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THE ENVIRONMENTAL AND ECONOMIC IMPACTS OF OCEAN ACIDIFICATION

HEARING

BEFORE THE

SUBCOMMITTEE ON OCEANS, ATMOSPHERE, FISHERIES, AND COAST GUARD

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED ELEVENTH CONGRESS

SECOND SESSION

APRIL 22, 2010

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

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THE ENVIRONMENTAL AND ECONOMIC IMPACTS OF OCEAN ACIDIFICATION

THURSDAY, APRIL 22, 2010

U.S. SENATE,
SUBCOMMITTEE ON OCEANS, ATMOSPHERE, FISHERIES, AND COAST GUARD,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Subcommittee met, pursuant to notice, at 10:02 a.m. in room SR–253, Russell Senate Office Building, Hon. Maria Cantwell, Chairman of the Subcommittee, presiding.

OPENING STATEMENT OF HON. MARIA CANTWELL, U.S. SENATOR FROM WASHINGTON

Senator CANTWELL. The Senate Committee on Commerce, Science and Transportation, Subcommittee on Oceans and Atmosphere and Fisheries, Coast Guard, will come to order.

Today, we're having a hearing on the environmental and economic impacts of ocean acidification. And welcome, to our panelists here. We appreciate them testifying before us today, and we will introduce them shortly.

We live on a blue planet. And on this day, the 40th anniversary of Earth Day, it's no coincident that we are focusing our attention on our oceans. They are 70 percent of the Earth's surface and provide a foundation for all of life.

And yet, there is a grave threat that lies hidden beneath the surface, called "ocean acidification." And since the start of the Industrial Revolution, humans have increased the global atmospheric carbon dioxide concentration by 35 percent. But, carbon dioxide is not only accumulating in our atmosphere, it is being absorbed by our oceans. Approximately one-quarter of our global carbon dioxide emissions end up in oceans, and we know now that this is changing the very chemistry of our oceans. And while the full implications of these changes are unclear, the initial signs are frightening.

As sea water becomes more acidic, it begins to withhold the basic chemical building blocks needed by marine organisms. Scientists predict that a more acidic ocean could dissolve the shells of tiny organisms that make up the base of the ocean's food chain. And when it comes to ocean acidification, we are not just damaging the ocean's ecosystem, we are threatening its very foundation.

And even though these changes are occurring out of sight and below the surface of the ocean, we are starting to see some of the very worrying signs. And that's what this hearing today is to discuss.

In May 2008, I held a field hearing, in Seattle, of this subcommittee to examine the impacts of ocean acidification and climate change on Washington State's marine environment. The most vivid testimony came from one of my constituents, a fifth-generation shellfish farmer named Brett Bishop.

Mr. Bishop's family shellfish farm is on the Little Scookum Bay in Mason County. His parents live next door, and his two teenaged sons are the sixth generation to live on that homestead and grow clams and oysters. And over the past several years, ocean acidification decimated the source of oyster by dissolving the larvae shells and increasing the susceptibility to dangerous marine bacteria.

Damaged natural reproduction, coupled with failing oyster hatcheries, is threatening the entire shellfish industry in the Pacific Northwest. Generations of Brett Bishop's family have invested everything they have into their family farm, growing shellfish for 126 years. And if ocean acidification prevents the Bishop family from growing shellfish, they will lose their farm, their home, and six generations of hard work, hopes, and dreams.

Today, I received a letter from the shellfish growers, commercial fishermen, seafood industry representatives from across the United States, requesting that Congress work to mitigate the cause and reduction—the economic harm resulting from ocean acidification. I want to read just a paragraph from that letter, because I think it sums up today's hearing, quote, "While some organisms are likely to be more adaptive than others to high CO_2 oceans, seafood producers and consumers cannot afford to whistle in the dark about these changes. The U.S. seafood industry generates approximately 60 billion annually, fueling jobs and businesses that sustain thousands of families along the Gulf, Atlantic, Pacific and ocean—and Alaskan Coast. Even for the fisheries, where no direct harm from acidification has yet been documented, the disturbing signs of trouble on the front lines reveal a very compelling case to prevent the impacts from spreading and growing more severe."

Stories like the Bishop family and this letter is why we called this hearing today, so this subcommittee can look at the threats, challenges, and questions posed by ocean acidification to our coastal communities, to the businesses and the people who rely on these healthy systems.

It is also why this committee worked so hard to enact legislation Senator Lautenberg—Federal—in his Federal Ocean Acidification Research and Monitoring Act, which I was proud to cosponsor; that law established the Nation's first comprehensive program to specifically study ocean acidification.

And there he is, on cue.

[Laughter.]

Senator CANTWELL. We're glad to see you.

Ocean acidification is real, and there is a clear link between our society's carbons emission and the resulting change in the ocean's chemistry. Fortunately, we can slow down this process by ending our dangerous over-reliance on fossil fuel and transitioning to a cleaner, more diverse energy source. This effort has been one of my top priorities, and I will continue to fight to craft responsible, effective, bipartisan legislation to move us forward.

Doing so is not only vital for our oceans and our environment, but for people like Brett Bishop and some of our witnesses who are here today, Mr. Waters and Mr. Ingram, but also for our Nation's long-term economy and our sustainability.

So, again, I would like to thank the witnesses for being here, and like to turn it over to the Ranking Member, Senator Snowe, to make an opening statement.

STATEMENT OF HON. OLYMPIA J. SNOWE, U.S. SENATOR FROM MAINE

Senator SNOWE. Thank you, Madam Chair, for calling this hearing today.

It's only appropriate that we would be convening this hearing today on the 40th anniversary of Earth Day, to discuss perhaps the greatest threat facing our planet's oceans. If current trend of ocean acidification continues, by the end of this century vast areas of the sea could very well become inhospitable to many species which form the foundation of the marine food web.

Our oceans, which make up 70 percent of the planet's surface, are far too often overlooked, and as a source of the very building blocks of life, we cannot risk placing them in jeopardy.

That's why I'm very pleased today to be able to welcome our witnesses. Dr. Barry and Dr. Everett, your efforts to identify, to monitor, and to predict the trend of ocean acidification will be integral to protecting the marine environment, and the businesses that will be directly affected, like those represented here today.

Mr. Waters and Mr. Ingram, your work in the industry drives our coastal economy, and you're on the front lines of the battle to protect our ocean resources.

And, Ms. Weaver, thank you for being here and for adding your eloquent voice and your presence in working as an ocean advocate and narrator of the stunning piece that we'll have the opportunity to see a portion of here today, in the documentary, "The Acid Test: The Global Challenges of Ocean Acidification." This will continue to raise the public profile of this issue. It's vital that we not only garner the public's attention, but also galvanize public action, both here and across this country, and, indeed, around the world. So, thank you for your contribution and being such a champion.

In just a few short years, ocean acidification has developed from a relatively new theory into one of the most disconcerting aspects of global climate change. In 2005, when the U.S. Commission on Ocean Policy submitted its final report to Congress—it just seems like yesterday—the term "acidification" did not appear in the 676-page document. And yet, today we're holding the second subcommittee hearing on this topic since May of 2007.

In the past 250 years, atmospheric and oceanic carbon concentrations have increased by 40 percent, and the pH of our oceans has decreased by roughly 30 percent, a rate of change not seen in more than 800,000 years, and that was underscored in the National Research Council's publication, which was released this week. That report, coauthored by Dr. Barry, on ocean acidification, confirms the current state of knowledge about this issue and delineates the areas requiring additional information. In effect, this document provides a litany of things we still don't know: how individuals and species will react to acidification in conjunction with other environmental stressors, the potential for adaptation and acclimation to lower pH levels, and the socioeconomic fallout that we will experience.

Clearly, following through with this work, which has been outlined in the NRC's report, will be vital to the future of our coastal economies, as I'm sure Mr. Waters and Mr. Ingram will attest. And what affects our coastal economy drives our national economy; in fact, more than 75 percent of the growth in this country between 1997 and 2007 was in coastal states, whether measured by population, jobs, or GDP. Every year, the ocean-dependent economy, comprised of tourism, fishing, and other marine industrial activities, generated more than $138 billion in revenues, including $70 billion from tourism alone.

As ocean acidification weakens coral reef structures that protect many of our southern shores, we also risk losing a vital buffer against coastal storm surges, leaving these regions increasingly vulnerable.

In my home State of Maine, our shellfish industry, led by the iconic Maine lobster industry, represents more than 80 percent of our landings totalling over $250 million, in fact, in 2008. To date, the brunt of the effects of acidification has been outlined very eloquently by the Chair regarding the Pacific Northwest. So, it remains unclear what increasingly acidic oceans will mean for New England's fishermen. Some reports have shown that lower pH levels can result in lower shellfish reproductive rates and decrease shell thickness, leading to greater vulnerability to predators. However, in some species, such as lobster, shell growth can actually speed up. The point is, we don't know.

Regardless of what the final results will be, we simply cannot leave the future of our oceans and their valuable resources to chance. That's why I joined the Chair in cosponsoring legislation offered by Senator Lautenberg that, fortunately, became law in 2009, to create a program within NOAA to study ocean acidification. I also joined in sending a letter to the NOAA Administrator, Dr. Jane Lubchenco, in her appearance at Copenhagen asking her to prioritize, not only climate change, but also the issue of ocean acidification.

As we know, the conference did not, ultimately, produce a consensus on climate change; acidification was a prominent topic. The world is beginning to acknowledge this looming catastrophe, and our obligation to act quickly and decisively to manage it. To do that, we must enhance our research capabilities, including a greater commitment to the Integrated Ocean Observing System. I sometimes sound like a broken record on this issue.

At this subcommittee's hearing in 2007 on ocean acidification, all six of the witnesses underscored the view that the ocean observing systems are integral to boosting our ability to monitor this problem.

I introduced legislation that was enacted along with the Ocean Acidification Act, paving the way for enhancement of this vital tool. Unfortunately, NOAA has failed to adequately support the implementation. For 2011, the agency has requested just $21 million for this program, more than $12 million less in the previous year, and less than half of the $53 million that has been requested by the National Federation of Regional Associations that estimates the regional components of the system required in order to function properly. The NRC report, released today, lists an ocean-observing network as its first recommendation, and rightfully so, further reinforcing the imperative to sustain and enhance this system.

As we'll hear from our witnesses today, the implications of ocean acidification are still being researched, but the basic equation is simple: acidification makes it more difficult for shell-building organisms to survive. This leaves less food for larger fish that we catch and eat. It leaves fewer corals to serve as fish nurseries, act as storm buffers, and to inspire visitors, as vibrant reminders of the diversity and the complexity of marine life. Follow this trend to its logical conclusion, and the cost of inaction is too great to contemplate.

So, again, Madam Chair, thank you for holding this hearing today, and thank you all for being here.

Senator CANTWELL. Thank you. And I want to give my colleagues, who have been leaders, Senator Boxer and Senator Lautenberg, a chance to make opening statements, and then we'll turn to the witnesses, as well.

And I want to just thank Senator Boxer for her leadership as Chairman of the EPW Committee—and has been an advocate of oceans policies, passed many bills through this committee. And so, we appreciate her being here today.

