats) supported by shipboard surveys and process studies.

The NSF supported ocean carbon time-series stations at Hawaii and Bermuda are pivotal to the U.S. and international research community, the ocean equivalent of the iconic Mauna Loa atmospheric CO_2 record. But such long records over time, critical for identifying trends due anthropogenic CO_2 and acidification, are the exception not the rule. With our present funding mechanisms, it is difficult to maintain and support long-term, sustained time-series. Each three- to five-year funding cycle, the principal investigators need to create a new scientific justification for making continued measurements when in fact the unique value of time-series is their continuity over time, the value growing dramatically as the records extend over multiple decades (and funding cycles). The research community continues to struggle with simply maintaining current capabilities, and few new time-series are being established in different ocean environments.

In a similar vein, satellite measurements provide an unprecedented view of the temporal variations in ocean ecology. The ocean is vast, and the limited number of research ships move at about the speed of a bicycle, too slow to map the ocean routinely on ocean basin to global scales. By contrast, a satellite can observe the entire globe, at least the cloud free areas, in a few days. The detection of gradual trends such as those due to ocean acidification is challenging. Currently remote sensing can be used to estimate a number of biological and chemical properties of the ocean (e.g., particulate calcite, pCO_2) relevant to understanding the impacts of an acidifying ocean on ocean ecology and chemistry. Finding trends in these records requires long, coherent and internally consistent, high-quality global time series. Potential gaps in data coverage between satellite missions are particular worrisome; each sensor has its own unique calibration issues, and without overlap of missions in orbit, it is often impossible to construct a climate quality time record the extends over multiple missions. At present, the on-going availability of high-quality, climate data records is not assured during the transition of many satellite ocean measurements from NASA research to the NOAA/DOD operational NPOESS program. For example, the present NASA satellite ocean color sensors, needed to determine ocean plankto, are nearing the end of their service life, and the replacement sensors on NPOESS may not be adequate for the climate community. Further, refocusing of NASA priorities away from Earth science may dramatically limit or full preclude new ocean satellite missions need to characterize ocean biological dynamics.

U.S. ocean acidification research is also limited, at present, by the size and scope of potential field research projects. In particular, the current funding environment does not encourage the next generation of mesocosm (large enclosed tanks or floating bags of water) and ecosystem-scale field experiments where scientists manipulate environmental conditions (e.g., CO_2, pH) and then examine how ocean biology changes. Many of the major unresolved questions concerning ocean acidification involve impacts on scales too large to test in the laboratory and on communities of organisms and species. The infrastructure and logistics for manipulative experiments is costly, but the scientific payoff can be substantial, and for some problems manipulation of the ecosystem provides new scientific insights that are not easily attained in other ways. Deliberate ocean iron release experiments are one such example. European scientists have made considerable headway on ocean acidification using a dedicated mesocosm facility for water-column plankton studies, and design studies are underway for manipulative coral reef acidification experiments, similar in concept to terrestrial Free Air Carbon Experiment (FACE) system used to study CO_2 fertilization effects on terrestrial grasses, shrubs and trees. The University of Washington is moving forward, with State and private foundation support, on plans for an ocean mesocosm system, which could be expanded into a facility broadly available to the U.S. research community.

There are also a number of issues with the coordination and management across science agencies. Interagency coordination on U.S. ocean acidification research occurs via several related pathways involving both program managers from the federal science agencies and federal and university scientists. The U.S. Carbon Cycle Science Program (CCSP) is an interagency partnership (*http://www.carboncyclescience.gov/*) focused broadly on the global carbon cycle in the ocean, on land, and in the atmosphere and the interactions with climate. The CCSP is part of the U.S. Climate Change Science Program, and it has an Interagency Working Group (agency representatives from NOAA, NASA, NSF, DOC, USGS and a number of other, more terrestrially oriented agencies) and a Scientific Steering Group. The Carbon Cycle Science Program initiated an ocean research program, the Ocean Carbon and Climate Change (OCCC) Program, focused on monitoring the ocean carbon system and predicting its future behavior.

A key issue with regards to ocean acidification is that the Carbon Cycle Science Program covers only a portion of the ocean acidification problem, namely the controls on the oceanic uptake of CO_2, resulting changes in seawater chemistry and ocean mechanisms that could damp or accelerate climate change by altering atmospheric CO_2 levels. Key aspects of the acidification problem on ecological and socioeconomic impacts extend well beyond the purview of the Carbon Cycle Science Program, however. While there are elements of the U.S. Climate Change Science Program that could address ecological research and coordination needs on ocean acidification, the interactions have been minimal and disjoint to date reflecting the conflicting demands of a Program covering such a wide research domain and not focused specifically on the ocean.

There is also an existing, informal interagency effort on ocean biogeochemistry and ocean acidification, the Ocean Carbon and Biogeochemistry (OCB) Program (*http://us-ocb.org/*), which is supported by federal program managers at the NSF, NASA, and NOAA and assisted by input from a scientific steering committee consisting of academic and government scientists. The OCB Program encompasses the scientific direction of the OCCC program and also expands into ocean ecology to the degree that it interactions with biogeochemical cycling. The OCB and OCCC scientific steering groups overlap in membership and meet jointly. The OCB has taken the lead on organizing a recent major U.S. ocean acidification workshop last Fall in La Jolla, CA (Kleypas et al., 2008b), and is also working to ensure the appropriate international linkages with emerging and existing ocean acidification programs supported by the European Union, Australia and Japan. The informal interactions facilitated by OCB are working well but do not cover the full scope of acidification research, for example the more fisheries and coral reef oriented work currently supported internally within NOAA or socioeconomic components of the problem.

Recommendations on the Federal Ocean Acidification Research and Monitoring Act

The *Federal Ocean Acidification Research and Monitoring Act,* H.R. 4174, is an important step toward a comprehensive U.S. ocean research program. The proposed funding level ramping to $30 million in FY 2012 will greatly enhance U.S. research capabilities. But even this level may fall short of true needs, which are estimated at closer to $50–$55 million a year based on recent scientific community-wide planning efforts. To put this in context, one can compare against the funding levels of prior major oceanographic research programs. The U.S. JGOFS and U.S. GLOBEC programs in the 1990s involved large-scale field research on ocean biogeochemistry and ecology, similar to what is envisioned in a new ocean acidification program. In the late 1990s the NSF component of those two programs totaled about $24 million a year. Adding the contributions from NOAA, NASA and DOE approximately doubled the total funding to about $40–$45 million per year in late 1990s dollars unadjusted for inflation and the rising ship operation costs. This cost estimate does not consider that a comprehensive acidification program will include additional research components on coral reef, fisheries, and human dimensions.

- The total authorization for FORAM (H.R. 4174) should be increased to $50–$55 million per year, a reasonable minimum to conduct the required basic and applied research and deliver those results in a timely fashion to stakeholders, resource managers and policy-makers.

The U.S. scientific community is well poised to take advantage of increased funding on ocean acidification. As demonstrated by the consensus recommendations from two recent major U.S. ocean acidification science workshops (Kleypas et al., 2006; Fabry et al., 2008b), a roadmap for a coherent acidification program is in place and the community could move quickly toward implementing these research plans as increased funding becomes available. Forward progress on an expanded U.S. ocean acidification research program should not be delayed waiting for the completion of the proposed National Academy of Sciences study on ocean acidification research priorities.

- The ramp-up in research funding in H.R. 4174 should be accelerated in order to more quickly get needed information into the hands of stakeholders and decision-makers.

Other recommendations on funding approaches for ocean acidification include:

- Funds should be directly authorized to the major ocean science agencies (NSF and NASA), rather than distributed to NOAA; this would streamline planning, speed research progress, and take better advantage of the unique capabilities of the other agencies.
- A substantial portion of the authorized funding should be not just competitive but also extramural, to harness the tremendous capacity of our university academic research community—considering the scope of this problem, we need to bring all available resources to bear on developing the science quickly and efficiently.

The structure of the ocean acidification research program should remain adaptive and encourage exploration of a broad range of scientific areas. Ocean acidification is a new area of research, and many surprises remain ahead. This is illustrated by dramatic findings announced just in the last few weeks on accelerated acidification along the U.S. west coast (Feely et al., 2008) and increased calcification by some phytoplankton under high CO_2, counter to our expectations about an increasing corrosive ocean (Iglesias-Rodriguez et al., 2008). Ocean acidification research is at present multi-faceted and fast-moving, and marine plants and animals and ocean biogeochemical cycle are affected by more than simply reduced seawater pH. There is much that we do not understand as yet about ocean acidification and the multiple pathways by which acidification and rising CO_2 will alter the marine environment.

- The current definition of "ocean acidification" in the bill should be expanded from simply reduced pH to incorporate the full suite of changes in ocean chemistry arising from increased carbon dioxide.
- The scope of the ocean acidification research program should leave wide latitude for the types of exploratory and discovery-based science investigations generally supported by the NSF, NASA and the extramural components of NOAA (e.g., NOAA Climate Program Office).

Strong interagency cooperation and coordination is critical to leverage the diverse expertise and research infrastructure of the individual federal science agencies, which tie into different parts of the U.S. ocean science community. But this may be best accomplished through successful existing structures rather than by creating a new interagency committee. These include the National Ocean Partnership Program (NOPP; *http://www.nopp.org*) and the NSTC Joint Subcommittee on Ocean Science and Technology (JSOST; *http://ocean.ceq.gov/about/jsost.html*). There is also considerable merit to more informal interagency partnerships, such as those that supported the U.S. Joint Global Ocean Flux Study and that are now supporting the U.S. Ocean Carbon and Biogeochemistry Program. A strong and on-going dialogue needs to be maintained between federal agency program managers and the scientific community, consisting of both federal and university researchers, on the planning, implementation and synthesis of ocean acidification research. This can be accomplished through a variety of mechanisms including scientific steering groups and community workshops. Finally, ocean acidification is a global problem, and the U.S. and international research communities should work closely to increase the pace of discovery and the development of adaptation strategies.

- The bill should support a strong, interagency consultative process on the science of ocean acidification with substantial and ongoing input from the scientific community.
- The U.S. ocean acidification program should establish strong ties with similar international research programs and develop mechanisms for U.S. researchers to participate freely in international research activities.

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1991—Massachusetts Institute of Technology-Woods Hole Oceanographic Institution Joint Program in Oceanography, Ph.D. Chemical Oceanography

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U.S. Carbon Cycle Science Program (CCSP)

- Scientific Steering Group (2002–present)
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Ocean Carbon and Climate Change (OCCC)

- Chair Scientific Steering Group (2005–present)

Ocean Carbon Biogeochemistry (OCB)

- Chair Scientific Steering Committee (2006–present)
- Director OCB Project Office (2006–present)

Community Climate System Model (CCSM)

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- *Reviews of Geophysics,* Assoc. Editor (1997–2001)
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Joint Global Ocean Flux Study (JGOFS)

- U.S. Scientific Steering Committee (1993–2003)
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World Ocean Circulation Experiment (WOCE)

- U.S. Scientific Steering Committee (1997–2002)

AWARDS

2007–2011—W. Van Alan Clark Sr. Chair, Woods Hole Oceanographic Institution

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Chairman LAMPSON. Thank you, Dr. Doney.

Dr. Caldeira, you are recognized for five minutes.

STATEMENT OF DR. KEN CALDEIRA, SCIENTIST, DEPARTMENT OF GLOBAL ECOLOGY, CARNEGIE INSTITUTION OF WASHINGTON

Dr. CALDEIRA. Good morning, and thank you for inviting me here today to testify before you.