STATEMENT OF HON. BARBARA BOXER, U.S. SENATOR FROM CALIFORNIA

Senator BOXER. Well, I want to thank you, Madam Chairman and Ranking Member Snowe. Senators Lautenberg, and I know we've been joined by Senator Nelson.

You know, all of us see this in a very similar light. We have to act. And it's very fitting that, on this day, Earth Day, we're discussing ocean acidification. Because I believe it is one of the biggest threats facing our oceans.

I want to thank our panel, each and every one of you, for coming forward.

About a third of the carbon dioxide we've emitted into the atmosphere has been drawn down into the ocean. The climate change our planet is experiencing would be even more severe without this important process. The ocean is a very large carbon sink, and it is now showing the stress and the strain of that.

Adding so much carbon dioxide to the ocean has caused its pH to decrease by a tenth of a unit since the beginning of the Industrial Revolution, and that is what ocean acidification is. When you add carbon dioxide to water, it makes calcium carbonate minerals that dissolve more easily, and that threatens species whose shells or skeletons contain these materials, such as the corals, commercially imported shellfish, like mussels, clams, and oysters, and some microscopic algae that form the basis of the entire marine food web.

Earlier this morning, I did a little experiment. I was thinking of doing it out here, but I thought that this—"This belongs in the science lab." But, I did a little experiment.

We had a jar of plain water, and we had a jar of sparkling water, which has carbon dioxide added to it, and we took two pieces of chalk and—those are basically calcium carbonate—and we dropped one into each glass. And when you drop the chalk into the still water, nothing happened. It just—the chalk sat there. But, immediately upon dropping it into the carbonated—the carbon dioxide water, you saw, immediately—immediately, the chalk began to dissolve. And it's a very simple, well- known chemical reaction, but it has complex impacts on our marine ecosystems.

And I won't reiterate what Senator Snowe said about the economic impact of losing this very special and precious environment. My estimates are, from my staff, that if you take "the rainforests of the sea," as we call them, and you look at the tourist attraction they are, and you look at everything else that goes along with it, you're looking at a global economy of fishery resources and tourism of $375 billion. Imagine. And the devastation would be enormous, in so many ways, if we lose this environment.

I won't go into my support of Frank's—Lautenberg—Senator Lautenberg's legislation. I was proud to do that, as well. We all are working to make sure that we have this research done.

But, I want to give you my opinion, and it may be worth something to somebody, and that is that unless we have a climate change bill, we're going to whistle past the graveyard, because this is—we're talking about a carbon sink. This is the problem. The carbon is going into the ocean, so much of it.

And so, I hope, and even pray, yes, that, here in the Senate, we will have the breakthrough with the bipartisan efforts—I would say tripartisan—an Independent, a Republican, and a Democrat—the Kerry-Lieberman-Graham bill, and I'm working with them, and hope it will a good bill. And if we can make that breakthrough, we're going to turn this around. And I just am so committed to that and hope that my colleagues will move forward, because we can study this, and we must, and we should. But, we know the oceans are a carbon sink. So, the obvious thing to do is just cut down on the amount of carbon we're putting into the atmosphere. It's simple. It's not simple to pass the bill, I understand. But it—we know what we have to do.

And I just want to say to my colleagues on this committee, on both sides of the aisle, what leaders they have been on the environment. And it gives me a lot of solace, to know that they're here, looking at these issues. At the end of the day, we have to be bold, and we have to address this.

I just want to say to Ms. Weaver, you know, I—representing the State of California, we have so many very, very famous stars, and we have famous directors, and we have—a lot of fame.

[Laughter.]

Senator BOXER. And I so appreciate when people with that aura come forward, because what you do—first, you give up a little bit of your privacy, and I know that's hard. But, what you do is, you gain attention to the issue that—a lot of us try to gain attention to it. We get a little bit, but we really can't hold a candle to the attention that you will get by your testimony here. And, obviously, your work in the movies—and Jim Cameron and all the rest. So, I want to thank you from the bottom of my heart for that.

And I would yield back to the Chair or the Ranking Member.
[The prepared statement of Senator Boxer follows:]

PREPARED STATEMENT OF HON. BARBARA BOXER, U.S. SENATOR FROM CALIFORNIA

Thank you, Madam Chairman, for holding this hearing—fittingly, on Earth Day—to discuss ocean acidification. This is one of the biggest threats facing our oceans.

About one-third of the carbon dioxide we have emitted into the atmosphere has been drawn down into the ocean. The climate change our planet is experiencing would be even more severe without this important process.

Unfortunately, as reported by the National Research Council today, adding so much carbon dioxide to the ocean has caused its pH to decrease by a tenth of a unit since the beginning of the industrial revolution, a process called ocean acidification.

When you add carbon dioxide to water, it makes calcium carbonate minerals dissolve more easily, threatening species whose shells or skeletons contain these minerals—such as corals, commercially-important shellfish like mussels, clams, and oysters, and some microscopic algae that form the basis of the entire marine food web.

The economic consequences of ocean acidification could be enormous. The ocean economy generates $230 billion in economic activity and 3.6 million jobs nationwide, with more than half of those revenues and two-thirds of those jobs coming from ocean tourism, recreation, and fishing. Coral reefs, which have been called "rainforests of the sea," provide an estimated $375 billion per year in economic activity, while covering less than 1 percent of the Earth's surface. Imagine the economic devastation if we lose these important resources.

Much is still unknown about exactly how ocean acidification will affect marine ecosystems, and this is a top priority for ocean research. That's why I proudly cosponsored the Federal Ocean Acidification Research and Monitoring Act, which was signed into law in March 2009. This legislation established a coordinated Federal research and monitoring program on ocean acidification.

While we continue to study the impacts of ocean acidification, we also need to reduce our emissions of carbon dioxide that are changing global climate and ocean chemistry—which is why moving clean energy legislation has been one of my top priorities as Chairman of the Environment and Public Works Committee.

I look forward to hearing from our panelists about the latest information on ocean acidification, and will continue to work with my colleagues in Congress to address this important issue.

Senator SNOWE. Thank you very much, Senator Boxer.
Senator Lautenberg.

STATEMENT OF HON. FRANK R. LAUTENBERG, U.S. SENATOR FROM NEW JERSEY

Senator LAUTENBERG. Thank you, Madam Chairman. And my colleagues, I think, amply laid out the problem. Around here, everything may have been said, but everybody hasn't said it. So, we'll take our——

[Laughter.]

Senator LAUTENBERG. And, Ms. Weaver, thanks for your help. The last time I saw you, you weren't looking back at me, but you were in outer space, and it was quite something. And, at that time, I also had hair. So, we've had——

[Laughter.]

Senator LAUTENBERG.—we've had changes.

Our oceans cover, as we know, 70 percent of the Earth's surface. In my home State, New Jersey, though small in size, we have 127 miles of shoreline, and we're terribly—extremely dependent on our coast to energize our economy, create jobs, and support families. In fact, our coast is a $50-billion-a-year economic powerhouse that's responsible for one out of every six jobs in the State of New Jersey. Whether it's fishermen, hotel workers, shop owners, our state depends on this natural resource; so does our country. Our oceans generate more income for our economy, the U.S. economy, than the entire agricultural sector. And despite that, our oceans are under assault—water pollution, climate change, offshore drilling—all pose severe threat to their future. But, it doesn't end there, and the ocean acidification is a problem that is intensifying, as we've heard.

About one-third of all carbon dioxide pollution that we release into the air is absorbed by the Earth's oceans, making the oceans more acidic. This increase in acidity threatens to decimate entire species, including those that are at the foundation of our marine food chains. If that occurs, the consequences are devastating.

And when I look at my grandchildren—and that's my motivator—and I think about what life might be like in 20 or 30 years, it's not a pleasant prospect. And I'm going to do whatever I can to fight against it.

Imagine what the collapse of the food chain would mean to commercial fishing, tourism, and coastal communities. And that's why I wrote the Federal Ocean Acidification Research and Monitoring Act. It became law last year, and coordinates all Federal research on this serious threat.

And, once again, Sigourney, your help—immense on being—in getting that law passed, and I'm equally grateful to you. We all should be.

The President's budget funds this new law for the first time, and it includes more than $11 million to assess the effects of the ocean acidification. It's a good start, but I have questions about whether it's enough.

And now, even as we zero in on the effects of ocean acidification, we also have to address the causes, as Senator Boxer said. We cannot sit on our hands while carbon pollution continues to spew from trucks, cars, power plants. And that's why we've got to pass an effective climate change bill that's going to cut global—the global warming pollution and spark a new clean energy economy.

Putting limits on carbon pollution will not only protect our vibrant coastal economies, it's going to create manufacturing jobs, clean up the air that our children breathe, and reduce our dependence on dirty, unsafe fuels.

And I thank all of you for being here, for your willingness to testify. And it's even possible we might have a disagreement, but welcome.

Thank you.

Senator SNOWE. Thank you very much, Senator Lautenberg, I appreciate it.

Before we hear from our panel of witnesses, I'd like to play a short video produced by the Natural Resources Defense Council.

We thank you very much for creating this documentary that I think sends a very powerful message about the challenge that we're facing with respect to our oceans.

Now we'll see if the technology works.

[Video presentation.]

Senator SNOWE. Well, it's clear that that portion of the video, I think, again underscores and powerfully portrays the challenge that we face and must confront.

So, again, I thank all of you for joining us today, and now I'd like to introduce our panel for their testimony.

Ms. Sigourney Weaver, Actress, narrator of "The Acid Test: The Global Challenge of Ocean Acidification"; Dr. James Barry, Senior Scientist,, Monterey Bay Aquarium Research Institute; Mr. Donny Waters, Commercial Fisherman from the Gulf of Mexico; Mr. Tom Ingram, Executive Director, Diving Equipment and Marketing Association; Dr. John Everett, President, Ocean Associates, Incorporated.

Ms. Weaver, we'll begin with you.

STATEMENT OF SIGOURNEY WEAVER, ACTRESS

Ms. WEAVER. Red light—oh, testing, testing.

[Laughter.]

Ms. WEAVER. OK, thank you.

[Laughter.]

Ms. WEAVER. Hi. My name is Sigourney Weaver, and I am honored to appear before you today, the 40th anniversary of Earth Day, as we've all said, to testify about ocean acidification. I am not here as a science—a scientific or a policy expert, but as a concerned American and as an Earthling.

[Laughter.]

Ms. WEAVER. My father was a Navy man. His one requirement as we grew up was that he always had to be in sight of a body of saltwater. So, I had the great advantage of growing up next to the sea and listening to foghorns at night and being chased by horseshoe crabs by day. And I think, like a lot of us, I thought of the oceans as these vast, infinite places, certainly infinitely forgiving, in terms of whatever we were doing to them or throwing into them. And now, of course, we know that this is not the case.

One of the things I love about the ocean is the mystery of marine life. The oceans contain so much life and variety, as you've just seen, and a lot of it is hidden from our sight. A lot of it is, if you'll excuse the pun, alien to us. And this makes the process of learning about the oceans, and what lives in them, an unending series of surprises and discoveries, because the oceans are so full of organisms that are unlike anything we know on land, that sometimes their very existence seems impossible. For instance, there are life forms that don't even need light or food to survive. They consume chemicals, like hydrogen sulfide, that bubble up from deep sea vents.

And these same features that make the ocean so wonderful, their mystery and their otherworldliness, have actually worked to the oceans' disadvantage now, because for many of us, the oceans are sort of out of sight and out of mind, and we take them for granted. Their inaccessibility has limited our scientific exploration, and their vastness and power have made them seem indestructible, with endlessly renewing resources. So, we tend to forget the oceans are finite and vulnerable, and that we all depend on them for our survival, and for our completeness, regardless of where we live or what we eat.

The oceans generate most of our oxygen, they regulate our climate, they provide most of our population with sustenance. We cannot prosper unless the oceans prosper, too. And the oceans are not prospering.

Unfortunately, one secret that the oceans have kept very well is their sensitivity to carbon dioxide pollution. Scientists have known for decades that when CO_2 mixes with ocean water, it creates carbonic acid; but only recently did we begin to realize that this growing quantity of carbonic acid—what that would mean for ocean life. And, you know, as you have seen in "Acid Test," this new understanding has many of the world's leading scientists deeply concerned.

So, what they say is that the oceans are 30 percent more acidic today than they were during pre-industrial times, and if we continue burning fossil fuels as we are now, we will actually double the ocean's acidity by the end of this century. And scientists believe that many organisms may not survive so radical a shift in chemistry. Some of those organisms, certain plankton and corals, for instance, which form the foundation of ocean food webs, if they perish—and they are already suffering; we have scientific data that is indisputable—what happens to the hundreds of thousands of species further up the food chain? What happens, then, to our shellfish, our oysters, clams, and mussels that appear particularly vulnerable to ocean acidification?

Now, despite scientists' concern, this phenomenon of ocean acidification was, until very recently, little known to the public, certainly not known to myself. And that is the reason "Acid Test" was made, and certainly the reason I joined the project, which Natural Resources Defense Council, an organization whose work I have long admired, called and said, "Will you participate in this?"

Now, despite the seriousness of this threat from ocean acidification, there is cause for hope. And my hope, one that's shared by millions of Americans, is that you, our legislators, will put aside your differences and enact climate and energy legislation that will move America to a clean energy economy, an economy based on efficiency and renewable power that will build a workable future for all living things.

In addition, lawmakers must help ocean ecosystems adapt to the changes brought about by a warming climate and acidifying oceans. To make the oceans more resilient to these changes, we need to do a better job of keeping oceans healthy. That means restoring depleted fish populations, protecting important marine and coastal habitats, and reducing pollution, particularly nutrient pollution, in the coastal zones.

Finally, it is critical in—critically important that our Nation invest in research that will help us all better understand the implications of ocean acidification, because we're only now beginning to understand the changes that occur in an increasingly acidic ocean world.

Having been in the movie "Avatar," I know how passionately people feel all over this country, and all over the world; they want to preserve and protect our planet. This is particularly true in our country, I think. It's not considered a partisan issue for Americans. And we need your leadership, we need your courage, and we need your willingness to act.

The recent documentary series on our National Parks showed how, time after time, with the Grand Canyon and Yellowstone and the Adirondacks, it was our legislatures—legislators who had the foresight and courage to save us from our own lack of vision. The oceans are sending us a message, loud and clear: Dirty fossil fuels are killing them, and time is running out. We need you to listen and to lead.

Thank you for this opportunity.

[The prepared statement of Ms. Weaver follows:]

PREPARED STATEMENT OF SIGOURNEY WEAVER, ACTRESS

My name is Sigourney Weaver and I am honored to appear before you today, the 40th Anniversary of Earth Day, to testify about ocean acidification. I am here not as a scientific or policy expert, but as a concerned citizen.

My father was a Navy man and the one requirement he had as I was growing up, in terms of where we lived, is that we had to be within sight of a body of salt water at all times. So I grew up listening to foghorns at night and being chased by crabs by day. And I think like a lot of us, I thought of the oceans as infinite and vast, and certainly infinitely forgiving in terms of what we were doing to them. We now know, of course, that that is not the case.

What I love about our oceans is the *mystery* of marine life. The oceans contain so much life and variety and most of it is hidden from our sight. A lot of it is—if you'll pardon the pun—*alien* to us. And this makes the process of learning about the oceans and what lives in them an unending series of surprises, a constant discovery of treasures.

The ocean is full of organisms that are so unlike anything we know on land that their very existence seems impossible. For instance, there are life-forms that don't need light or what we'd think of as food to survive. They simply consume chemicals, such as hydrogen sulfide, that bubble up from deep sea vents.

These same features that make the ocean so wonderful—its mystery and other worldliness—have actually worked to the oceans' disadvantage, because for many of us, the oceans are out-of-sight and out-of-mind. Their inaccessibility has limited our scientific exploration, and their vastness and power have made them seem indestructible, with endlessly renewing resources.

So we tend to forget that the oceans are both finite and vulnerable, and that we all depend on them for our survival, regardless of where we live or what we eat.

Organisms in the oceans generate most of our oxygen, the oceans regulate our climate, and they provide a large portion of the world's population with sustenance. We cannot prosper unless the ocean prospers, too. And the oceans are not prospering.

Unfortunately, one secret the oceans have kept very well is their sensitivity to carbon dioxide pollution. Scientists have known for decades that when CO_2 mixes with ocean water it creates an acid; this is textbook chemistry. But only recently did they begin to realize what this growing quantity of acid would mean for ocean life. As you see in the film *Acid Test: The Global Challenge of Ocean Acidification*, this new understanding has some of the world's leading ocean scientists deeply concerned.

What they say is this: the oceans are 30 percent more acidic today than they were during pre-industrial times and, if we continue burning fossil fuels as we are now, we will *double* the ocean's acidity by the end of the century.

Now scientists fear many organisms may not survive so radical a shift in chemistry. And some of those organisms—certain plankton and corals, for instance—form the foundation of ocean food webs. If they perish, what happens to the tens of thousands of species further up the chain? What happens to our shellfish—our oysters, clams, mussels—that appear particularly vulnerable to ocean acidification?

Despite scientists' concern, the phenomenon of ocean acidification was, until very recently, little known to the public. That is the reason the film *Acid Test* was made. And it is the reason I joined the project when the Natural Resources Defense Council (NRDC), an organization whose work I have long admired, called.

Despite the seriousness of the threat from ocean acidification, there is still cause for hope. My hope, one shared by millions of Americans, is that you, our legislators, will put aside your differences and enact climate and energy legislation that will move America to a clean energy economy—an economy based on efficiency and renewable power—that will build a workable future for *all* living things.

In addition, lawmakers must help ocean ecosystems adapt to the changes brought about by a warming climate and acidifying oceans. To make the oceans more resilient to these changes, we need to do a better job of keeping the oceans healthy. That means restoring depleted fish populations, protecting important marine and coastal habitats and reducing pollution, including nutrient pollution, in the coastal zones.

Finally, it is critically important that our Nation invest in research that will help us better understand the implications of ocean acidification. We are only beginning to understand the changes that could occur in an increasingly acidic ocean world.

Thank you for the opportunity to share my testimony today.

Senator CANTWELL [presiding]. Thank you, Ms. Weaver. And let me add my thanks to you for your leadership on this issue. In Washington State, we have a statement, that environmentalists make great ancestors. And——

[Laughter.]

Ms. WEAVER. We hope.

Senator CANTWELL.—I think that your—I think that your stewardship is about helping us take care of the planet. So, thank you for being here on Earth Day and for——

Ms. WEAVER. Pleasure.

Senator CANTWELL.—your active effort in helping to explain this to the—to many people, who yet need to be convinced. So, thank you.

Mr. Ingram, we're going to turn to you and go right down the line of our panelists, and then we'll go to questions.

STATEMENT OF THOMAS INGRAM, EXECUTIVE DIRECTOR, DIVING EQUIPMENT AND MARKETING ASSOCIATION

Mr. INGRAM. OK, thank you very much.

Good morning, Chair Cantwell, Ranking Member Snowe, members of the Committee. I'm Tom Ingram, I am Executive Director of the Diving Equipment and Marketing Association, and I want to thank you for the opportunity to testify on the potential economic impacts of ocean acidification on the recreational scuba and snorkeling industries.

DEMA is a nonprofit trade association, we represent dive businesses worldwide. Our mission is to promote sustainable growth in safe recreational diving and snorkeling while protecting the underwater environment. So, we have a vested interest in what's going on here today.

My testimony today will focus on several areas: the dependence of the diving industry on a healthy marine environment, now and for the future; the overall economic value of recreational diving and snorkeling; how ocean acidification could impact diving-related businesses; and then DEMA's ability and desire to provide additional input as policies are considered and crafted.

You know, divers, perhaps more than many, are very aware of the need for a long-term sustainability of this resource; far more than others, perhaps, because we see it firsthand every time we go into the water. The health of the ocean directly and immediately impacts our business, and without an appropriate place to dive, there simply isn't a diving industry at all. Divers, and diving professionals for that matter, are stewards of the aquatic environment; they respect it, they want to protect it. And DEMA itself, as a representative of the industry, has been an advocate of appropriate legislation, where science and economics indicated the need.

In the past, we've advocated reauthorization of the National Marine Sanctuaries Act, we supported and commented on the creation of marine life protection areas, we drafted the 2008 Ships To Reefs legislation in Florida to take pressure off natural reefs by sinking retired ships as artificial reefs.

There are between 2.7 and 3.5 million active scuba divers in the U.S., and about 6 million active scuba divers worldwide. In that little chart that you all had up here earlier, we're about a sliver, that big, we're very tiny. But, every year, about 200,000 people become certified in the United States. And by some estimates more than a million people worldwide try diving under the direct supervision of a dive professional, without ever becoming certified. All of these groups are attracted to coral reefs, and all help support the diving business. Any loss of access to dive sites, or the destruction of coral reefs due to ocean acidification—or any other reason, for that matter—are going to impact our industry in a number of different ways.

Probably the most immediate is the loss of activity, which equals the loss of jobs. In the U.S. there are about 92.5 million snorkel diver days per year and about 22.8 million scuba diver days per year. U.S. economics studies show that diving activity alone, just the activity itself, aside from manufacturing and training and travel and retail and the diving media, the activity itself is responsible for about 340,000 full-time equivalent jobs here in the U.S. We also contribute about $11 billion to the gross domestic product through direct, indirect, and induced revenue.

So, we have a contribution to make, as well, and I think, beyond dollars and jobs, there's something that's very important. Reefs have another value, and I like to call this a "nonmarket value." And it's truly an economic value for divers, because we like to see these reefs, and we like to see them in an unharmed state. And that is our economic value. Long-term, you can think of that nonmarket value as being something that's giving me, giving my industry, the ability to show these coral reefs to my children and to my grandchildren, two of whom are sitting right here in the room today.

The loss of reefs through ocean acidification will impact business, for sure; it will hit the human side of our business. There are approximately 1800 retail dive centers in the United States, there are about 200 DEMA member destinations around the world; all of those could be lost if we were to lose our coral reefs, because they all depend on them, to some extent.