I am a scientist and a concerned citizen who has been studying ocean chemistry and the carbon cycle for over 20 years. Last night I took a taxi from Dulles to my hotel building, and outside, out of the tailpipe of that taxi came carbon dioxide gas. Today that carbon dioxide is probably mostly over Maryland, could be impacting the Chesapeake Bay already. Within a few days it will certainly be impacting the chemistry of the Atlantic Ocean. Within a year that CO_2 will travel throughout the atmosphere, around the world, and impact the chemistry of the upper ocean everywhere, from Alaska, to Florida, from Antarctica, the North Pole.

When CO_2 dissolves in seawater, it becomes carbonic acid. In high enough concentrations carbonic acid can dissolve seashells. Even at lower concentrations it can threaten the survival of many marine organisms.

So far we have studied just a few species. Typically, a small coral head or a few sea urchins are exposed to high CO_2 concentrations in a fish tank in a laboratory. It is just the beginning, but what we have seen so far is very disturbing.

In many cases organisms show malformed or stunted growth. In many cases we don't know if they would be able to survive in the wild or be able to reproduce.

We have little idea what ocean acidification will do to fish eggs or fish larvae or how the loss of organisms at the base of the food chain might affect the larger fish that so many people have come to depend on.

We do know that ocean acidification threatens the survival of coral reefs everywhere. If we are lucky, we will lose just coral reefs and maybe a few other sensitive things like that. But if we are unlucky, we might see a wholesale shakeup of marine ecosystems across the board.

At this point we just don't know, and that is why we need to focus significant resources to understand this issue now.

We should expect surprises, so we need to monitor what is going on. For example, our models predicted it would take over a century for corrosive waters to start showing up along our coasts, but just two weeks ago Dick Feely and his colleagues reported in the prestigious journal *Science* that corrosive waters, burdened with fossil fuel carbon, have already been threatening the shoreline along parts of the west coast of the U.S. They saw water corrosive enough to start dissolving seashells.

So we need better observations and better computer models to help us anticipate what might occur under different policy options.

For my Ph.D. research I studied what happened to ocean chemistry when a meteorite slammed into the Earth some 65 million years ago. At that time there was a lot of carbon dioxide and a lot of sulfuric acid, and the oceans became acidified. Nearly everything with a calcium carbonate shell or skeleton disappeared. Coral reefs weren't seen again for two million years.

You have to go back to events like this, many tens of millions of years ago, to find anything comparable to what we are doing today to ocean chemistry with our carbon dioxide emissions. What we do over the next years and decades will affect ocean chemistry for tens of thousands of years and could harm marine life for millions of years.

So I wholeheartedly support House Resolution 4174, the *Federal Ocean Acidification Research and Monitoring Act* but wish it were even more ambitious.

It is impossible to say what the oceans are worth to us, but it has to be at least many tens of billions of dollars per year. We are talking about a research investment starting at several millions of dollars per year, so that is a ratio of about 10,000 to one. That is like having a $20,000 car and when it starts making funny noises and not running right, spending only $2 to find out what is going wrong. With this level investment we shouldn't be surprised when it breaks down unexpectedly in the middle of the highway.

I thank you for your good work and your attention and look forward to your questions.

[The prepared statement of Dr. Caldeira follows:]

PREPARED STATEMENT OF KEN CALDEIRA

Thank you for inviting me to testify before the Committee on Science and Technology Subcommittee on Energy and Environment of the United States House of Representatives. I would be happy to provide more information on any of the issues discussed below.

I am a scientist and a concerned citizen. I have been studying ocean chemistry and carbon cycle for over 20 years. I worked for a Department of Energy Laboratory for 12 years, and co-led the DOE center for research on ocean carbon sequestration. I led the writing of the Intergovernmental Panel on Climate Change chapter on ocean carbon storage. Recently, I acted in the capacity of the representative of the Intergovernmental Oceanographic Commission (a branch of the United Nations) to international negotiations held under the London Convention and London Protocol.

I now work for the Carnegie Institution of Washington, a non-profit organization dedicated to "investigation, research, and discovery [and] . . . the application of knowledge to the improvement of mankind. . .."

Every time we drive a car, carbon dioxide gas comes out of the taxi tailpipe and goes right into the air.

Within a year, that CO_2 will travel throughout the atmosphere and impact the chemistry of the ocean surface everywhere—from Alaska to Florida, from Antarctica to the North Pole.

That CO_2 will stay in the oceans, changing ocean chemistry, for tens of thousands of years.

When CO_2 dissolves in seawater, it becomes carbonic acid. In high enough concentrations, carbonic acid can dissolve sea shells. Even at lower concentrations, it can threaten the survival of many marine organisms.

So far, we've studied just a few organisms—typically a small coral head or a few sea urchins will be exposed to high CO_2 concentrations in a fish tank in a laboratory. It's just a beginning, but what we've seen so far is very disturbing.

In many cases, organisms show malformed or stunted growth. In many cases, we don't know if it would be able to survive in the wild or be able to reproduce.

We have little idea what ocean acidification will do to fish eggs, or fish larvae, or how the loss of organisms at the base of the food chain might affect the larger fish that so many people have come to depend on.

In general, we have little idea what the ecosystem-scale consequences of ocean acidification might be.

Corals are perhaps the best studied kind of organism.

Several of us use computer models to predict how future CO_2 would affect ocean chemistry. If carbon dioxide emissions continue along current trends, within a few decades there will be no water left anywhere in the ocean with the kind of chemistry that has supported coral growth over the past thousands and even millions of years.

CO_2 threatens the survival of coral reefs everywhere.

If we're lucky, we'll lose just coral reefs and maybe a few other things. If we're unlucky, we might see a wholesale shake-up of marine ecosystems across the board.

At this point, we just don't know, and that's why we need to focus significant resources to understand this issue now.

We should expect surprises, so we need to monitor what is going on.

For example, our models predicted it would take over a century for corrosive water to start showing up along our coasts.

But, just two weeks ago, Dick Feely and his colleagues reported in the prestigious journal *Science,* that corrosive waters, burdened with fossil-fuel carbon, have already been threatening the shoreline along parts the west coast of the U.S.

They saw water corrosive enough to start dissolving sea shells.

We need better observations and better computer models to help us anticipate what might occur under different policy options.

Our computer models must get much better at representing the coasts and representing what goes on in ecosystem dynamics. These models must be based on and tested with careful observations, made both by scientists on ships in the oceans and by scientists working in the laboratory.

For my Ph.D. research, I studied what happened to ocean chemistry when a meteorite slammed into the Earth some 65 million years ago. At that time, there was a lot of carbon dioxide and a lot of sulfuric acid, and the oceans became acidified.

Nearly everything with a calcium carbonate shell or skeleton disappeared. Coral reefs weren't seen again for two million years.

You have to go back to events like this, many tens of millions of years ago, to find anything comparable to what we are doing to ocean chemistry today with our carbon dioxide emissions.

What we do over the next years and decades will affect ocean chemistry for tens of thousands of years and could harm marine life for millions of years.

Ocean acidification will stress ecosystems. One important thing we can do now is to reduce other stresses on ecosystems, including over fishing, coastal pollution, loss of coastal wetlands, and so on, so we can give the oceans a fighting chance while we figure out how to address the underlying problem.

There may be engineering options to help protect small bays or semi-enclosed marine sanctuaries, but the only way to really save the oceans is to greatly reduce carbon dioxide emissions soon.

We have investigated the potential to dissolve minerals that would add alkalinity to the oceans, counteracting the acidity from the carbon dioxide. This is essentially accelerating a process that would occur naturally over many thousands of years. DOE patented the idea, but hasn't pursued a careful assessment or its development.

It looks feasible from an engineering standpoint, but at this point it is little more than an idea and a few preliminary calculations. My guess is that it may only prove feasible at the scale of a small bay or other semi-enclosed area, but other people think it may prove feasible at much larger scales.

Again, we don't really know. This is another area in which the research is just waiting to be done.

We need to investigate what mitigation options might be available to reduce the impacts of carbon dioxide on the marine environment.

I would like to see every federal agency that might get funded under this H.R. 4174 send a signal through the bureaucracy to their scientists and technicians asking them what capabilities and ideas they might have to bring to bear on this important problem.

And then I would like to see the agencies coordinate their activities, taking advantage of existing structures.

I wholeheartedly support House Resolution 4174, the *Federal Ocean Acidification Research and Monitoring Act,* but wish it were even more ambitious.

It's impossible to say what the oceans are worth to us, but it has to be at least many tens of billions of dollars per year. We are talking about a research investment starting at several millions of dollars per year. So that's a ratio of about ten thousand to one.

That's like having a 20,000 dollar car and when it starts making funny noises and not running right, spending only two bucks to find out what's going wrong. We shouldn't be surprised when it breaks down unexpectedly in the middle of the highway.

BIOGRAPHY FOR KEN CALDEIRA

EDUCATION

Ph.D., 1991, New York University, Atmospheric Sciences, Department of Applied Science

M.S., 1988, New York University, Atmospheric Sciences, Department of Applied Science

B.A., 1978, Rutgers College, Philosophy

RESEARCH EXPERIENCE

Staff Scientist (Carnegie Institution of Washington, Department of Global Ecology, 2005–present)—Research controls on long-term geochemical cycles, chemical oceanography, climate, and energy systems.

Professor [by courtesy] (Stanford University, Department of Environmental Earth System Science, 2006–present)—Originally appointed to Dept. of Geological and Environmental Sciences in 2006; founding member of Department of Environmental Earth System Science, 2007). Appointment allows teaching at Stanford.

Physicist/Environmental Scientist (Lawrence Livermore National Laboratory, 1995–2005)—Research ocean carbon cycle, atmospheric CO_2, ocean/sea-ice physics, climate, and energy systems.

Post-doctoral Researcher (Lawrence Livermore National Laboratory; 1993–1995)—Research the ocean carbon cycle, atmospheric CO_2 and climate.

NSF Earth Sciences Postdoctoral Fellow (Earth Systems Science Center & Dept. of Geosciences, The Pennsylvania State University; 1991–1993)—Role of the carbonate-silicate cycle in long-term atmospheric CO_2 content and climate.

GENERAL RESEARCH INTERESTS

Climate/carbon-cycle interactions; numerical simulation of climate and biogeochemistry; marine biogeochemical cycles; global carbon cycle; long-term evolution of climate and geochemical cycles; energy technology and policy.

SCIENTIFIC CONTRIBUTIONS

Among Caldeira's scientific contributions are:

(1) Ocean Acidification. Caldeira was lead author of the first publication in which the term "ocean acidification" appeared (Caldeira and Wickett, *Nature,* 2003), showing that anticipated changes in ocean chemistry are large when compared with the range of change in ocean chemistry experienced in the geologic past. This work has been followed up by more detailed investigation for a range of CO_2 emission and

stabilization scenarios (e.g., Caldeira and Wickett, *JGR,* 2005) and analysis of combined threats to corals (Hoegh-Guldberg et al., *Science,* 2007).

(2) Land-cover change and climate. Caldeira has participated in studies showing that growing forests can warm the Earth by absorbing solar radiation, and that these effects can be much larger than cooling effects of carbon dioxide storage (Bala et al., *PNAS,* 2007; Gibbard et al., *GRL,* 2005).

(3) Energy systems and climate modelling. Caldeira has investigated the amount of carbon-emission-free energy that would be required to prevent further climate change under a range of assumptions, and investigated what types of energy systems could supply this power (Caldeira et al., *Science,* 2003; Hoffert et al., *Science,* 2002; Hoffert et al., *Nature,* 1998).

(4) Intentional climate modification. Caldeira has participated in studies on the possible effects of intentional climate modification on Earth's climate system and biosphere (Govindasamy and Caldeira, *GRL,* 2000; Govindasamy et al., *GRL,* 2002; Govindasamy et al., *Glob. Planet. Chg.,* 2003; Matthews and Caldeira, *PNAS,* 2007).

(5) Ocean carbon storage. Caldeira was coordinating lead author of an IPCC report on carbon storage in the ocean (Caldeira et al, IPCC, 2005). He has investigate how long carbon is retained in the ocean (Caldeira et al., *GRL,* 2002) and proposed ways of reducing the ocean chemical effects of ocean carbon storage (e.g., Caldeira and Rau, *GRL,* 2000).

(6) Coupled atmosphere/ocean carbon-cycle modelling. Caldeira was part of the research team that produced the first studies by an American group on the three-dimensional interactions of Earth's climate and carbon cycles. Caldeira was responsible for the ocean biogeochemical components of this modelling effort and proposed the overall experimental design (Bala et al., *Tellus B,* 2006; Bala et al., *J. Climate,* 2005; Govindasamy et al., *Tellus,* 2005; Thompson et al, *GRL,* 2004).

(7) Calcification and long-term ocean chemistry. Caldeira has shown that both shallow-water calcifiers (Caldeira and Rampino, *Paleoceanography,* 1993) and deep-water calcifiers (Ridgwell, Kennedy, and Caldeira, *Science,* 2003) play important roles stabilizing the global carbon cycle and climate.

(8) Ocean uptake of anthropogenic carbon dioxide. Caldeira and Duffy (*Science,* 2000) showed that transport along surface of constant density was the primary mode of uptake of fossil-fuel carbon dioxide from the atmosphere in the Southern Ocean.

(9) Ocean observations as tests of models. Caldeira has been a pioneer of using observations of tracers such as CFCs and radiocarbon in the ocean and marine organisms (e.g., corals) to test ocean models (Doney et al., *GBC,* 2004; Matsumoto et al., *GRL,* 2004; Grumet et al., *GBC,* 2005; Fallon et al., 2003).

ADVISORY PANELS

UNESCO International Oceanography Commission, Chair, ad hoc Consultative Group on Ocean Fertilization and representative to the London Convention/London Protocol (2008)

IPCC Special Report on CO_2 Capture and Storage, Oceans Chapter, Coordinating Lead Author (2005)

U.S. Climate Change Science Program SAR 2.2, Lead Author (approaches to reduce CO_2 and CH_4 sources) (2007)

American Geophysical Union Meetings Committee, member

AGU Biogeochemistry Section Meetings Committee, member

Dissertation Committees of students at Stanford, MIT, and University of Illinois

UNESCO International Oceanography Commission CO_2 Panel of Experts (2002–2004)

IGBP Global Analysis Integration and Modeling (GAIM) Task Force (2002–2004)

U.S. Global Carbon Cycle Scientific Steering Group (2001–2004)

AWARDS AND ACCOMPLISHMENTS

Caldeira was invited by the National Academy of Sciences Ocean Studies Board to deliver the 2007 Roger Revelle lecture, "What coral reefs are dying to tell us about CO_2 and ocean acidification." Caldeira was a lead author of the "State of the Carbon Cycle Report," an interagency report of the U.S. Government requested by the U.S. Congress. Caldeira was one of two technical advisors accompanying the

U.S. Government delegation in climate change negotiations leading up to the 2005 G8 summit in Gleneagles, Scotland. Caldeira was a member of the U.S. Carbon Cycle Steering Group (2001–2004), an advisory panel to U.S. agencies involved in carbon cycle funding. Caldeira was chosen to be Coordinating Lead Author of an IPCC report on carbon storage in the ocean (2005). He was a member of the UNESCO International Oceanography Commission CO_2 Panel of Experts (2002–2004). While at Lawrence Livermore National Laboratory, he was awarded the Edward Teller Fellowship (2004), the highest award given by the laboratory.

Caldeira's work has been discussed widely in major media outlets such as the *New York Times,* the *Washington Post, Los Angeles Times, U.S. News and World Report,* and *USA Today.* He has appeared on radio many times, most often on NPR (Science Friday, Bryant Park Project) and BBC World Service Radio (Business Daily). He has also discussed his work on television (BBC World, The Weather Channel, The Discovery Channel, etc.), both on news programs and in documentaries.

Caldeira now has a highly privileged position at the Carnegie Institution, wherein his only job responsibility is "to make important scientific discoveries." His salary is covered for the length of his career by the Carnegie Institution endowment and other private foundation sources. Caldeira also holds the position of Professor (by courtesy) in the Stanford University Department of Environmental Earth System Science.

PRINCIPAL PUBLICATIONS

Archer CL, Caldeira K, Historical trends in the jet streams, *Geophysical Research Letters* 35, L08803, 2008.

Hoegh-Guldberg O, Mumby PJ, Hooten AJ, et al. Coral adaptation in the face of climate change—Response, *Science* 320, 315–316, 2008.

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Caldeira, K., What corals are dying to tell us about CO_2 and ocean acidification, *Oceanography* 20(2), 2007.

Caldeira, K., The maximum entropy principle: A critical discussion, *Climatic Change* 85 (3–4): 267–269, 2007.

Caldeira, K., D. Archer, J.P. Barry, et al. Comment on "Modern-age buildup of CO_2 and its effects on seawater acidity and salinity" by Hugo A. Loaiciga, *Geophysical Research Letters* 34 (18): Art. No. L18608, 2007.

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Matthews, H.D., and K. Caldeira, Transient climate-carbon simulations of planetary geoengineering, *Proceedings of the National Academy of Sciences of the United States of America* 104 (24): 9949–9954, 2007.

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R. Schlitzer, R.D. Slater, M.–F. Weirig, Y. Yamanaka, and A. Yool, Impact of circulation on export production, dissolved organic matter, and dissolved oxygen in the ocean: Results from Phase II of the Ocean Carbon-cycle Model Intercomparison Project (OCMIP–2). *Global Biogeochemical Cycles,* 21, GB3007, doi:10.1029/2006GB002857, 2007.

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Chairman LAMPSON. Thank you very much.

Mr. Warren, you are recognized.

STATEMENT OF MR. BRAD WARREN, DIRECTOR, PRODUCTIVE OCEANS PARTNERSHIP PROGRAM, SUSTAINABLE FISHERIES PARTNERSHIP

Mr. WARREN. Thank you. I am very pleased to be here, and I appreciate very much the opportunity. It is an honor, and it is heartening to see the problem drawing real attention.

The scientists who are here today and some of their colleagues deserve medals I think. I very much agree with Jay Inslee on that point. If it weren't for them, we wouldn't know this were coming. We might have driven right off the cliff without knowing it was there.

The early warning that these guys have made possible through developing the technologies and the monitoring tools and through literally volunteer efforts in some cases, uncompensated, make it possible for us to be literally the first generation in human history that had a chance against a problem of this magnitude. No prior generation could have taken this on. We might just be able to do it. We've got a fighting chance.

My background, 25 years as a journalist and consultant working in fisheries and oceans. I was the editor of *Pacific Fishing Magazine* for eight years, built the Productive Oceans Partnership, a program of SFP, because acidification looks to be an overriding sustainability challenge for fisheries.

I believe the seafood industry will play a major role in defending the ocean that feeds us from this problem, and that is the centerpiece of my work.

Disclaimers are important here. We advise but do not represent the industry. They speak for themselves. Most of them listen, some agree, some don't, to the kinds of things we put in front of them. There is generally strong agreement on the importance of this problem, but there are differences of opinion about how urgent it is.

Our view, not necessarily those of the folks we know in the industry and work with, we support emissions reduction policies in the U.S. and globally. We support national investment in research like this. This is an example of the sort of thing. We don't endorse particular bills. We encourage the people we work with to do that. We are not a lobby group.

Acidification is a more clear-cut problem for fisheries than is global warming, and that makes it a lot easier to communicate about with this industry.

Early impacts of acidification for fisheries are in the sort of vague area. More still, there may be some that are becoming more clear, but mostly it is a new source of uncertainty concerning fishery productivity and for the financial planning of enterprises in fisheries.

For some it may possibly be an immediate threat. Some of the oyster farmers have raised issues that make it sound pretty urgent now.

Acidification risks for the seafood industry. Obviously, the first risk is reduced productivity in fish stocks. If we have reduced productivity of key plankton species that they eat, we would expect to see fewer fish. We would expect to see things like recruitment failures in stocks. That is where the young fail to grow up because there is not enough food for them. Reduced productivity in shellfish is another of the possibilities.

Risk of market confusion. Although supply will likely diminish if this problem continues unabated, there is pretty strong science-based governance of fisheries in a lot of places, for example, in Alaska, and that will likely ensure that you can eat the fish on your plate in good conscience. There is some concern that consumers might not be able to keep track of that fact and might just panic.

Then there is a third risk, that is a significant risk, that the industry faces in this, and that is really panic-button management. If we don't know enough about the problem, we have little to do that amounts to a rational, firm-minded management. Management of fisheries is a little like monetary policy. You don't want Bernanke having a panic-button response to minor changes in the inflation rate or, in the case of fisheries, if you have an over-fishing problem, well, you cut back on fishing. In this case under-reaction is probably worse than overreaction, but there is still an underlying difference that is very important to bear in mind here. The risks that fishery managers are used to facing are mostly reversible. You can, if you over-fish once, you slow down, you fish less later. The fish generally come back. This in human terms is an irreversible change. When this happens, we can't take it back.

Is acidification hurting fisheries now? There is very, very little research on this. Fundamentally we don't have very good answers on that. It may possibly be hurting oysters right now. There is testimony on May 27 from Brett Bishop representing West Coast Growers, and we will get to that in a little bit. I recommend highly looking at the testimony he submitted last week.

Other potential signs of known change that have not yet been studied for relation to acidification include scallops in some areas show slow growth, fragile shells. We don't know the cause. Reduced forage abundance in places like the Bering Sea and I think many others as well. We don't know the cause. That is the stuff that fish eat.

West Coast hypoxic dead zone, and there are salmon effects going on. We don't know whether this is driven by greenhouse gases or not. There are a lot of people who think it is. There is some scientific discussion of that question. I think it deserves closer look.

Fish stocks that show long-term declines despite very low fishing pressure. There are some of those around. We don't know they are declining. Some of them look like they might be candidates for an acidification affect. We just don't know. There are likely to be multiple effects causing these things, and it is worth bearing in mind acidification is not the only one that can do it. But we have never looked, so we don't know.

Shellfish farmers, hypoxia contributed to greenhouse gas emissions by many. This is a quote from Brett Bishop from Little Skookum Shellfish, who delivered this in testimony last week. "The current situation puts both the marine ecosystem and shellfish growers in extreme jeopardy." And then regarding acidification, which is a longer-term issue for him still, "This acidity dissolves calcium carbonate, the stuff that shells are made of. If diatoms, corals, and shellfish succumb to this, it might collapse not only the shellfish industry but also the entire marine food chain."