And I think the challenge for this committee with regard to ocean acidification, at least from our perspective, is finding the balance of keeping these businesses viable while protecting the oceans. We, at DEMA, believe we can assist in understanding what that market value is, and what the nonmarket value is, of these resources, and in finding the balance that allows continued usage and access, but also helps protect the resource and the businesses that are built around them. We can provide you with firsthand information that could be helpful to the Committee.

We strongly support the economic and environmental investigation of the effects of ocean acidification being undertaken by this committee. We look forward to working with Congress to develop a balanced approach between the immediate economic business issues and the long-term health of the critical coral reef and ocean resources.

Thank you very much for this opportunity to express the diving industry's concerns regarding ocean acidification.

[The prepared statement of Mr. Ingram follows:]

PREPARED STATEMENT OF THOMAS INGRAM, EXECUTIVE DIRECTOR, DIVING EQUIPMENT AND MARKETING ASSOCIATION

Introduction

Good morning Mr. Chairman, Senator Cantwell, and members of the Committee. I am Tom Ingram, Executive Director of the Diving Equipment and Marketing Association. Thank you for the opportunity to testify on the potential economic impacts of ocean acidification on the recreational scuba diving and snorkeling industries.

The Diving Equipment and Marketing Association (DEMA) is a non-profit trade association (501 (c) 6) based in San Diego California, representing the business and consumer interests of the recreational scuba and snorkel diving industries all over the world. DEMA's mission is to promote sustainable growth in safe recreational scuba diving and snorkeling while protecting the underwater environment.

My testimony today will focus on the interest of snorkeling and scuba diving participants in protecting and respectfully using the marine environment while keeping it clean and healthy, on the economic benefit of access to healthy dive sites for U.S. and international recreational scuba diving and snorkeling interests, on job creation and economic benefit to communities based on diving activity and access to an attractive environment, and on the economic concerns of these industries should such access be lost due to ocean acidification or for any reason. I will also reiterate our industries' interest in participating in and assisting with policy development and implementation as such policies are considered.

Interest of Snorkelers and Scuba Divers in Protecting the Marine Environment

DEMA strongly supports scientific and economic investigation to determine the potential impacts of ocean acidification and looks forward to working with Congress to ensure that the marine environment remains clean and healthy, a viable place for continued diving consumer use, and remains open to careful stewardship by diving businesses around the world. We applaud Congress for scheduling this hearing as a means of gathering information for such investigations.

The diving industry depends on continuing interaction with a healthy marine environment for its very existence, and is aware of the need for long term sustainability of these resources for all. Consequently, the diving industry is dedicated to protecting the marine environment for its own well-being and for the well-being of all. For these reasons DEMA's mission statement includes an expressed acknowledgment of the need for protecting the aquatic environmental.

Scuba divers and snorkelers are strong advocates for environmental protection in part because they can observe first-hand the coastal marine ecosystem, and can relate that information to friends, family and acquaintances. Divers have long been concerned with the effects of pollution and other potential sources of damage; whether from run-off that originates from populated regions in proximity to diving areas, from potential sources of CO_2, or from other sources. Scuba divers and snorkelers are stewards of a unique environment upon which they depend for recreation and study. All "certified" scuba divers today are educated to maintain proper buoyancy and positioning while diving, which helps to prevent accidental damage to natural marine and other aquatic resources. Many divers seek additional training to better understand the complex nature of coral reef communities, fishery resources and how to contribute to the knowledge base needed to monitor and protect these environments. With their first-hand observation of these protected areas, divers can and do encourage others to protect these resources.

The most active divers in the U.S. today participate in diving activities in many areas of the country, including such locations as the Florida Keys National Marine Sanctuary, areas of California and Hawaii, and other U.S. territories in the Caribbean and in the Pacific. According to a study by the Professional Association of Diving Instructors (PADI), 78 percent of divers travel to dive within 12 months of receiving their initial diver training and certification.

According to a 2006 and 2009 DEMA study, today's most active divers fit the following profile:

- Age—Between 38 and 53 years old—Mean: 45 Median: 46

- 76 percent are male
- Household Income—56 percent make between $75,000 and $100,000
- Occupation—80 percent are White-Collar/Professional/Technical/Management
- Home ownership—93 percent own their own home
- Mortgage amount—Median of $148,000
- Marital Status—71 percent married
- Presence and age of children—17 percent have kids under 18

Generally an affluent demographic such as described above is concerned with the environment and with the sustainable use of natural resources (Source: Murch, Arvin. 1971. "Public Concern for Environmental Pollution." *Public Opinion Quarterly* 35:100–106). The environmental concerns of divers are consistent with this study.

A 2003 study by Flexo, Hiner and Partners (FHP), which included divers and non-divers in the age range of 20 to 59, indicated that 81 percent participate in aquatic activities because they wish to be "closer to nature." In addition, a 2005 study by Knowledge Networks indicates that adults within this demographic (age 41–59) are attracted to "Adventure Activities" indicating an affinity for nature or "eco-related" activities (See Exhibit B).

Scuba divers and snorkelers regularly participate in such activities as underwater photography, observing and counting fish, reporting environmental concerns to state and Federal authorities, and participating in beach and submerged coastal clean-up activities. Non-profit, U.S.-based organizations, such as The Reef Environmental Education Foundation (REEF), the Coral Reef Alliance (CORAL), and the Project AWARE Foundation provide many opportunities for divers and others to understand more about reefs, ecosystem management, sustainable tourism, and how to become effective environmental advocates. To date for example, REEF has involved divers in more than 118,000 surveys of aquatic life, contributing to the knowledge base in areas of fish populations and invasive species. During almost two decades, Project AWARE Foundation has completed thousands of beach and underwater clean-up activities involving divers and non-divers with an interest in protecting the marine and aquatic environments.

A study by Knowledge Networks in 2005 indicated there are 60 million active travelers vacationing specifically for outdoor activities, one-third of which are over the age of 45. The Outdoor Industry Association Foundation indicates that adults with similar demographic characteristics as those of the most active divers are predisposed to water-related activities on vacation. This predisposition appears to be related to their desire to observe the diversity of marine environments accessible first-hand only to divers and snorkelers, and helps explain the attraction of diving to the described adult population. In fact, some organizations use this environmental concern as a means of promoting diving and attracting new diving participants.

In conclusion of this point, divers and diving professionals, and all of those connected with the diving industry actively observe and protect the environment on which they depend for recreation, and for their livelihoods. Perhaps John J. Cronin, one of the founders of PADI said it best, "If divers do not take an active role in preserving the aquatic realm, who will?"

Economic Impact of Access to Healthy Dive Sites: the Economics of Recreational Diving and Snorkeling

There are approximately 2.7 to 3.5 million active divers in the U.S. alone, with estimates as high as 6 million worldwide. According to *Understanding the Potential Economic Impact of SCUBA Diving and Snorkeling: California (2006),* Linwood H. Pendleton, Associate Professor, Environmental Science and Engineering Program at the University of California, Los Angeles, estimated that by 2010 there would be about 11 million snorkelers in the US. PADI estimates that there are some 20 million snorkelers worldwide.

Leeworthy and Wiley estimate that about 5.07 percent of the U.S. population participates in snorkeling (approximately 11 million) and they participate at the rate of 92.5 million diver-days annually. Leeworthy and Wiley further estimate that 1.35 percent of the U.S. population participates in scuba diving (about 2.79 million) at the rate of 22.8 million diver-days annually (See Exhibit F).

A 2006 DEMA study indicated that divers remain active in the sport for a long time. Studies indicate that divers have a participation "half-life" of about 5 years. That is, some 5 years after receiving their initial training and diver "certification," about 50 percent of the diver population will have discontinued their diving activity. Approximately 5 years later an additional 50 percent of the initial diver population will cease or reduce diving activities, and so on. In the U.S. about 200,000 new divers are trained and certified each year.

Interestingly, many "divers" never actually become "certified." A large number (by some estimates more than one million globally) participate in "try diving" experiences. These individuals are under the direct supervision of a diving professional, and though they never complete a certification course, they nonetheless participate in diving activities, many on living coral reefs in the ocean. They are therefore impacted by potential environmental degradation such as ocean acidification.

Recreational scuba divers and snorkelers contribute to U.S. and international tourism revenue by purchasing dive trips, equipment and other diving-related items, and by spending on ancillary items such as hotels, food, fuel, air, water and ground transportation, and other items while traveling to local and distant dive destinations. Divers contribute to sales tax revenues for local counties, municipalities and states, and to Federal and state tax revenues through the creation of diving tourism-related jobs.

Divers visit natural and artificial reefs, as well as other bodies of water to observe natural or man-made structures. Recreational diving is, therefore, possible under a variety of conditions and in a variety of locations. Most are attracted to clear warm water, and natural coral reefs and clean ocean environments play a key role in developing the "market value" of these diving experiences.

Natural Reefs: Trade and Industry Value Including Snorkeling and Scuba Diving

Numerous individual economic studies have contributed to the economic picture of recreational diving and the value of natural reefs in terms of usage, tourism revenue, goods and services, and shoreline protection. Several of these are cited here.

Overall Reef Value

According to *Coral Reef Ecosystems Value: Enhancing Resilient Communities* presented during Capitol Hill Ocean Week, June 4, 2008, Billy D. Causey, Ph.D., Regional Director, Southeast Region, National Marine Sanctuaries (See Exhibit C—Florida Coral Reefs Recreational Use), natural coral reefs contribute some $375 billion in goods and services annually to the world. Rodney V. Salm, PhD in his presentation, *Taking the Heat in Tropical Seas* (also for Capitol Hill Ocean Week, June 4, 2008) indicated that the average value of coral reefs was estimated to be about $813,000/sq. mile for recreational use, food, jobs and other services combined.

A 2002 study of Hawaii estimated the value of that state's coral reefs at $364 million. It was noted in this same presentation that reefs provided shoreline protection that would otherwise cost an estimated $400,000 to $24 million/mile. In the Caribbean, shoreline protection provided by coral reefs is valued between $0.7 billion and $2.2 billion.

Clearly, natural reefs have a significant impact on local and state economies in the U.S. as well as providing cost savings in terms of shoreline protection.

Value of Recreational Divers and Snorkelers Attracted to Natural Reefs

Recreational divers, snorkelers, fishers, and others are attracted by the presence and accessibility of coral reefs, making them a significant part of diving tourist and travel promotional strategies.

In the March 2003 *An Assessment of the Socio-Economic Impact of the Sinking of the HMS Scylla* the South West Regional Economy Centre at the University of Plymouth indicated that for every 10,000 diver days, three full time equivalent (FTE) jobs were created, half of which were direct (associated directly with diving) and half of which were indirect (associated with hotels, restaurants and other tourist and service employers). This same study indicates a contribution to the GDP of approximately £669,000 (US$1,027,800) for every 10,000 diver-days (See Exhibit E).

A 2000 report from the World Resources Institute indicates that coral reefs in the Caribbean alone contribute $2.1 billion for dive-specific tourism. This same presentation recorded more than 8.80 million visitor-days in Florida annually by snorkelers and scuba divers. The annual direct economic value of coral reefs to world tourism is estimated at some $9.6 billion.