Now, this is a question. This is not a statement that we know what is happening to Greenland turbot. Greenland turbot has shown recruitment failures for many years. There are some signs recently that they are coming back a little bit, but if you look at this graph, it goes back to 1964, if I recall, and goes forward to 2007. You can see that there used to be a lot of them. The amplitude of those bumps was high, and there were lots of fish. You go forward in time, and you get less fish, and they show some signs of recovery recently, but it is a generally downward trend, and the overall biomass index is sharply down.

We really don't know why. It is probably not because of fishing. Fishing rates have been, harvest rates have been below seven percent since 1984, and they are currently below 1.8 percent. Those are extremely low harvest rates. This is almost certainly not caused by fishing.

So it is an interesting case. It is a fish that lives pretty deep. Deep water would be more likely to be affected. It might be a candidate to look at.

Some info fisheries will need. People are going to need to know which commercial species are more vulnerable, which ones are less so, how fast is this happening, will fish abundance change quickly or slowly? How do we estimate sustainable yields when the ocean is changing in these ways? That is a critical question. You got to figure it out to be able to manage fisheries.

Adaptive seafood production methods. Is there anything we can do to keep growing things we like to eat as the ocean changes? In a high CO_2 ocean there are a lot of questions around that.

And then, obviously, we are going to need, and this is going to be true in the industry and the management community, technical and policy tools to address the root problem of high CO_2.

Industry perspectives that we have picked up from people we talk to about FOARAM, these are not our own views. I am just relaying what I pick up from people we talk to all the time. The need for research is very well accepted. People agree, and they support this thing in principle.

They do have some reservations. A major one is the potential for robbing Peter to pay Paul. It is already the case that regular fish stock surveys are being suspended in some cases for budgetary reasons. That is a real-time, current need. We need that information to manage fisheries. If we suspend more of them in order to put money into this, it will be very much robbing Peter to pay Paul. You kind of have to know how many fish you have to be able to catch them responsibly. And figuring that out on a regular basis is also one of the ways we will know whether fish stocks are being affected by this. This is a monitoring tool that should be maintained.

And so people are very strongly in favor of more research on this problem and doing it not by whacking sort of the obvious candidate to whack in the budget, which would be surveys. We really need both.

And with that I thank you for your time, and I think we are open for questions.

[The prepared statement of Mr. Warren follows:]

The need for research on ocean acidification and fisheries

Seafood industry perspectives

Testimony of Brad Warren
Sustainable Fisheries Partnership
June 5, 2008

Thank you!

- It's an honor to be here, heartening to see this problem drawing real attention.
- I think the scientists who are here today deserve medals for bringing this light.
- Early warning reveals a key: we are the first generation in history that has a chance against such a huge problem.

Personal background & interest

- 25 years as journalist and consultant working in fisheries & oceans
- Was editor of Pacific Fishing Magazine for eight years
- Built the Productive Oceans Partnership, a program of SFP, because acidification looks to be an overriding challenge to the future of oceans and fisheries.
- I believe the seafood industry will play a key role defending the ocean that feeds us from effects of excessive CO_2 concentrations.

Disclaimers

- We advise but do not represent industry.
- Most listen, some agree, some don't.
- Many now view acidification as a major concern.

One seafood exec on acidification:
"This is indisputable. We've got to deal with this."

Our view on emissions and research policy

- We support emissions-reduction policies in the U.S. and globally.
- Support national investment in research to understand ocean acidification impacts —so that fisheries can be managed as the ocean changes, not just shut down.
- Acidification is a more clear-cut problem for fisheries than warming.

Initial impacts of acidification for industry

- A new source of uncertainty:
  - in fishery productivity;
  - in financial planning.

Potential acidification impacts on seafood industry

- Risk of reduced productivity of fish stocks.
- Risk of "panic button" management.

Seafood: Canary in the Coalmine?

- "The North Pacific is the most likely place for this to show up first and if it does show up it's going to be very,very significant impact on fisheries of the North Pacific. It could potentially eliminate a lot of them."

Shellfish farmers

Hypoxia (attributed to GHG emissions): "... the current situation puts both the marine eco-system and shellfish growers in extreme jeopardy..."

Acidification: "This acidity dissolves calcium carbonate, the stuff that shells are made of. If diatoms, corals and shellfish succumb to this, it might collapse not only the shellfish industry, but also the entire marine food chain."

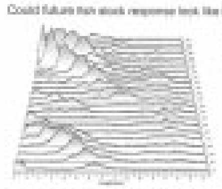
Fishery impacts of acidification: important, but poorly understood

- Research is urgently needed.
- Delay will leave industry exposed to sudden shocks.
- Worst case: decline or outright collapse.
- Best case: manage change by understanding effects on fisheries and underlying ecosystems.

Will plankton impacts of GHGs curtail fisheries?

Greenland turbot

Could future fish stock response look like this?



BIOGRAPHY FOR BRAD WARREN

Brad Warren directs the Productive Oceans Partnership, a program of the non-profit Sustainable Fisheries Partnership that works to inform and advise the seafood industry in addressing the problem of ocean acidification. He has worked for 25 years as a journalist and consultant in fisheries. He edited the trade journal *Pacific Fishing Magazine* for eight years, founded the National Fisheries Conservation Center (a California-based think tank) and has served as a consultant to NMFS and the UN Food and Agriculture Organization. His books on fisheries include *"Win-Win Bycatch Solutions," "The Rise of Icicle Seafoods,"* and *"Conserving Alaska's Oceans."* His work has appeared in the *Wall Street Journal Europe, Audubon Magazine,* the *Seattle Times,* and numerous other business and general interest publications. He lives in Seattle.

DISCUSSION

Chairman LAMPSON. Thank you, Mr. Warren. I appreciate that.

At this point we will go into our first round of questions. I will recognize myself for the first five minutes, and I will start with you, Dr. Doney.

INTERAGENCY COORDINATION

H.R. 4174 establishes a new interagency committee to develop a research and monitoring program for ocean acidification studies. You indicate we should use the existing interagency committees to coordinate the program. It seems the Joint Subcommittee on Ocean Science and Technology, JSOST, and the Interagency Committee on U.S. Global Change Research Program, I tried to make a word out of that but it doesn't fit, are both involved in this issue.

Would you recommend we direct one of these to take the lead in developing a plan for the program with a budget to support the program activities?

Dr. DONEY. Yes. I have talked to a number of people across the federal agencies on this, and one of the problems with the Global Change Research Program is they have a lot of other things on their plate. They have to look at the atmosphere, the land, and climate. This is a very focused ocean program, and we need to basically look at it from the basic science end all the way up to fisheries and human impacts.

So given the current structures, I think JSOST would be the most likely candidate, but that would have to be something that would have to be worked out in detail with them if this moves forward.

OCEAN ACIDIFICATION MONITORING

Chairman LAMPSON. Dr. Feely, how extensive is the corrosive acidified water that you found during your research last summer along the West Coast? Are there other coastal regions in the world that could be experiencing ocean acidification as well?

Dr. FEELY. This effort, we thought we might see it somewhere along our coast, and what surprised us the most about the study is that going from Queen Charlottetown in Canada through all the Washington, Oregon, California, and into Baja, California, we saw it everywhere. It ranged in depth from near the surface off of California to depths around 40 to 80 meters everywhere we looked.

What this implies is that we need to look further. It probably occurs all the way down through South America and probably up into Alaskan coastal waters, which are naturally shallower in the waters than anywhere on the planet.

Chairman LAMPSON. Well, now that you know that this exists, what strategies are being put into place to continue monitoring it?

Dr. FEELY. Well, we have been working with our State and local agencies as well as the Federal Government, put together a coalition of efforts to have a monitoring effort along the Continental Shelf, particularly a series of moorings, and we are recommending that we would also have continued surveys. I have a proposal for a survey again next summer, and we would like to continue that on a more regular basis. And we are hoping with new technologies such as gliders and floats, that we could put carbon system monitoring instruments on the gliders and floats and have regular surveys with the gliders and floats, which would provide us the right kind of observational data to allow us to monitor this in real time.

INTERNATIONAL COOPERATION

Chairman LAMPSON. What cooperation are you finding, particularly among other places in the world? Are our scientists working together with other folks in other countries?

Dr. FEELY. Oh, absolutely. Several of us are on the advisory panel for the POKA Program, which is a European program, and I have been participating in their national program development efforts. We are working directly with the Canadians and the Mexicans on our Continental Shelf programs, and I am also working with the Japanese and the Koreans on this effort.

Chairman LAMPSON. Are we pretty much up to speed with them, or are there some areas that may be more advanced in support of this than what we in America are?

Dr. FEELY. Generally speaking our international colleagues are looking to us for leadership in developing the monitoring activities because we have some of the best instrumentation for monitoring this problem within the United States. But our colleagues in other countries have done a very nice job of looking at physiological responses, particularly for phytoplankton and zooplankton, corals. So we want to interact with our colleagues that have a great deal of experience in this arena.

Chairman LAMPSON. Thank you very much.

Mr. Inglis, I will recognize you for five minutes.

Mr. INGLIS. Thank you, Mr. Chairman.

MORE ON INTERAGENCY COORDINATION

I think each of you mentioned something about who is best equipped to help lead this effort, but I admit to being somewhat mystified at the conclusion of that. I am not sure I am drawing any real conclusions about how best to organize this effort.

Anybody want to take a shot at telling me, giving us the specific proposal? If you don't like the bill, and apparently each of you had some criticisms of the bill in your testimony, as to how it should be structured. I mean, if you—is it, first of all, is it a good idea to try to orchestrate this effort? And if so, then who is the best conductor of the symphony?

Dr. DONEY. I will take a crack at that. I think one of the problems with the way we have looked at the bill is that the funds and the leadership are all directed at NOAA, where the expertise within the Federal Government is really spread over multiple agencies with NSF and NASA having an equal role on many of these problems.

And I think the perception of the community is that we just want to make sure that those agencies have an equal seat at the table, and one of the ways to do that is to authorize funds directly to those agencies rather than having the funds sent to NOAA and then have it trickle out to the other agencies.

Mr. INGLIS. And so, Dr. Feely, what was your reaction to that? It is a challenge to you being the conductor, I suppose.

Dr. FEELY. Well, I think it is NOAA's viewpoint that they would be very happy to coordinate the interagency activities through the JSOST Subcommittee has been recommended. Dr. Spinrad is one of the co-chairs of the JSOST Committee, and he was very comfortable with that position, and we feel very strongly that NOAA should be playing a leadership role in this process and are willing to do so. But we fully agree that we have to do this in a cooperative manner with our sister agencies, as we have always done in the past and are very comfortable with that relationship.

Mr. INGLIS. And speaking of which, that happens now, right? In other words, I imagine there is informal contact among the agencies on these kind of questions. And so if the bill is mostly helpful in that it provides additional funding for support staff or somebody that is going to actually run the symphony or what? I mean, what role would the bill play in helping what already goes on, I suppose, with some contact between the agencies?

Dr. FEELY. Well, certainly there is a lot of coordination activities, and that takes personnel to handle those coordination activities. And I think some of the support would have to go into coordinating activities, developing research priorities, making sure that there are gaps that are being filled, and that the individual agencies carry out their roles in a cooperative manner.

And this type of interagency cooperation takes a lot of coordination and therefore, some support to carry that out. This is what we are looking for with this bill in particular.

The second point is that the amount of resources that are presently available to do ocean acidification research as Scott has pointed out certainly is not adequate to the task at hand, and we suspect that the requests for funds that have been laid out by Dr. Doney is certainly appropriate for the research that we are looking to see happen.