A study of Martin County Florida published in 2004 indicates that snorkeling on Martin County reefs generates about $465,000 in annual expenditures within the county, of which one-half are spent on boat, oil, and gas. Scuba diving on Martin County reefs generates about $672,000 in annual expenditures within the county of which about one-half is spent on boat, oil, and gas. For all activities combined, the use of natural reefs generates $6,886,000 in annual expenditures within the county. Total annual reef-related expenditures, including natural and artificial reefs, are estimated at $12,000,000.

According to the *Socioeconomic Study of Reefs in Southeast Florida* (October 2001, Florida Fish and Wildlife Conservation Commission, National Oceanic and Atmospheric Administration, in association with Florida State University), reef-related expenditures generated over $4.395 billion in sales in Palm Beach, Broward, Miami-Dade and Monroe Counties combined, during the 12-month period from June 2000 to May 2001. These sales resulted in generating $2.047 billion in income to Palm Beach, Broward, Miami-Dade, and Monroe County residents during the same time period. During the same period, reef-related expenditures provided 71,300 full and part-time jobs in these four southeast Florida counties. Two-thirds of the economic contribution was associated with natural reef-related expenditures in Miami-Dade and Palm Beach Counties, 75 percent of the economic contribution was associated with natural reefs in Monroe County, and about fifty percent was associated with natural reefs in Broward County (See Exhibit A—Economic Contribution of Reef-Related Expenditures in Four Florida Counties).

It should be clear that recreational diving and snorkeling contribute significantly to tourism-related businesses, in addition to the revenue contribution from diving activities derived directly by diving-related businesses. It should also be clear that recreational diving and snorkeling generate jobs in many different sectors, some of which are highly specialized, requiring extensive training.

Economic Concerns of Recreational Scuba Diving and Snorkeling Regarding Loss of Coral Reefs or Coral Reef Access Due to Ocean Acidification

The recreational diving industry is dependent on the availability of quality diving and snorkeling sites, and this economic dependency extends to hotels, restaurants, marinas and other businesses associated with coastal and coral reef diving activities.

As noted, it is estimated that three full time equivalent (FTE) jobs are created for every additional 10,000 diver-days. With approximately 115 million combined snorkeling and scuba diver-days annually in the U.S. alone, it is projected that such recreational diving activity, through direct and indirect contributions, delivers about $11 billion to the U.S. annual GDP (See Exhibits E and F) and creates more than 340,000 FTE jobs.

The Effects of Ocean Acidification and the Human Side of Coral Reef Loss

There are approximately 1,800 retail dive centers in the United States, most offering diving instruction, diving equipment sales and rental, providing clean filtered breathing air, and often selling dive travel (for a complete listing of retail dive store fronts, see *www.BeADiver.com*). There are more than 200 international destination DEMA members, many of which depend almost solely on healthy coral reefs to attract scuba divers and snorkelers.

These businesses are the “customer interface” for the diving industry. They are the conduit by which diving equipment manufacturers, training organizations, the media and travel access potential diving consumers. All of these (typically larger) businesses depend to some extent on the retail dive center or its Internet equivalent. Without retail stores and tourist diving destinations, the industry cannot easily reach customers and the scuba and snorkel diving industries suffer.

Many of these retail businesses are small or micro-businesses, most are independently owned and operated, and many are family operations, providing household income which puts children through school, buys homes, and feeds and clothes the entire family. These businesses are also job centers for specialized and highly trained professionals such as diving instructors, underwater photographers, biologists, aspiring writers, life-support service technicians, Coast Guard-licensed vessel captains, and a variety of others.

Undoubtedly, losing coral reefs due to ocean acidification, or losing access to coral reefs for any reason would be economically detrimental to the recreational scuba and snorkeling industries in the U.S. and in every nation or territory that enjoys access to these natural wonders. Such loss would be devastating to members of the diving community and their families, and would place an economic burden on the coastal communities which depend on recreational diving and snorkeling for their livelihood.

Research and Policies

By investigating both the economic and environmental impacts of ocean acidification, the Congress is being appropriately cautious and prudent in their actions. The recreational scuba diving and snorkeling industries could be detrimentally impacted by regulatory policies that create more immediate cost or reduction of access when such policies may be unnecessary or overly burdensome. In times of economic downturn the recreational diving industries experience many of the same circumstances as do other small recreational businesses; reduced revenue, fewer new customers, and less overall participation. According to a recent CNBC article (*Survey: Pilates*

Exploding, Darts & Billiards Plummeting, published Tuesday, 30 Mar 2010), this reduced participation is common to many other water-related activities, "Water sports are almost toxic. Since 2000, jet skiing (down 18.5 percent), scuba diving (36.7 percent) and water skiing (44.5 percent) have seen massive declines."

To introduce regulation without the critical research input that this Congress is now sensibly seeking may adversely impact these industries during the first fragile part of the economic recovery. By understanding more about the economics of ocean acidification on the diving industries, and on the families that participate in these businesses, it should be possible to balance the long term environmental needs of the oceans and reefs, with the more immediate concerns of those that help their customers enjoy the ocean environment.

Since its inception DEMA as an organization has worked for the betterment of the environmentally sensitive resources on which our industries depend, while balancing the needs of diving businesses, and encouraging diving consumers to further protect these resources. Our efforts to protect the ocean, create jobs and recruit additional stewards for oceans and coral reefs have been enhanced by programs such as our Ships 2 Reefs program, providing information to those who would create environmentally safe artificial reefs. Using retired ships, carefully submerged in appropriate locations, takes fishing and diving pressure off natural reefs and helps increase aquatic life populations. DEMA's efforts resulted in the Ships 2 Reefs legislation enacted in Florida in 2008. DEMA has also been privileged to advocate for the reauthorization of the National Marine Sanctuaries Act, and comment on establishment of Marine Life Protected Areas, as well as other efforts to protect the underwater environment. We openly offer our assistance in understanding the economics of these industries or in other ways that make the most sense to this committee.

Suggestions from the Recreational Scuba and Snorkeling Industries

DEMA applauds the Congress for their efforts and recognition that there is a need for additional economic and environmental investigation with regard to impacts of ocean acidification or other factors which might limit or prevent access to natural coral reefs. DEMA suggests that such economic and environmental investigations should:

1. include input from all user groups
2. provide for a clear balance between the long-term environmental health and of this critical resource and the immediate economic issues such as access limitations and regulations that impact the industry and the cost to participate in diving

The Diving Industry's Interest in Continued Participation in the Economic Investigation of the Effects of Ocean Acidification

DEMA and the recreational scuba diving and snorkeling industries appreciate the opportunity to be included in this economic discussion regarding the effects of ocean acidification. As the trade association for the recreational diving industries, DEMA has a strong interest in additional and continuing opportunities to contribute suggestions and ideas with regard to policy considerations and related activities.

Conclusion

In closing, DEMA strongly supports the economic and environmental investigation of the effects of ocean acidification on coral reefs being undertaken by this committee. The recreational scuba diving and snorkeling industries can continue to be a formidable instrument in this committee's toolbox for discovering, reporting, studying and evaluating the impact of ocean acidification by providing first-hand information in areas such as coral reefs status, fish counts and other observable areas. DEMA willingly offers its assistance in these areas and looks forward to working with Congress to ensure that there remains a balance of consideration between the immediate economic issues and the long term health of the critical coral reef and ocean resources.

Thank you for the opportunity to offer my thoughts on how the diving industry could be economically impacted by ocean acidification.

EXHIBITS

Exhibit A—Economic Contribution of Reef-Related Expenditures in Four Southeast Florida Counties

Economic Contribution of Reef-Related Expenditures to Each County
June 2000 to May 2001—Residents and Visitors

Type of Economic Contribution	Palm Beach County	Broward County	Miami-Dade County	Monroe County
Sales—All Reefs (in millions of 2,000 dollars)	$505	$2,069	$1,297	$490
Artificial Reefs	$148	$961	$419	$127
Natural Reefs	$357	$1,108	$878	$363
Income—All Reefs (in millions of 2,000 dollars)	$194	$1,049	$614	$139
Artificial Reefs	$52	$502	$195	$33
Natural Reefs	$142	$547	$419	$106
Employment—All Reefs (number of full- and part-time jobs)	6,300	36,000	19,000	10,000
Artificial Reefs	1,800	17,000	6,000	2,000
Natural Reefs	4,500	19,000	13,000	8,000

Source: *Socioeconomic Study of Reefs in Southeast Florida,* Johns, Leeworthy, Bell, Bonn

Exhibit B—Top 10 Adventure Activities of Adult Travelers

Top 10 Adventure Activities on the "Most Adventurous Trip" for adults age 41 to 59:	
1.	Hiking/backpacking/rock and mountain climbing
2.	Escorted or guided tour
3.	Snorkeling
4.	Camping (tent)
5.	Fresh or saltwater fishing
6.	Horseback riding (tied for 6th)
6.	Biking (tied for 6th)
7.	Whitewater rafting/kayaking
8.	Sailing
9.	RV camping
10.	Scuba diving

Source: *2005 Travel Survey,* Knowledge Networks

Exhibit C—Florida Coral Reefs Recreational Use

Recreational Use of Coral Reefs in Florida	
Snorkeling	4.24 million visitor days
Scuba Diving	4.56 million visitor days
Fishing	9.72 million visitor days
Glass-bottom Boats	0.12 million visitor days
TOTAL	18.64 million visitor days
Ref: Dr. Vernon R. Leeworthy, Chief Economist, Office of National Marine Sanctuaries	

Exhibit D—Recreational value of coral reefs in Hawaii in 2001 (US dollars)

	Consumer Surplus	Value Added of Direct Expenditure	Value Added of Indirect Expenditure	Multiplier Effect	Total Value Added
Snorkelers					
Residents	10,053,899	2,318,704	—	579,676	12,952,279
U.S. West	47,833,826	20,882,055	23,136,504	11,004,640	102,857,025
U.S. East	33,174,006	14,482,250	20,450,444	8,733,174	76,839,874
Japan	13,340,508	5,823,854	2,189,058	2,003,228	23,356,648
Canada	5,236,964	2,286,218	3,587,133	1,468,338	12,578,653
Europe	3,809,326	1,662,977	2,246,766	977,436	8,696,505
Other	11,782,791	5,143,826	6,794,101	2,984,482	26,705,200
Subtotal	*125,231,322*	*52,599,883*	*58,404,007*	*27,750,973*	*263,986,183*
Scuba Divers					
Residents	3,450,231	5,137,088	—	1,284,272	9,871,591
U.S. West	1,588,179	3,152,878	3,545,777	1,674,664	9,961,498
U.S. East	1,101,444	2,186,603	3,134,126	1,330,182	7,752,355
Japan	1,255,768	2,492,969	2,710,742	1,300,928	7,760,407
Canada	173,878	345,185	549,745	223,733	1,292,541
Europe	126,477	251,085	344,327	148,853	870,742
Other	391,212	776,641	1,041,228	454,467	2,663,548
Subtotal	*8,087,190*	*14,342,448*	*11,325,946*	*6,417,099*	*40,172,682*
Total Recreational Value					
Residents	13,504,130	7,455,792	—	1,863,948	22,823,870
U.S. West	49,422,006	24,034,932	26,682,281	12,679,303	112,818,522
U.S. East	34,275,450	16,668,853	23,584,570	10,063,356	84,592,229
Japan	14,596,276	8,316,823	4,899,800	3,304,156	31,117,055
Canada	5,410,842	2,631,403	4,136,878	1,692,070	13,871,193
Europe	3,935,804	1,914,062	2,591,094	1,126,289	9,567,249
Other	12,174,003	5,920,467	7,835,329	3,438,949	29,368,748
Total	*133,318,511*	*66,942,331*	*69,729,953*	*34,168,071*	*304,158,866*

Multiplier effect: The total economic contribution of the reefs of Hawaii includes the contribution of reef expenditures to sales, income and employment. Expenditures by visitors generate income and jobs within industries that supply reef-related goods and services, such as charter/party boat operations, restaurants and hotels. These industries are called direct industries. In addition the visitor expenditures create multiplier effects wherein additional income and employment is created as the income earned by the reef related industries and their employees, is re-spent in the local economy. These additional effects of reef-related expenditures are called indirect and induced. Indirect effects are generated as the reef-related industries purchase goods and services from other industries locally. Induced effects are created when the employees of the direct and indirect spend their money locally.

Exhibit E—The Impact of Scylla on the South West Economy with Projected U.S. GDP

The Impact of Scylla on the South West Economy					
Extra Diver Days					U.S. Diver-Days 115,300,000
	2500	5000	7500	10000	
Employment (FTE)					
Direct	3.9	7.7	11.6	15.5	
Indirect	3.5	7.1	10.6	14.2	*Projected U.S. Employment (FTE) 342,441*
Total	*7.4*	*14.8*	*22.2*	*29.7*	
GDP (£)					
Direct	66,060	132,120	198,180	264,240	
Indirect	101,275	202,551	303,826	405,102	
Total	*167,335*	*334,671*	*502,006*	*669,342*	
TOTAL Contribution to GDP					*Projected U.S. GDP Contribution* (Direct and Indirect) *US$11,856,415,621.34*

Exhibit F—Participation in SCUBA and Snorkeling Recreation (2000)

	Participation Rate (%)*	Number of Participants (millions)*	Number of Days (millions)***
United States			
Snorkeling	*5.07*	*10.46*	*92.5*
Scuba Diving	*1.35*	*2.79*	*22.8*
California			
Snorkeling	*0.34*	*0.71*	*3.818*
Scuba Diving	*0.14*	*0.29*	*1.383*

From Leeworthy and Wiley (2001), *Percent of the U.S. population that participated in the activity, **Number of participants is equal to the participation rate multiplied by the non-institutionalized population 16-years or older in all households in the U.S. as of September 1999, ***The number of days the respondents participated in each activity over a year. Note figures from top to bottom of table differ due to the use of different base population levels in each report.

Senator CANTWELL. Thank you, Mr. Ingram. And we have a lot of diving in the Northwest, although people don't believe that, because they think it's dark and cold waters, but they are——

Mr. INGRAM. It's beautiful there.

Senator CANTWELL. Yes, right off—right where I live, in Edmunds, Washington——

Mr. INGRAM. Oh, you bet.

Senator CANTWELL.—there is a big underground city that people dive to, so——

Mr. INGRAM. We're very privileged to see all of that stuff that you saw in the video, firsthand.

Senator CANTWELL.—yes, thank you.

Mr. Waters, welcome. We look forward to your testimony.

STATEMENT OF DONALD A. WATERS, COMMERCIAL FISHERMAN, PENSACOLA, FLORIDA

Mr. WATERS. Good evening. Thank you, Chair Cantwell, Ranking Member Snowe. And I also want to thank the Senators of the Gulf State regions for my support and their hard work to promote sustainable fisheries in the Gulf of Mexico.

I have been a fisherman owner-operator for most of my life in reef fishing—better part of four decades. My home port is in Pensacola, Florida. I currently fish for red snapper and king mackerel. I've also participated in other fisheries in the Gulf of Mexico, and I also participate in stock-assessment panels for red snapper and king mackerel.

In this business, we have to keep our eyes open and be prepared to what we meet on the ocean. In my opinion, this is something that's unseen as we have our battles amongst the commercial fishermen on how we want to do policy, catch shares, no-catch shares, this, that. And this seems to be something that has been put on the back burner by a lot of the commercial fishermen, but it seems to be really creeping up on us. And it was my first eye opener, when I came up last December to testify in front of some of my Senators on some of the changes in Magnuson-Stevens. And I met Mark Wiegardt, from Oregon, and his oyster hatchery there, and got to talking to him, and he was telling me how the oysters were just dying off from acidification. And I—you know, I just kind of said, "Well, if that's really going on in a closed-loop circuit, what's really going on in the wild?" So, it really got my attention.

So, the more that I thought about it and started investigating and started reading up on it, I learned things, you know, about what is really happening in the wild, what is happening to the food for our commercial fin fish. This acidification could just totally devastate the food chain, therefore we would lose our main fin fish that we harvest for the customers of the United States. These are the citizens, they own a part of this resource.

So, I—it just upset me dearly. And I know I'm kind of talking behind everybody that's a whole lot more speaker, but this is just—to me, this is just a——

Senator CANTWELL. Mr. Waters?

Mr. WATERS.—devastating——

Senator CANTWELL. Mr. Waters, I think you're actually stealing the show. You're doing such——

Mr. WATERS. Yes, I mean—[Laughter.]

Mr. WATERS.—as you can all tell, I'm a commercial fisherman, not a public speaker. But, this is just—to me, would be totally upsetting. It would just totally destroy our economic survival—I mean, in a whole nationwide capacity. The—it's just—the whole bearing of it is just incomparable. I mean, it's just something that you can't imagine. If you could—if you lost the jobs, the men, the boats—it's just—I mean, it—to me, it's just—you can't even speak of the devastation that our country would be facing if our oceans turned, more or less, into poison.

I mean, I know that this is basically off of my written testimony, but it just really takes—just really takes it to my heart. And I'm speaking with passion, I'm speaking from my heart. And I know my fellow fishermen, sometimes we compete—we compete hard in the fields, and we—you know, it's a competitive—but, this is something that we have to join hands with, and we have to move forward with, and we have to get a hold of. We need to move forward and try to protect, because this is something that we do need to fight over; this is something that we need to join up with and move forward with.

And my opinion is that this is something that we need to be proactive on, and not reactive to something after it's too late.

And I'm sorry that I really can't sit here and stay straight to my written testimony. My written testimony's from the heart, too. But, when I start speaking—I'm sorry I have to speak with such passion, because this is a devastating ghost lurking in the shadows that would just totally devastate our economy in this country. Because without the shores and the beaches and the restaurants, the—I mean, it would just change our whole lives. We would be—I mean, I can't even explain it. I mean, you could use your imagination, and it takes you to another world.

Mr. INGRAM. It sure does.

[The prepared statement of Mr. Waters follows:]

PREPARED STATEMENT OF DONALD A. WATERS, COMMERCIAL FISHERMAN, PENSACOLA, FLORIDA

Chair Cantwell, Ranking Member Snowe, and members of the Committee, I would like to thank you for the opportunity to offer testimony of my concerns about ocean acidification and its possible effect on fisheries in the Gulf of Mexico and other U.S. waters. And I would also like to express my appreciation for all the support that I have received in the past from my Gulf State Senators. It has been a privilege to work together to keep our fisheries sustainable.

I have been an owner-operator fisherman for most of my life, reef fishing for the better part of four decades. My home port is Pensacola, Florida. I currently fish for red snapper and king mackerel but have also worked the waters of the Gulf of Mexico for others species. People need to work hard on and off the water to keep our fisheries sustainable, so I am heavily involved in the fisheries management process, participating on both the red snapper and king mackerel assessment panels.

In this business we have to keep our eyes and ears open. When an issue comes up that could affect my fishery and livelihood, I learn everything I can about it. That's what I've done since I first heard about ocean acidification.

I don't pretend to be an expert on ocean acidification but I do know this problem is real, and we need to get on top of it. I first got word of ocean acidification not long ago, in December 2009, when I was in D.C. to talk with my Senators and Representatives about proposed changes to the Magnuson-Stevens Act. I ran into a group of fishermen and shellfish growers who were in D.C. to talk to their Senators about ocean acidification.

One of the shellfish growers I met was Mark Wiegardt from the Whiskey Creek Shellfish Hatchery in Netarts, Oregon. Three or four years ago, for no apparent reason, the oyster larvae that Mark grows for a living started dying in the first few days of their lives. The usual culprits, like marine bacterial infections, turned out to be innocent this time. After a few years of major larvae die-offs and barely staying in business, scientists working with Mark and his partners correlated the die-offs with upwelling deep water that is acidified by high concentrations of CO_2. For juvenile oysters, the water was corrosive, and larvae simply couldn't survive in it.

The other people in the group I met in December were mostly fishermen from Washington and Alaska. They saw the problem of larval shellfish die-offs as a canary in a coal mine. It was a problem to get ahead of before it expanded to their fisheries. If the seawater that was pumped into the hatchery from the ocean was killing the oyster larvae, what was going on in the wild? Wild larval shellfish and other tiny marine plants and animals are the food source for most commercially important finfish in their juvenile stages of life. The way these fishermen saw it, less food for juvenile fish would mean fewer adult fish to catch. Sometimes it doesn't take much to push a stock below the threshold for commercial production. No fish means no fishermen. I started to consider fisheries in the Gulf of Mexico and how ocean acidification might affect us.

I have learned since I started looking into ocean acidification that:

- Research shows that CO_2 emissions from burning of fossil fuels and other man made sources of CO_2 are absorbed into the ocean from the atmosphere. In the ocean, the CO_2 reacts to form carbonic acid. The acid changes the ocean's chemistry.
- As a fisherman I can tell you that a lot of us aren't sure where we stand on climate change, but ocean acidification is real. It has been documented by re-

searchers all over the world and there is no doubt that the pH of the ocean is dropping, becoming more acidic. Measurement show that the open ocean, on average, is about 30 percent more acidic today than it was before the Industrial Revolution. In some places, like the West coast, local factors compound that change in seawater. With upwelling or the kind of conditions that produce nutrient-driven hypoxia like we get in the Gulf of Mexico, seawater can become corrosive to some of the fish and shellfish and to the species *they* eat.

- Mixing CO_2 into seawater doesn't just make it more acidic. The carbonic acid from CO_2 changes a lot of the ocean's chemistry. For one thing, it reduces the availability of nutrients in seawater that clams, oysters, crabs, lobsters; corals need to build and maintain their shells and skeletons. They absorb nutrients from the seawater. The increased acidity depletes those nutrients. That makes it harder (and sometimes impossible) for a lot of these shell-builders to survive.
- Even small changes in the ocean's chemistry can disrupt the marine food web and cause trouble for fish higher in feeding order. For fishermen to make a living, we need fish stocks that are abundant and dense enough so we can harvest them efficiently.
- Cold water absorbs more CO_2 than warm water. The oceans in high latitude places like Alaska are more acidic than the warmer waters nearer the equator.
- For a lot of species, it looks like they are most vulnerable in early life, especially their larval stages.
- Even adult shellfish, corals and other calcifiers show slower rates of shell building, diminished reproduction, muscle wastage, and other problems when exposed to acidified seawater.