Mr. INGLIS. Yes. Dr. Caldeira.

Dr. CALDEIRA. There is another dimension to this coordination, and that is to make sure that the people representing each of the agencies really understand the capabilities and resources that each agency has to bring to bear on this problem. This is a problem that spans from biology to oceanography to physics and so on.

So it would be very useful if the civil servants at the top of these organizations would send a signal down through the bureaucracies to ask the scientists working, you know, in the field exactly what are the various skills, capabilities, resources within the agencies that could be brought to bear on this problem. Because I have a feeling that there are people at the top of the agencies that don't really understand what their capabilities really are in this area.

Mr. INGLIS. Very helpful. One thing I might point out, Dr. Feely, on the excellent trip that Dr. Baird led to Antarctica that included the stop in Australia, we saw wonderful cooperation between NOAA and the Australians with the Great Barrier Reef, and it really is, I think, tremendously helpful to our position in the world to be involved in that way. And so I am particularly pleased to see NOAA doing that and working so closely with the Australians. Actually, a couple of Australians who worked for you, that work for NOAA in Townsville. So that is really neat.

Dr. FEELY. Yes. In fact, they have invited us to participate with them even further as of two weeks ago.

Mr. INGLIS. That is very helpful.

Chairman LAMPSON. Mr. McNerney, you are recognized.

OCEAN ACIDIFICATION MODELS

Mr. MCNERNEY. Thank you, Mr. Chairman.

Dr. Caldeira, my background is in modeling, computer modeling. How sophisticated would you say the models of ocean acidity are in comparison to the atmospheric CO_2 models that are out there now?

Dr. CALDEIRA. I would say they are approximately at a similar level of development. The open oceans near surface environment, very simple models, are adequate in the sense that for, at least to understand the chemistry. In fact, you could take a bucket of water and put it under a bell jar and change the CO_2 and get a pretty good estimate of how the surface chemistry would change.

But the kind of stuff that Dick Feely observed off the west coast of the U.S. involves very detailed processes along coastal environments and the current generation of models is typically very coarse and does not represent the kind of features that Dick and his colleagues were observing. And so the representation of coastal processes is very primitive.

Furthermore, the representation of ecosystem processes is nearly non-existent, and part of that is due to the lack of fundamental science and our lack of understanding of ecosystem processes, but also there is just a lack of modeling in there.

And so I would say that the representation of coastal environments and ecosystem properties, maybe Scott would like to amplify it.

Dr. DONEY. Yeah. I suggest, one of the key things that we need to do is bridge between the basic science and the basic modeling that Ken and I do and the kind of models that resource managers need. You know, they need specific models for specific species; oysters, clams, scallops. And so there is a big gap right now on the biological side, you know, of how to go from what we are seeing in sort of the fish tank experiments to something that a resource manager could use to set sustainable limits or set up marine-protected areas, things like that.

Mr. MCNERNEY. So it is not the computer resources that is limiting you. It is the basic science.

Dr. DONEY. You know, we could always use a bigger computer. Every modeler will tell you that, but right now I think we are fundamentally limited by our scientific understanding.

Mr. MCNERNEY. So you don't have enough, not you personally, but there is not enough understanding to understand, to predict whether there will be sort of sudden shifts or gradual shifts in there ecosystems, say sudden being 10 years or less.

Dr. DONEY. The experience in looking back at historical data with ecosystems is that there are often thresholds or tipping points, and to date we typically don't know that we are at a threshold until it is already behind us in the rearview mirror.

And that is something we really need to be concerned about, is are the fisheries today reaching a threshold where ocean acidification along with warming and over-fishing will tip them beyond the spot that they can't recover from.

THE EFFECT OF OCEAN ACIDIFICATION ON CALCIFYING ORGANISMS

Mr. MCNERNEY. Thank you.

Dr. Kleypas, you said that it makes it—the acidity makes it harder for organisms to secrete carbonate. Is that—it doesn't just eat it away. It makes it harder for them to secrete it biologically?

Dr. KLEYPAS. It does both, you can think that organisms, most organisms, responds to something called the saturation level in the oceans. That means if there is an adequate amount of calcium and carbonate ions to build those shells. We used to think it was on/off switch, so below that level they would stop calcifying. Above that level they would calcify. Now we realize it is more like a dimmer switch.

So the higher the saturation rate, the more they calcify. And so they will—many organisms will change the rate at which they calcify or the amount at which they lay down relative to that, you know, the level of ocean acidification.

MITIGATION OF OCEAN ACIDIFICATION

Mr. MCNERNEY. Then what we don't have or you don't have, is there some idea of what mitigation is being discussed and what the side effects of that, of those processes might be?

Dr. KLEYPAS. You are talking about local mitigation in terms of say on a coral reef, what we can do?

Mr. MCNERNEY. Right. Local or global or any kind of mitigation.

Dr. KLEYPAS. The only way to really stop ocean acidification is to stop CO_2 concentration in the atmosphere, because the ocean at the surface is so well mixed with the atmospheric concentration that as long as you increase it in the atmosphere, the ocean acidification will increase as well.

Now, there have been talks at a very small scale, the scale of an atoll or a small bay, of putting in sources of, you know, another chemical that would raise the pH back up, like the way you change pH in a swimming pool or an aquarium. But it is, the scale would be very small and expensive. So we can't do it for most of the oceans.

Mr. MCNERNEY. And the side effects wouldn't be understood either.

Dr. KLEYPAS. Some would and some wouldn't. It depends on what you put in to buffer the system.

Mr. MCNERNEY. Okay. Thank you.

I yield back.

Chairman LAMPSON. Mr. Bartlett, you are recognized for five minutes.

Mr. BARTLETT. Thank you very much. I was very pleased to note that almost all of you kept repeating over and over, we don't know, we just don't know. People out in the working world don't understand the scientists, and that is why we are scientists because we just don't know. This is why we do research. Thank you very much for taking that position.

Dr. Kleypas, you mentioned that in your little aquarium when the algae increased that was bad. If I was an algae-eating critter in the ocean, I don't think I would think that was bad. I think it was Dr. Doney who mentioned that there will be biological winners and biological losers, and the oceans will be very different with higher CO_2. I am not sure whether that will be bad or whether that will be good.

But there is always a risk that it will be bad, and if you are concerned about the rising CO_2 levels, I would suggest that there are two other groups that you need to lock arms with, groups that you may not ordinarily identify with.

One is a group that is really concerned about national security, the fact that we have only two percent of the world's oil, and we use 25 percent of the world's oil, getting much of it as the President said from countries that don't even like us. To solve that problem what you need to do, of course, is to move away from fossil fuels to renewables, which will, of course, stop the CO_2 rate increase.

There is a second group that you need to identify with. Of course, you are a subset of the global warming climate change group, and so you already, I suspect, are identifying with those. The geopolitical concerns, the national security concerns are shared by a lot of people in our country, and then there is a third group that you need to identify with, and that is the group who believes that the fossil fuels just aren't going to be there. And that we have known that for 28 years that we were going to be roughly here today with oil at $120 some a barrel, because 38 years ago the United States reached its maximum oil production. That was predicted in 1956. By 1980, we knew darn well that M. King Hubbert was right about the United States peaking in oil production in 1970.

So now for 28 years we have done absolutely nothing, and of course, you may argue that with global warming, our Earth will be different, more acid ocean, our oceans will be different. That may not be all that bad. They will be different. If I lived in Siberia, you would have a hard time convincing me a warmer world would be all that bad. And as far as the national security thing is concerned, the Arabs may play nice and continue to give us the oil.

But if it just isn't there, it just isn't there. And there is increasing evidence that we have reached a peak oil production in the world. It will be plateaued for a little while and then the world will do what the United States has been doing ever since 1970, pumping even less and less at higher and higher costs.

If you are concerned about rising ocean CO_2 levels, and you should be, because it may be better and it may be worse, but, gee, it is okay now, and why should we run the risk that it might be worse in the future, are you reaching out to these other groups, these other two groups, those who are concerned about national security and those who are concerned that the fossil fuels just aren't going to be there? Because all three of these groups have common cause, and instead of nit-picking each other's premise, don't you think we ought to be locking arms and marching together?

Yes, sir.

Dr. DONEY. Well, I am sympathetic with many of your remarks, and I think that we haven't done enough to bridge across communities.

With regard to the effect of the change in the oceans, that it is true that wherever there is light and nutrient, something will grow, and so we are not worried about sterilizing the oceans or anything like that. But change is a significant thing, even if the end state might not be completely terrible. But let us say that we know now that coral reefs are at least threatened, that the levels of acidification that we are likely to reach haven't been experienced for many tens of millions of years, and so there are communities that have built up, assuming that there would be certain fish stocks or certain resources available in coral reefs or say the salmon industry.

And you know, it might be that the salmon aren't there and some other fish might be there. Then there is the question, well, will we be able to eat that fish? Yes or no? And so there is a risk, and typically what we are seeing is changes in ocean chemistry that are about 100 times faster and bigger in magnitude than the kinds of changes that occurred naturally.

And so, you know, the expectation is that the systems that are adapted to very precise chemical or climatological conditions will disappear and be replaced by more invasive, generalist species, which on land we call weeds.

And so the expectation is to see a loss of diversity and essentially increased weediness of the oceans, and it is true that we will as humans adapt to that and find something to eat in that, but that will be a big dislocation cost and a big loss of diversity.

And so, you know, and we can't say exactly how bad it will be, but I think we know that some major systems will go. I mean, I think, just to broaden it out to the climate change, you know, there is a question, it looks now like we are going to lose Arctic ecosystems, and we are going to lose coral reefs, and some people say, well, if that is all it is, then let us not worry about it. But maybe that is just the beginning, and we are starting to lose major systems, and we don't know what other major systems we are going to lose.

And so to a certain extent it is, what is your level of risk, of irreversible environmental risks that you are willing to take on? And to me a precautionary approach seems prudent, and if we know that for a relatively minor investment we could avoid this risk, it seems reasonable, and there are other risks that can be avoided like national security risks and risks to our economy through loss of fossil fuels. And so the people, so addressing this carbon-based energy system and replacing it with a system that doesn't release greenhouse gases to the atmosphere has multiple advantages, and we need to work more broadly together as you suggest.

Mr. BARTLETT. Mr. Chairman, since I am not a gambler, I would have to concur with what Dr. Caldeira says. Thank you.

Chairman LAMPSON. Thank you very much.

Mr. Baird, you are now recognized for five minutes.

COMMENTS ON H.R. 4174

Mr. BAIRD. Thank the Chairman and I thank our outstanding witnesses.

Now, when you first, the first time you ever go out into an area with a coral reef and you are walking on the surface of the water and, or, you know, walking on a pier, and you sort of see some colored fish, you think, that is pretty interesting. There is some pretty fish down there. And then you put on a mask and a snorkel, and you put your head under water, and you pop up, and you think, my God. Have you guys seen what is down here? Do you have any idea what is down here?

And then you do more diving and things of that sort, and to that, Dr. Caldeira, because I know from your background that when you say, well, people might, don't think it is a big deal to lose a coral reef. It is a huge deal to lose coral reefs. It is unimaginably horrible if we have done this as a species to this planet. Only people who live on Earth solid terra firma but have never stuck their head under water with the lens so they could actually see something would ever imagine that we are not damaging this Earth in ways that are unforgivable and inexcusable.