What does ocean acidification mean for fisheries in the Gulf of Mexico?

In the Gulf of Mexico, we already experience serious impacts from the dead zones that are usually attributed to hypoxia. The coastal communities that rely on the shrimp and oyster industries and fishing are beginning to recover from the devastation caused by Hurricane Katrina and the other storms that followed on her heels. New management tools that fishermen and managers put in place have helped to rebuild fish stocks. The last thing we need is to have our recovery efforts threatened by something we didn't even see coming.

I have invested a lot of my time and money to participate in reef fishing. I don't go out to sea unprepared for whatever might come up while I am on the water. Right now I feel like those of us in the Gulf States have no idea what we may be up against with ocean acidification. So far, it looks like there isn't much research yet on this problem in the Gulf I found out about one study by USGS that's meant to create baseline data on ocean chemistry for the West Florida shelf. That's a start, but it's not enough. We ought to be monitoring the Gulf so we can recognize changes when they come our way. For instance, if this is affecting coral, we need to know. We need healthy reefs to have a healthy reef fishery.

Commercial fishing and the shellfish industry in the Gulf of Mexico are not only important to the fishermen and the coastal communities that they live in. Inland regions of the Gulf States also receive the benefits of the seafood industry. I offload fish in both Florida and Louisiana so let's consider the State of Louisiana. Commercial saltwater fishing has a dockside value of $264.9 million in Louisiana. Once that seafood leaves the fishing boat, hits the dock and gets into distribution that dockside value turns into retail sales of $1.8 billion with a total economic impact that is ripples out to $2.3 billion. Shellfish and commercial fishing support 26,345 jobs from the dock to inland in Louisiana. Every person who touches that fish from ocean to plate sees the economic benefit. The state and local tax revenues that result from the seafood industry are $166.9 million in Louisiana. These numbers show that commercial fishing and the shellfish industry play a big part in the providing jobs and a viable economy in Louisiana.

If the fisheries of the Gulf States went away the impact would be felt nationwide. The money from our healthy fisheries works its way through marinas, repair shops, gas stations, fish gear shops, grocery stores, lodging, seafood restaurants—the list goes on. So you can see a lot of people have an economic interest in keeping our fisheries strong. And we haven't even considered the revenue and jobs from recreational fishing or the saltwater tourist industry with people who want to walk on beaches or dive on reefs.

I've talked about the Gulf of Mexico because that is where I work, where I live, and what I know. The 2008 edition NOAA's annual document called "Fisheries of the United States" looked at fisheries landings and how the value is amplified as our catch moves from the fisherman to the consumer. Nationwide, the revenues swell from the dock to the dinner plate:

- Fishermen $4.5 billion
- Processors $7.6 billion
- Exporters $23.4 billion
- Importers $28.5 billion
- U.S. commercial marine fisheries industry $35 billion (producing and marketing fishery products for domestic and foreign markets)
- Consumers: $69.8 billion (about two thirds in food service venues, one third in stores)

Fishing is a way of life for me and a whole lot of other people from coast to coast. Fish and shellfish provide jobs and food. The ocean that makes all this possible needs to be taken care of. People are seeing changes on the water and we don't yet know why. Without increased research and monitoring we are not going to find out if ocean acidification is eating our lunch. Looking the other way and hoping for the best is not the way I respond to challenges to my livelihood. It's not the way we should respond as a country, either. I think that it would better to be proactive than reactive.

I want to thank the Chair and members of this subcommittee for taking a good hard look at this problem and how it might affect the country. In closing I hope that you can supply adequate funding for monitoring and research on ocean acidification. Let's keep our eyes open.

Senator CANTWELL. Thank you, Mr. Waters.

Mr. WATERS. Thank you, ma'am.

Senator CANTWELL. Thank you for that testimony. It's very—we appreciate it very much.

[Applause.]

Senator CANTWELL. And I think that you are right, it takes that passion to convince people. And you're right, it's unfathomable what would happen. And I thank you for delving into it, and understanding, and for bringing a real face and passion to that issue. So, we thank you.

Dr. Barry?

STATEMENT OF JAMES P. BARRY, PH.D., SENIOR SCIENTIST, MONTEREY BAY AQUARIUM RESEARCH INSTITUTE (MBARI) AND MEMBER, COMMITTEE ON DEVELOPMENT OF AN INTEGRATED SCIENCE STRATEGY FOR OCEAN ACIDIFICATION MONITORING, RESEARCH, AND IMPACTS ASSESSMENT, NATIONAL RESEARCH COUNCIL, THE NATIONAL ACADEMIES

Dr. BARRY. Sometimes you just have to stand up and shout because things are changing. And I hope that the science about ocean acidification is incorrect, actually; but there are so many unknowns with this that we're not sure about how it will translate into ecosystems services. In many cases, it looks a little bit scary. But, it's nice to have passion about issues. Now I'll start my testimony.

Good morning, Madam Chair, Ranking Member Snowe, and members of the Committee. My name is Jim Barry. I'm a marine biologist at the Monterey Bay Aquarium Research Institute, where we perform research and development—technology development for important issues in ocean science.

Today, I'm going to highlight some information concerning ocean acidification based on research from myself and others, and then touch briefly on the report summary that was released today from the National Research Council's Committee on Ocean Acidification.

Carbon dioxide emissions are now being absorbed in the ocean's surface at a massive rate. Roughly 1 million tons per hour enter the sea surface, leading to higher CO_2 levels, increased acidity, and reduced levels of calcium carbonate minerals that are important to the formation of shells and skeletons by a wide variety of marine organisms.

Changes that we expect to occur by the end of this century as ocean acidification intensifies will be the largest and most rapid shift in ocean chemistry thought to have occurred for many millions of years, if the science is right about this.

Ocean acidification does not affect ecosystems directly, it affects individual marine organisms. And marine organisms faced with ocean acidification, or other environmental stresses, respond based on physiological adaptations that have been developed throughout their evolutionary history. They may respond by acclimation, adaptation, or extinction.

Individuals may acclimate to new conditions by adjusting their physiology a bit. Over generations, adaptation may allow species to tolerate new conditions. If not, generate—or, extinction is the only other option. The ability to acclimate, or adapt, is expected to vary greatly among organisms and among habitats in the oceans.

Several physiological functions are affected by ocean acidification. Photosynthesis, calcification, the formation of these skeletons, acid-based balance of our internal tissues, and metabolic rates are—as well as respiration rates—are all important processes that can be affected by environmental stress of any kind. Some photosynthetic species exposed to ocean acidification may benefit, but many animals may be stressed by these higher CO_2 levels.

Can I have the first slide, please?

On this graph, I'd like to talk about changes in physiological performance and how they play out with environmental stress, because they have consequences for individuals that then play out through the food web.

So, this is just a simple pie diagram, on the left, that shows how much we're spending, or how much an organism spends on taking care of its body; the cost of living, you might think about it. And you can think of this as the same as a household budget; that cost of living is just as much as, maybe, how much we pay for rent. And when we have an income we pay for rent, the rest of it goes to education and toys. And for animals it goes to growth and reproduction.

Now, if our cost of living goes up, the rent goes up, we just can't buy as many toys. But, for an individual organism that's more stressed, if it has to spend more energy taking care of its body, there's less energy for growth and reproduction. Now, for that individual what happens is, it may grow more slowly, it may reach a smaller size, and it may die earlier. And that translates, through the population, to a lower abundance of those sorts of animals in the ocean, maybe a lower productivity for the food chain up above it, as well as a greater likelihood of extinction of that species.

Next slide, please.

Ecosystem performance—for example, how many fish actually are taken by humans or make it up to the top of the food chain—depends upon the flow of energy through food webs. Any change in the abundance or loss of key species due to environmental stress can disrupt this flow of energy and degrade ecosystem performance.

So, if we start pulling out important species in this food web, maybe we can do that for awhile, but as we lose too many, you can collapse that. And if—in extreme cases, this can lead to ecological tipping points; for example, the failure of a fishery.

Next slide, please.

There is much we can learn from Earth history. This is a slide of the number of animals on Earth from 542 million years ago to the present, starting from right to left. And those black arrows point out where we've had mass extinctions on Earth.

CO_2 levels have been much, much higher in the past, more than 25 times higher than they are now, and life has thrived. But, there have been many episodes of mass extinction during the past 600 million years of Earth history, several causing more than 70 percent of all species to be lost. Coral reefs disappeared during most of these massive extinctions. Each of these events is associated with a rapid change in environmental conditions. Life recovered, but that recovery required 10 to 20 million years.

The general lesson is that when the environment changes, many species may, and do, go extinct. The change in condition during these extinctions was far greater than we're experiencing now, but how much environmental change is too much?

Next slide, please.

Because this field is relatively new, there are major uncertainties in how future ocean acidification will affect ecosystems. Marine fisheries are a good example. Will changes in primary productivity at the base of the food chain lead to more or less fish at the top? What about coral reefs? The preponderance of the recent scientific literature, and the fossil records, suggest very strongly that coral reefs may be in real trouble, both because of ocean acidification and other environmental change. It's my view that ocean acidification is very likely to affect various vulnerable ecosystems, leading to changes in ecosystem resources and services important to society.

Now, a touch on the NRC report. The NRC Ocean Acidification Committee released, today, a summary of their report, "Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean." In this report, we outline a plan for observations and monitoring of ocean conditions, coupled with priorities for research, to examine the potential effects of future ocean acidification on natural resources.

Thank you for the opportunity to comment on this very important issue.

[The prepared statement of Dr. Barry follows:]

PREPARED STATEMENT OF JAMES P. BARRY, PH.D., SENIOR SCIENTIST, MONTEREY BAY AQUARIUM RESEARCH INSTITUTE (MBARI) AND MEMBER, COMMITTEE ON DEVELOPMENT OF AN INTEGRATED SCIENCE STRATEGY FOR OCEAN ACIDIFICATION MONITORING, RESEARCH, AND IMPACTS ASSESSMENT, NATIONAL RESEARCH COUNCIL, THE NATIONAL ACADEMIES

Good morning Madam Chair, Ranking Member Snowe, and members of the Committee. My name is Jim Barry. I am a Senior Scientist at the Monterey Bay Aquarium Research Institute (MBARI), located in Moss Landing California, where I have been employed for nearly 19 years. MBARI is a nonprofit research and technology institute funded principally by the David and Lucile Packard Foundation where we perform research and technology development to address important issues in ocean science. My research concerns the biology and ecology of marine animals, particularly those inhabiting the deeper waters of the oceans. During the past several years, my studies have focused on the effects of high ocean carbon dioxide levels on marine animals, from either the direct injection of waste CO_2 into deep-sea waters or by ocean acidification due to the passive influx of CO_2 from the atmosphere. I was a contributing author for the *Special Report on Carbon Capture and Storage* produced by the IPCC (Intergovernmental Panel on Climate Change) in 2005, and am currently serving for the National Research Council as a member of the Committee on the Development of an Integrated Science Strategy for Ocean Acidification Monitoring, Research, and Impacts Assessment (hereafter NRC Ocean Acidification Committee). The National Research Council is the operating arm of the National Academy of Sciences, chartered by Congress in 1863 to advise the government on matters of science and technology.