That is why we are working so hard on this. I am not saying you are condoning that for sure, but I just want to state I sort of wish we could take every single Member of Congress and spend a day at a coral reef. Just start the session there. We will fly down in

January, we will go down to Florida, see a healthy reef, and we will say what would happen if we lost it.

Dr. DONEY. You know, when ocean acidification happened 65 million years ago, it took two million years for the coral reefs to repopulate the coast of the continents, and so what we are doing over the next years and the next decades is going to affect, you know, coral reefs not just for years and decades but for millions of years, and then so, I mean, to me the idea that we are even talking about risking these systems is incredible.

And so, you know, what I am saying it is just, we might be lucky and it is just coral reefs, it is not——

Mr. BAIRD. I mean, we might not lose the entire planet.

Dr. DONEY. Yeah. Yeah. You know, I mean——

Mr. BAIRD. Doctor told you, hey, the good news is you are only going to lose your liver.

Dr. DONEY. Right. Right. And so, I mean, the real thing to do is to reduce CO_2——

Mr. BAIRD. Yeah.

Dr. DONEY.—emissions.

Mr. BAIRD. I get the point, and I just want to under-scribe, I sincerely mean that. I sincerely mean this Congress could do well to go to these places. I have had the profound privilege and I went with Mr. Inglis, of seeing the Great, the once Great Barrier Reef, which is not so great in most of it anymore. I have been to the University Institute in Eilat and seen some of the base science being done on acidification there and the Red Sea and the Gulf of Aqaba. And I have been to the Aquarius Lab down in Florida, and I want to especially acknowledge all of those institutes and also the Atlantic Oceanic Meteorological Laboratory, which does phenomenal work in these areas.

So I have managed to see different areas of reefs around the world, and in all cases, every single case, we are facing real threats.

The legislative process is an iterative process at its best. We don't have pride of ownership so much as we want to get the job done right. The legislation we—that is the basis for this hearing is really the basis for the hearing. It is not necessarily what we should do. And so what we are really out with the hearing is not to ask for kudos. We don't really care about that. It is, really, let us do the right thing.

And so we have heard some suggestions. I absolutely share the belief that the magnitude of the problem warrants a much greater and more urgent investment financially. So we will stipulate to that.

Secondly, I am interested in this discussion of whether or not an interagency organization is the best or whether or not targeted funds, but at the same time how do you coordinate where the funds best go? And I am interested in that. If we need to modify this bill or do something completely different, tell us what you think needs to be done.

And then the third thing I am real interested in is you look, you know, you look at the science articles, and I have followed them very closely over the last few years. It is great how international this is. What, I don't think our bill does enough, frankly, on the international front by a darn sight.

What are your thoughts, if you could, if you were saying, write the bill instead of us who don't know what the heck we are doing, what would you do? Each of you. What would you do differently?

And fire away. You can say this is a crappy bill. Let us throw it out and get something better, and I am okay with that. Maybe in more delicate language.

Dr. FEELY. I want to answer a little bit the question to Dr. Caldeira. I just—coral reef systems provide protein and resources to at least 500 (million) if not a billion people on Earth. So they are a resource we can't afford to lose. It is a really important issue that we need to address. That is the first point.

Secondly, I think that the agencies work extremely well together. They, the program managers work on a daily basis together, so we are very comfortable working with the federal agencies to have an interagency program on this issue.

And if the responsibility is given to JSOST, I am absolutely certain we can work out those details from that point on. I don't think that is going to be a major issue, because they are very comfortable in doing that. And we work with all the program managers, so we know that quite well. So I think that is the right way to go personally.

The third issue is, and something that has not come up yet, is that there are some technological developments that have to be part of this effort. The way we have operated with NOAA is to add carbon measurements on the existing moorings and floats and instrumentation packages that are part of the climate program. They are part of the National Climate Program, and we do so by adding them to existing investments, and this is the right way to proceed in the future. This is what allows us to get global coverage, allows us to get regional coverage in the coastal regime.

But with ocean acidification the problem is different. We have to develop the technologies to measure two components of the carbon system, not just one as we are doing now. And so we have to make an investment in those technology development to do that. This is something that needs to be done right away, right now.

And here is where we need help to get that started, and I think the federal agencies are well poised to move quickly on this issue, but we need to have the resources to do so.

Dr. KLEYPAS. I would like to make a comment on two things. One is just thanks for bringing up the level of appreciation for coral reefs. I did my Ph.D. on the Great Barrier Reef myself. Every time I go back I have tears in my eyes, and it is still one of the best reef systems we have, but as you know globally they are threatened not just by ocean acidification but by coral bleaching, which is due to global warming. And so they are hit, you know, it is a double whammy from CO_2 in the atmosphere on coral reefs.

On the international cooperation——

Mr. BAIRD. Dr. Kleypas, the way I talk to people about that is if you had a 103 degree fever every day for the rest of your life and to treat it they gave you acid water to drink, you might get a sense of why this is a problem.

Dr. KLEYPAS. I am going to use that one in the future.

Internationally what I think has been remarkable about ocean acidification is there has been a tremendous amount of goodwill between our international colleagues. So we have invited them to our workshops, and they have been very helpful and very uncompetitive, very giving in terms of what they know and advice on how we should design our reef program and vice versa. In fact, three of us at least are going to the European Program on ocean acidification kick-off meeting this coming week, and that is invitational. They have put us on the board, and this is continuing, and it is growing, and verbally we are very supportive of each other's research.

Now, some of the work that Dick has been describing with moorings and so forth, a lot of that can be expanded and really made efficient with our own research, but also on an international basis by capitalizing on what they have in terms of their observing system, sharing lab facilities, but particularly these big, open ocean experiments that will probably be very expensive, can really do well by engaging them through some sort of exchange program, some sort of structure for international funding that supports these kind of things. Maybe similar to the way the ocean drilling program is operated. I am not exactly sure exactly how to do it, but I think the goodwill is there, the need is there, and if we can put something in that bill, I am sure many of us on this panel will help you write that in the right way.

Dr. DONEY. If I can continue, I want to echo Dr. Feely's comments. The front-line program managers in the ocean agencies work very well together. I work with them on a day-to-day basis. I am Chair of the U.S. Ocean Carbon and Biogeochemistry Program, which is an NSF, NASA, and NOAA-sponsored research program.

One of the things the bill does do, and I think is very good, is it brings at a higher level within the agencies the priority of ocean acidification. We do have an ocean research priority plan that is across agencies. This is what JSOST is working off of. There are four priorities at present, and we have been pushing them to make ocean acidification the fifth national priority for ocean sciences.

The only reason I hesitate in establishing a new interagency committee is that we have one in place already for ocean sciences. We don't need more bureaucracy. We can take advantage of what is there right now to coordinate across the agencies.

Mr. BAIRD. Well, if we had JSOST but we directed them, for example, to make this one of their top five priorities, this is really helpful. I appreciate your indulgence, Mr. Chairman. If we were to say, make this one of your top five priorities, include an international component, work on the instrumentation. We are getting towards a better bill here.

Chairman LAMPSON. Yes.

Mr. BAIRD. There are others. Mr. Chairman, may we hear from the others?

Chairman LAMPSON. Yes. Go ahead. This is important.

Mr. WARREN. I don't know that I am really qualified to say how the bill should be, nor is that really what we do. I think it is a better point and really to address the question, what we would like to see and what we think a lot of the people in the industry would like to see is not specifically an issue with the bill. It is about the process.

Everybody knows it is a tight budget time. We are dealing here with one of the greatest problems, as has been said, that we know about, and rather than pulling out some of the legs underneath our system for understanding what is changing in the ocean in order to add a new leg, we ought to keep the ones that are there because we need them. And figure out how to do this in the best way.

What that way is I think you all are well qualified to figure out.

Chairman LAMPSON. Thank you very much.

Ms. Woolsey, you are recognized.

REDUCING OR REVERSING OCEAN ACIDIFICATION

Ms. WOOLSEY. Thank you, Mr. Chairman.

Last week or the week before my staff attended the Ocean Science and Climate Change Summit in Monterey, California, hosted by the Monterey Bay Aquarium Research Institute. They reported back, and these are two members of my staff that are sophisticated in all of this, and they were actually horrified to report back that acidification is the number one concern. They knew it, but they really heard it loud and clear down there.

So the irony is that that same week on the business page of almost every newspaper there was an article saying that the three U.S. automobile manufacturers in this country were stunned, they didn't use that word, I am using it, that they were going to go out of business because they weren't building small, fuel-efficient automobiles. Well, you know, this is, you don't answer this question. What took them so long?

But the question to you is how long will it take for us to address acidification, and how long do we have to prevent, reduce, and even reverse the effects of ocean acidification?

Dr. CALDEIRA. As I said in my prepared testimony, the taxi—the CO_2 from the taxi I took yesterday, some of that is going into the ocean already. And so the good side of that would be if I, you know, had had an electric car to drive here, then that would be CO_2 that would not be going into the ocean today.

And so the surface ocean feels our CO_2 emissions or our reductions in CO_2 emissions right away, and if we would stop emitting CO_2 today, the oceans would start getting better right away.

On the other hand, there is a lot of inertia in our energy system, in that power plants are typically the last 60 or more years when you build them, and so if you build a new power plant that emits CO_2 into the atmosphere, that will damage the ocean for many decades and millennia to come. And so while coral reefs will say still have water that they can grow well in for a few decades, if we build those power plants today, they won't. And so it is really essential to have action today if we want to have healthy oceans in the future.

Ms. WOOLSEY. Well, I admit it isn't just action from the United States. It is action globally.

Dr. CALDEIRA. Yes.

Ms. WOOLSEY. I was part of a China discussion this morning at breakfast. We have a huge role to play in the international global warming situation.

Dr. CALDEIRA. We need global action, but we need American leadership.

Ms. WOOLSEY. Absolutely.

Anybody else want to respond?

Dr. KLEYPAS. I just want to make one point that sometimes gets lost, and that is the response of the surface ocean. That is the shallow part of the ocean where most of marine life lives. We know that once carbon gets in the ocean that it will stay there for a long time because of the ocean conveyor belt bringing that carbon to deeper depths where it get stored for hundreds to thousands of years.

But that surface ocean is very responsive to the atmospheric CO_2 concentration or carbon dioxide concentration. So if, you know, just in an optimistic view, just to put this out there, and I know a lot of people will say this is impossible, but with new technology some of the stuff that Representative Inslee was mentioning, and American ingenuity, if we can find ways to remove CO_2 from the atmosphere, that surface ocean will start responding immediately and the ocean acidification will be reduced immediately as long as CO_2 goes back down.

If we could do that, that would be a really remarkable thing, and I think it is a nice star to put up there to aim for.

Ms. WOOLSEY. Well, Mr. Chairman, I would just like to brag a little bit about my district. My district is Marin and Sonoma Counties, and we have two national marine sanctuaries. We have the Gulf of the Farallones and the Cordell Banks National Marine Sanctuaries, and I have legislation that will double, more than double the size of that sanctuary and reach up the entire coast of Sonoma County into the southern part of Mendocino County. And we have gotten that legislation through the House of Representatives. It is out of the Commerce Committee and the Senate, and we are hoping it is going to be part of an omnibus bill coming through the Senate Floor.

So it is, you know, not, we are not going to rob Peter to pay Paul, but we have the many legs that we have to deal with.

Dr. CALDEIRA. I think it is important not to, you know, while ocean acidification is a very important issue, it is an additional stress on marine systems, and the better we can manage our fisheries or reduce coastal pollution or in other ways take care of our marine environment, then the better, the more likely that these ecosystems can meet the challenges posed by ocean acidification.

Ms. WOOLSEY. And if we prevent drilling for oil off of our coasts, we will prevent CO_2 in the atmosphere, I believe.

Thank you, Mr. Chairman.

Chairman LAMPSON. Just out of curiosity, Ms. Woolsey, how many fifth graders visit that facility each year?

Ms. WOOLSEY. Well, it isn't a facility. It is like a whole coast, and they have hundreds and thousands of them. It is 40 minutes from San Francisco. You can imagine.

Chairman LAMPSON. Dr. Baird and I were talking quietly here, as you all were going on, about perhaps us considering a requirement that every fifth grader in the world if possible, but at least in the United States, have a course that would teach so that we can begin now to make sure that the next generation, obviously not enough of our generations——

Ms. WOOLSEY. Right.

Chairman LAMPSON.—understand these problems. There are a handful of us who are talking, in comparison to the full population.

Ms. WOOLSEY. Right.

Chairman LAMPSON. Are you all doing anything to really get the word out to those who are writing school curricula at the very early level?

Ms. WOOLSEY. Well, before you say that, Mr. Chairman, I would like to respond.

I have a grandson who is in the second grade, and my grandchildren call me Alma, and we were at dinner the other night, and he said, Alma, have you heard about the polar bears? I mean, and he really was concerned. So, but that is Sonoma County, you know. Maybe, we are talking about the rest of the world. Right?

Chairman LAMPSON. Well, I hope that it spreads——

Ms. WOOLSEY. Okay. Ask the question.

Chairman LAMPSON.—because if it doesn't, then obviously we have heard the risks.

Dr. Baird, I understand you have more questions. You are recognized for five minutes.

AN INTERNATIONAL PANEL ON OCEAN ACIDIFICATION

Mr. BAIRD. I could go on for a long time with this panel and with some of the others in the audience here, and so this is a continuing process but a few other things I just want to make sure I understand.

We have had testimony in this committee, particularly from the IPCC. What attention is IPCC giving to acidification is one part, and do we need a comparable, I won't call it the acronym here, but ocean acidification, international panel of ocean acidification? Do we need or does such a thing exist?

Dr. DONEY. The fourth assessment for the IPCC had a fairly small discussion on ocean acidification, and I think that in part reflected, IPCC depends upon the published scientific literature, and this is a very fast-moving and fast-evolving field. So there really wasn't the literature base three or four years ago when they started that.

I do think in the future that there will be a much more substantial component within IPCC addressing ocean acidification, and in fact, I was just at a meeting yesterday with federal agency managers where we were trying to think about what would be the best way to put the right syntheses in the literature that can reach that step.

But I think the other thing is this is, you know, IPCC sort of looks at the global problem, but for resource managers and stakeholders this is a local issue, and I think one of the things that we need to do with this research program is bring this down to the scale of individual states, individual fishery council levels and that, the level of individual fishers and people who are using the ocean.

So I think we need to bring it into the global assessment level, but we really need to bring it home to a much smaller scale to see how it is actually going to affect human lives and our economic system.

Dr. CALDEIRA. The IPCC is a product of the UN Framework Convention on Climate Change, and ocean acidification is really a chemical change and not a climate change. And so the IPCC hasn't really felt that it was directly within its remit. But I do think rather than creating a new parallel organization it would be good if governments would make it clear to the IPCC that they would like ocean acidification considered to be within the remit of the IPCC and broaden the understanding that it is not just climate change but also chemical change.

Mr. BAIRD. Mr. Warren, I found that the National Shellfish Caucus and folks you alluded to earlier are interested in this issue, and one of the interesting things is to what extent do the fisheries, does the fisheries industry proactively take an active voice or should they proactively take a more active voice in issues of ocean acidification and carbon production and change in our energy supply, et cetera, because it is directly impacting the industry. What role are they playing in that?

Mr. WARREN. It is an emerging role. I think we will see it expand inevitably with time. I go around and give talks to people in fishing communities and in the industry all the time, and what I find is that they have moved rapidly, faster than other groups, into understanding the issue and knowing what is at stake. There is still a lot of education to do in the community.

Some of them are already ready to wave their swords in the air. Some are wanting to take a very circumspect approach. They have complex economic interests, and they have to be careful in how they address this. And that is perfectly valid.

That they will address it I am confident. How—is, for most of them, still being worked out.

ATMOSPHERIC TRANSPORT

Mr. BAIRD. We have a number of skeptics in the Congress and on this committee about the issue of climate change and whether or not there is any change in temperature, and if so, the degree to which it is human caused, and I think as a Science Committee it is healthy to have skeptics here. I disagree with how they interpret the evidence sometimes.

There are also some skeptics about the issue of ocean acidification, particularly the decline in carbonate levels. And at least one gentleman I have spoken to has suggested it is a result of changing wind patterns on the Gobi Desert not blowing minerals into the oceans. Is there any substance to that that any of you know of?

Dr. DONEY. Actually, Dr. Feely and I have done some work on looking at the atmospheric transport of trace gas species and dust. The limited data that is available from rain measurements actually suggest that the amount of base, the calcium carbonate which would neutralize the ocean, has actually gone up, and yet we still see the ocean being acidified.

So I don't think that hypothesis holds weight. It is something that we have worked a lot on looking at dust distributions, and that doesn't appear to be a plausible mechanism.

Dr. FEELY. I just want to add is from the ocean carbon observing system throughout the world, our own time series stations at hot off of Hawaii and back off of Bermuda, my own work over the last

30 years, we have actually measured the changes in CO_2 concentrations, increase in CO_2 in the surface waters, and the decrease in pH throughout the world oceans.

And so there is no doubt where this coming from.

Dr. CALDEIRA. Scott and I both run fancy models to predict surface ocean chemistry changes, but really, you don't need them. If you just took a bucket of water, stuck it under a bell jar, changed the CO_2 concentration, you could measure the change in pH and measure the change in carbonate ion concentration, and if you would stick a coral head in there, you would measure that its growth rate declines.

And so, you know, there is no, you can demonstrate this easily in a high school laboratory. You don't need the fancy things to see that this is right.

MORE ON OCEAN ACIDIFICATION MONITORING

Mr. BAIRD. I should also acknowledge, I see my good friend, Mr. Diaz-Balart here. He has actually dived to the Aquarius Lab. That is something we hope to do together somewhere down the road, and of course, AOML is very closely related to Aquarius and the great work down there. And we will go diving down there together, Mr. Diaz-Balart.

One of the things I saw at AOML, it was very interesting, was a Power Point, which maybe we should have done here. This would be very interesting, Mr. Chairman, about, I think it actually not just, it was real time log-on, it was, in fact, log-on monitoring to the monitoring stations where, not the stations, the floats that are distributed throughout the world, an entire global network of floats, some maintained by commercial shipping routes, where they drop floats off at periodic things, and they get remote sensing.

It would be very interesting for this committee to see that. Dr. Feely, you talked about instrumentation. Is that the kind of system where you would want to see CO_2 monitors giving up intel on real time?

Dr. FEELY. That is exactly what I have in mind. I am a colleague of Dr. Winacoff, who carries out those measurements. I do it in the Pacific, and he does it in the Atlantic. What we have is a series of moorings throughout the world that we are adding carbon system monitoring instrumentations on the moorings. We couple that with CO_2 instrumentation on ships of opportunity. These are usually cargo ships throughout the world, and we hope to have CO_2 instrumentation on Argo floats and gliders and things like this.

The problem we have right now is we only have one carbon measurement, that is PCO_2 at the moment. This is something we know how to do quite well. In order to study ocean acidification, we need two. We need PCO_2 measurement and dissolved organic or alglini, one of those two species we prefer to do that. That is a technology we have to develop.

In our scientific community those technologies are quickly being developed, but we have to implement them onto the moorings and floats and ships, and that takes some effort to do the testing to do that. That is something we have to do right now.

Mr. BAIRD. We should push for that in some way to give us much more information.

Dr. FEELY. Absolutely. So one of our recommendations is to point out very clearly that we need the development of the carbon measurements in this bill, and the carbon measurements are what is causing this problem.

Dr. CALDEIRA. One of the reasons this research is expensive is because ships are expensive, and the more you can invest in developing measurement tools that can be put out on unmanned drifters or gliders, the more you can reduce the long-term costs of this research effort.

Mr. BAIRD. I don't have, I have thousands of further questions. In the interest of the panel I won't ask them here.

I want to also, if I may, just personally, I know there are other experts in the audience here who have a lot of expertise on this. I personally would welcome if anyone wants to, in addition to the panel, wants to direct suggestions to us about ways that this legislation or some legislation could be improved, what we ought to do, because I want to move on this post haste, and I am very grateful, Mr. Chairman, for your leadership and for our colleagues.

Thanks again to the witnesses.

Chairman LAMPSON. Thank you, Mr. Baird.

It is a fascinating discussion, and obviously there is an awful lot of work that has to be done, and it would be great when we can start hooking up any other sources of information and see how so many other things are related.

We have got a lot to learn, and just this, as Dr. Baird was just saying, we have got to rely on you experts. Maybe we know how to get something through the governmental process sometimes, but without the knowledge that you give to us we don't know what to put in those bills and in that language. So think about it and we would always welcome the opportunity to have your input. We together are in this boat. It is not us. We are not the leaders. You all are the leaders. We are the followers. We will do our best to follow what you are trying to tell us.

So I thank all of you for appearing today at this hearing. And under the rules of the Committee the record will be held open for two weeks for Members to submit additional statements and any additional questions that they might have for the witnesses.

This hearing is now adjourned.

[Whereupon, at 11:47 a.m., the Subcommittee was adjourned.]

Appendix:

ADDITIONAL MATERIAL FOR THE RECORD

H.R. 4174: The Federal Ocean Acidification Research and Monitoring Act

SECTION-BY-SECTION ANALYSIS

Section 1. Short Title and Table of Contents

Provides the short title of the legislation: The Federal Ocean Acidification Research and Monitoring Act of 2007.

Section 2. Findings and Purposes

Designates the purposes of the legislation: to provide for development of an interagency monitoring and research plan; establishment of an ocean acidification program at NOAA; assessment of the impacts of ocean acidification; and research on adaptation strategies.

Section 3. Interagency Committee on Ocean Acidification

Establishes an interagency committee on ocean acidification chaired by NOAA and designates the membership of the committee to include representatives from the National Science Foundation, the National Aeronautics and Space Administration, the U.S. Geological Survey, U.S. Fish and Wildlife Service, the Environmental Protection Agency, the Department of Energy and other federal agencies. The section directs the committee to oversee the development of a plan to be submitted to Congress to coordinate federal efforts to understand ocean acidification and its potential impacts on marine ecosystems and to develop adaptive strategies to conserve marine organisms and marine ecosystems. Requires a report to Congress within two years of enactment and every three years thereafter of the progress of research and monitoring activities and recommendations for addressing impacts of ocean acidification.

Section 4. Strategic Research and Implementation Plan

Directs the Committee to develop a strategic research and implementation plan for coordinated federal activities within 18 months of enactment. Establishes criteria and topics to be included in the interagency program and requires the plan to include goals, priorities, and guidelines for coordinated research over a 10-year period. Requires the Committee to consider and utilize other relevant reports and studies in developing the research plan.

Section 5. NOAA Ocean Acidification Program

Directs the Secretary to establish an ocean acidification program within NOAA to implement activities consistent with the strategic research and implementation plan. Requires the program to provide grants through a competitive, merit-based process.

Section 6. Definitions

Defines the terms Committee, Ocean Acidification, Program, and Secretary.

Section 7. Authorization of Appropriations

Authorizes appropriations that escalate each year beginning in fiscal year 2009 at a funding level of $6 million through fiscal year 2012 when the funding level reaches $30 million. The authorization is permanent at a level of $30 million thereafter. The section also directs the Secretary to distribute sixty percent of the funds to agencies other than NOAA to carry out the purposes of the Act and directs that at least fifty percent of all funds be used for competitive grants.

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110TH CONGRESS
1ST SESSION

H. R. 4174

To establish an interagency committee to develop an ocean acidification research and monitoring plan and to establish an ocean acidification program within the National Oceanic and Atmospheric Administration.

IN THE HOUSE OF REPRESENTATIVES

NOVEMBER 14, 2007

Mr. ALLEN (for himself, Mr. INSLEE, Mr. GILCHREST, Mr. BAIRD, Mr. EHLERS, Ms. BORDALLO, Mr. HOLT, Mr. OLVER, Mr. DELAHUNT, Mr. KLEIN of Florida, Mr. RUPPERSBERGER, and Mrs. CHRISTENSEN) introduced the following bill; which was referred to the Committee on Science and Technology

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A BILL

To establish an interagency committee to develop an ocean acidification research and monitoring plan and to establish an ocean acidification program within the National Oceanic and Atmospheric Administration.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE; TABLE OF CONTENTS.

(a) SHORT TITLE.—This Act may be cited as the "Federal Ocean Acidification Research And Monitoring Act of 2007" or the "FOARAM Act".

(b) TABLE OF CONTENTS.—The table of contents for this Act is as follows:

SEC. 2. FINDINGS AND PURPOSES.

(a) FINDINGS.—The Congress finds the following:

(1) The oceans help mitigate the effects of global warming by absorbing atmospheric carbon dioxide. About a third of anthropogenic carbon dioxide is currently absorbed by the ocean.

(2) The rapid increase in atmospheric carbon dioxide due to human induced carbon dioxide emissions is overwhelming the natural ability of the oceans to cope with this increase.

(3) The emission of carbon dioxide into the atmosphere is changing surface ocean carbon chemistry and lowering the pH. These changes in ocean chemistry are detrimental to organisms including corals, which support one of the richest habitats on Earth, marine shells, and many other organisms that form the base of the food chain for many fish and marine mammals.

(4) The rich biodiversity of marine organisms is an important contribution to the national economy

and the change in ocean chemistry threatens tourism, our fisheries, and marine environmental quality, and could result in significant social and economic costs.

(5) Existing Federal programs support research in related ocean chemistry, but gaps in funding, coordination, and outreach have impeded national progress in addressing ocean acidification.

(6) National investment in a coordinated program of research and monitoring would improve the understanding of ocean acidification effects on whole ecosystems, advance our knowledge of the socioeconomic impacts of increased ocean acidification, and strengthen the ability of marine resource managers to assess and prepare for the harmful impacts of ocean acidification on our marine resources.

(b) PURPOSES.—The purposes of this Act are to provide for—

(1) development and coordination of a comprehensive interagency plan to monitor and conduct research on the processes and consequences of ocean acidification on marine organisms and ecosystems and to establish an ocean acidification program within the National Oceanic and Atmospheric Administration;

(2) assessment and consideration of regional and national ecosystem and socioeconomic impacts of increased ocean acidification, and integration into marine resource decisions; and

(3) research on adaptation strategies and techniques for effectively conserving marine ecosystems as they cope with increased ocean acidification.

SEC. 3. INTERAGENCY COMMITTEE ON OCEAN ACIDIFICATION.

(a) ESTABLISHMENT.—

(1) IN GENERAL.—There is hereby established an Interagency Committee on Ocean Acidification.

(2) MEMBERSHIP.—The Committee shall be comprised of senior representatives from the National Oceanic and Atmospheric Administration, the National Science Foundation, the National Aeronautics and Space Administration, the United States Geological Survey, the United States Fish and Wildlife Service, the Environmental Protection Agency, the Department of Energy, and such other Federal agencies as the Secretary considers appropriate.

(3) CHAIRMAN.—The Committee shall be chaired by the representative from the National Oceanic and Atmospheric Administration. The chairman may create subcommittees chaired by any member

agency of the committee. Working groups may be formed by the full Committee to address issues that may require more specialized expertise than is provided by existing subcommittees, or to receive advice, input, or comments from the academic community and other relevant stakeholders.

(b) PURPOSE.—The Committee shall oversee the planning, establishment, and coordination of a plan designed to improve the understanding of the role of increased ocean acidification on marine ecosystems and to identify and develop through research adaptation strategies and techniques to effectively conserve marine ecosystems as they cope with increased ocean acidification.

(c) REPORTS TO CONGRESS.—

(1) STRATEGIC RESEARCH AND IMPLEMENTATION PLAN.—The Committee shall submit the strategic research and implementation plan established under section 4 to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science and Technology of the House of Representatives not later than 18 months after the date of enactment of this Act.

(2) TRIENNIAL REPORT.—Not later than 2 years after the date of the enactment of this Act and every 3 years thereafter, the Committee shall trans-

mit a report to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science and Technology of the House of Representatives that includes—

(A) a summary of federally funded ocean acidification research and monitoring activities, including the budget for each of these activities; and

(B) an analysis of the progress made toward achieving the goals and priorities for the interagency research plan developed by the Committee under section 4 and recommendations for future activities, including policy recommendations developed as part of this research.

SEC. 4. STRATEGIC RESEARCH AND IMPLEMENTATION PLAN.

(a) IN GENERAL.—Within 18 months after the date of enactment of this Act, the Committee shall develop a strategic research and implementation plan for coordinated Federal activities. In developing the plan, the Committee shall consider and use reports and studies conducted by Federal agencies and departments, the National Research Council, the Ocean Research and Resources Advisory Panel, the Joint Subcommittee on Ocean, Science, and Technology and the Climate Change Science Program of the National Science and Technology Council, the Joint Ocean Commission Initiative, and other expert scientific bodies.

(b) SCOPE.—The plan shall—

(1) provide for interdisciplinary research among the ocean sciences, and coordinated research and activities to improve understanding of ocean acidification that will affect marine ecosystems and to assess the potential and realized socioeconomic impact of ocean acidification, including—

(A) effects of atmospheric carbon dioxide on ocean chemistry;

(B) biological impacts of ocean acidification, including research on—

(i) commercially and recreationally important species;

(ii) protected or endangered or threatened species;

(iii) ecologically important calcifiers that lie at the base of the food chain; and

(iv) physiological consequences of ocean acidification for ocean-dwelling organisms;

(C) identification and assessment of ecosystems most at risk from projected changes in ocean chemistry including—

(i) coastal ecosystems, including coral reef ecosystems;

(ii) deep sea coral ecosystems; and

(iii) polar and subpolar ecosystems;

(D) modeling the effects of changing carbon system chemistry, including ecosystem forecasting;

(E) identifying feedback mechanisms resulting from ocean chemistry changes and decreases in calcification rates of organisms;

(F) socioeconomic impacts of ocean acidification; and

(G) identifying interactions between ocean acidification and other oceanic changes associated with climate change, including changes in sea temperature, ocean circulation, terrestrial runoff, and other changes;

(2) establish, for the 10-year period beginning in the year it is submitted, goals, priorities, and guidelines for coordinated research activities that will—

(A) most effectively advance scientific understanding of the characteristics and impacts of ocean acidification;

(B) provide forecasts of ocean acidification and the consequent impacts on marine ecosystems; and

(C) provide research that could serve as a basis for policy decisions to reduce and manage ocean acidification and its environmental impacts;

(3) provide an estimate of Federal funding requirements for research and monitoring activities; and

(4) identify and strengthen relevant programs and activities of the Federal agencies and departments that would contribute to accomplishing the goals of the plan and prevent unnecessary duplication of efforts, including making recommendations for the use of observing systems and technological research and development.

SEC. 5. NOAA OCEAN ACIDIFICATION PROGRAM.

(a) IN GENERAL.—The Secretary shall establish and maintain an ocean acidification program within the National Oceanic and Atmospheric Administration to implement activities consistent with the strategic research and implementation plan developed by the Committee under section 4 that—

(1) includes—

(A) interdisciplinary research among the ocean and atmospheric sciences, and coordinated research and activities to improve understanding of ocean acidification;

(B) the establishment of a long-term monitoring program of ocean acidification utilizing existing global and national ocean observing assets, and adding instrumentation and sampling stations as appropriate to the aims of the research program;

(C) research to identify and develop adaptation strategies and techniques for effectively conserving marine ecosystems as they cope with increased ocean acidification;

(D) as an integral part of the research programs described in this Act, educational opportunities that encourage an interdisciplinary and international approach to exploring the impacts of ocean acidification;

(E) as an integral part of the research programs described in this Act, national public outreach activities to improve the understanding of current scientific knowledge of ocean acidification and its impacts on marine resources; and

(F) coordination of ocean acidification monitoring and impacts research with other appropriate international ocean science bodies such as the International Oceanographic Commission, the International Council for the Exploration of the Sea, the North Pacific Marine Science Organization, and others;

(2) provides grants for critical research projects that explore the effects of ocean acidification on ecosystems and the socioeconomic impacts of increased ocean acidification that are relevant to the goals and priorities of the strategic research plan; and

(3) incorporates a competitive merit-based grant process that may be conducted jointly with other participating agencies or under the National Oceanographic Partnership Program under section 7901 of title 10, United States Code.

(b) ADDITIONAL AUTHORITY.—In conducting the Program, the Secretary may enter into and perform such contracts, leases, grants, or cooperative agreements as may be necessary to carry out the purposes of this Act on such terms as the Secretary deems appropriate.

SEC. 6. DEFINITIONS.

In this Act:

(1) COMMITTEE.—The term "Committee" means the Interagency Committee on Ocean Acidification established by section 3(a).

(2) OCEAN ACIDIFICATION.—The term "ocean acidification" means the decrease in pH of the Earth's oceans caused by chemical inputs from the atmosphere, including anthropogenic carbon dioxide.

(3) PROGRAM.—The term "Program" means the National Oceanic and Atmospheric Administration Ocean Acidification Program established under section 5.

(4) SECRETARY.—The term "Secretary" means the Secretary of Commerce, acting through the Administrator of the National Oceanic and Atmospheric Administration.

SEC. 7. AUTHORIZATION OF APPROPRIATIONS.

(a) IN GENERAL.—There are authorized to be appropriated to the National Oceanic and Atmospheric Administration to carry out the purposes of this Act—

(1) $6,000,000 for fiscal year 2009;

(2) $8,000,000 for fiscal year 2010;

(3) $11,000,000 for fiscal year 2011; and

(4) $30,000,000 for fiscal year 2012 and each fiscal year thereafter.

(b) ALLOCATION.—

(1) Of the amounts made available to carry out this Act for a fiscal year, the Secretary shall allocate at least 60 percent to other departments and agencies to carry out the priorities of the plan developed by the Committee.

(2) Of the amounts made available to carry out this Act for any fiscal year, the Secretary, and other departments and agencies to which amounts are allocated under paragraph (1), shall allocate at least 50 percent for competitive grants.

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