This committee originated as a request from NOAA to the Ocean Studies Board, based on the call from Congress in the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006, and later the Consolidated Appropriations Act of 2008, to conduct a study of the acidification of the oceans and how this process affects the United States. In addition to NOAA, input and sponsorship of the Committee was provided by the National Science and Technology Council Joint Subcommittee on Ocean Science and Technology (JSOST), the National Science Foundation (NSF), and the U.S. Geological Survey (USGS).

I commend the Committee for convening a hearing on, The Environmental and Economic Impacts of Ocean Acidification,—the other CO_2 problem, due to the growing concern that this phenomenon may have important effects on marine organisms and ecosystems, as well as ecosystem services of great value to society. The history of ocean acidification research is relatively short. The notion that increasing carbon dioxide emissions absorbed through the sea surface are causing a change in ocean chemistry and may have important consequences for ocean biology was argued in the 1970s (Caldeira and Wickett, 2005). During the past ten to fifteen years, however, several studies and workshop reports have concluded that the very rapid and massive influx of CO_2 emissions into the oceans (now over 1 million tonnes of CO_2 per hour) could have very significant effects on marine ecosystems (Kleypas *et al.,* 1999; Raven *et al.,* 2005; Fabry *et al.,* 2008; Kleypas *et al.,* 2006; Doney *et al.,* 2009).

In my testimony, I would like to address two main themes. First, I will provide my personal perspective based on my own studies and others concerning the potential effects of ocean acidification on the biology of marine organisms and how these affects are expected to scale up to ecosystem services important to society. Second, I will provide an overview of the key points and recommendations from the NRC Ocean Acidification Committee's report on *Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean*. The key points of my personal testimony are as follows:

- Ocean acidification is changing the chemistry of the oceans at a scale and magnitude greater than thought to occur on Earth for many millions of years, and is expected to cause changes in the growth and survival of a wide variety of marine organisms, potentially leading to massive shifts in ocean ecosystems.
- Ocean acidification, like other sources of environmental variation, directly affects the physiological performance of organisms, which can respond individually by acclimation (tolerance), or collectively as a species by adaptation or extinction. Sensitivity to ocean acidification is known to vary among organisms and habitats, including "winners" and "losers", with some photosynthetic organisms apparently benefiting, while the performance of animals is generally impaired.
- Future changes in marine ecosystems expected to occur due to ocean acidification are poorly understood for most habitats, and difficult to predict from short-term studies of individual species, a research approach that has dominated this field to date. It is expected that biodiversity in many ecosystems may decrease due to the generally negative impacts of ocean acidification on marine animals, thereby impairing ecosystem function. Severe changes could lead to ecological "tipping points."
- Ocean goods and services important to society (*e.g.,* marine fisheries), are dependent on the healthy function of marine ecosystems. Although it remains unclear how marine fisheries will be affected, changes in the photosynthesis at the base of the food chain and shifts in the growth, survival, and productivity of higher trophic levels due to ocean acidification are expected to lead to important changes in ecosystems.

1. Ocean chemistry is changing rapidly due to the influx of fossil fuel carbon dioxide

Roughly 40 percent of all fossil fuel emissions now reside in the oceans (Sabine and Tanhua 2010), and the ocean surface is 25–30 percent more acidic than prior to human fossil fuel use. Increasing carbon dioxide emissions are expected to increase ocean acidity (pH) by ~200 percent by the end of this century, with even greater changes beyond 2100. In addition to increased acidity, ocean acidification causes higher carbon dioxide concentrations in seawater and a reduction in the saturation state of calcium carbonate minerals important for shells and skeletal formation in many marine organisms. This change in ocean chemistry is far more rapid and larger than has occurred throughout the past 800,000 years and perhaps as long as 25 million years, 10 million years before the first hominids appeared on Earth. Eventually, over 85 percent of all emissions will reside in the ocean, and this carbon dioxide will mix throughout the depths of the oceans.

2. Ocean acidification acts on the physiology of individuals

The response of organisms to ocean acidification depends upon physiological adaptations that have allowed them to survive and function in ocean ecosystems through their evolutionary history. In order to be successful—to survive, grow, and reproduce—organisms must maintain physiological function throughout a range of environmental variation or suffer reduced or impaired performance. As ocean chemistry diverges distinctly from the natural range of variation experienced through their recent evolutionary history, the tolerance of species is expected to decline.

Several key physiological functions are affected by ocean acidification in marine organisms including photosynthesis, calcification, respiration, internal acid-base balance, and metabolic rates. Photosynthesis has been observed to increase in some species in high-CO_2 waters, although rates of calcification may be reduced. Ocean acidification has been shown in general to reduce the rates of calcification in many marine organisms, due to the reduction in the saturation of calcium carbonate minerals in seawater (*e.g.,* Doney *et al.,* 2009; Fabry *et al.,* 2008). Ocean acidification can also disturb the internal acid-base balance of organisms, leading to reduced function of enzymes involved in a wide variety of fundamental biological processes. Increased seawater acidity can also impair oxygen transport and lead to lower metabolic rates in many organisms, which in turn limits their aerobic activity (*e.g.,* chasing prey or escaping predators).

Maintaining efficient physiological function in more acidic waters has been shown in some taxa to increase the energy required to cope with these stresses. This increased “cost of living” is expected to reduce the energy available for growth and reproduction in individuals. Reduced performance by individuals is expected to impact the entire species, leading to reduced abundance and productivity, and a greater likelihood of extinction.

Though limited, research to date indicates that there will be “winners” and “losers” in a high CO_2 ocean. In general, photosynthetic species may benefit in some ways from higher CO_2 levels in seawater, particularly some seagrasses (reviewed in Doney *et al.,* 2009). Shifts in photosynthesis rates could lead to massive changes in the dominant phytoplankton species forming the base of marine food webs, with effects reverberating throughout pelagic ecosystems. Most animals, however, either do not benefit or have exhibited various combinations of impaired shell or skeletal formation (calcification), and reduced rates of growth, reproduction, or survival. Corals, particularly those forming aragonite (a form of calcium carbonate) skeletons appear particularly vulnerable to ocean acidification, and along with other aragonitic taxa, may be the ecological ‘losers’ in the future high CO_2 ocean.

There is considerable variation among organisms in coping with physiological stress caused ocean acidification. Adaptations that allow some organisms to have very active lifestyles, with a high capacity for gas exchange (respiration) and metabolism (*e.g.,* actively swimming fishes or many mollusks), also preadapt these species for some of the stresses of ocean acidification. However, even though they may be able to tolerate ocean acidification, they may nevertheless experience reduced performance. In contrast, more sedentary animals may have less extra energy for coping with ocean acidification. Sensitivity also has been shown to vary among life stages of species and among habitats. Some deep-sea taxa have been shown to be sensitive to even moderately acidic waters (Barry *et al.,* 2004, 2005), and the physiological tolerance of various higher taxa (fishes, crustaceans) to ocean acidification decreases greatly with depth (Seibel and Walsh 2003; Pane and Barry 2007).

3. Future changes in marine ecosystems due to ocean acidification are understood poorly

“Scaling up” from the effects of ocean acidification on individuals to entire ecosystems is difficult. Except for a series of experiments on marine plankton communities, most research on ocean acidification has been performed on individual species, thereby limiting our understanding of population and ecosystem-level effects of a high-CO_2 ocean.

The function of marine ecosystems depends upon their biodiversity—the wide variety of species in the habitat. Biodiversity forms a biological network that functions though the interactions between species and with their environment. Predation, competition, and other interactions among species, as well as the effects of environmental variation on species, determine how and how much energy flows from primary producers at the base of food chains to top predators.

Biological networks with greater diversity (*i.e.,* more species) are thought to be more stable, more resistant to disturbances, and allow more efficient energy flow to top predators. In part, this is related to overlapping ecological roles among species—the ability of multiple species to perform the same or similar functions in food webs. For example, if one species of prey goes extinct, a predator will be able to find another to take its place. Although we still don't know how ocean acidification will affect ecosystems, it is expected that ecosystem function will degrade if biodiversity is lost, and may reach an ecological tipping point if key species are reduced or removed. Studies of large marine ecosystems housing marine fisheries indicate that lower biodiversity is associated with low catch rates, greater variability, and higher chances of fisheries collapse (Worm *et al.,* 2006). And though the specific effects of ocean acidification on marine fisheries in the future remains uncertain, loss of biodiversity caused by ocean acidification and other environmental perturbations can affect ecosystem function, potentially leading to ecological 'tipping points.'

4. Ocean resources and services important to society depend upon the healthy ecosystems

Humanity depends on the function of ocean ecosystems for a range of resources and services, from processes as fundamental as oxygen production by marine phytoplankton, to shoreline protection, fisheries and aquaculture harvests, and recreational or spiritual experiences. It is my personal opinion that although predicting changes in ecosystem function due to ocean acidification is difficult, key elements of some ecosystems appear to be at high risk due to the expected reduction in calcification (and perhaps other related physiological processes) with increasing ocean acidity. Tropical coral reefs, deep-sea coral reefs, and mollusk-dominated food webs in high latitude regions may experience reductions in calcification that lead to important ecosystem changes. Consequently, societies depending on tropical reef systems may experience significant ecological and economic disruption. On the other hand, the potential increase in photosynthetic rates by phytoplankton could increase the energy available within some ecosystems, potentially leading to increased production at higher trophic levels as long as food webs function efficiently. Finally, although there will be losers and winners throughout ecosystems, I expect society, along with most ecosystems, will be on the losing side of this "game." Throughout Earth history, periods of rapid environmental change have often (but not always) led to a contraction in biodiversity that disrupted the function of ecosystems.

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Key Findings from the NRC Committee Report on Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean

The ocean has absorbed a significant portion of all human-made carbon dioxide emissions, benefiting society by moderating the rate of climate change, but also causing unprecedented changes to ocean chemistry. Carbon dioxide taken up by the ocean decreases the pH of the water and leads to a suite of chemical changes collectively known as ocean acidification. The long term consequences of ocean acidification are not known, but are expected to result in changes in many ecosystems and the services they provide to society. This report, requested by Congress, reviews the current state of knowledge and identifies gaps in understanding, with the following key findings.

1. Ocean chemistry is changing at an unprecedented rate and magnitude due to human-made carbon dioxide emissions. The average pH of ocean surface waters has decreased by about 0.1 pH unit—from about 8.2 to 8.1—since the beginning of the industrial revolution, and model projections show an additional 0.2–0.3 drop by the end of the century, even under optimistic scenarios of carbon dioxide emissions.

2. Changes in seawater chemistry are expected to affect marine organisms that use carbonate to build shells or skeletons. For example, decreased concentrations of calcium carbonate make it difficult for organisms such as coral reef-building organisms and commercially important mollusks like oysters and mussels to grow or to repair damage. If the ocean continues to acidify, the water could become corrosive to calcium carbonate structures, dissolving coral reefs and even the shells of marine organisms.

3. It is currently not known how various marine organisms will acclimate or adapt to the chemical changes resulting from acidification. Based on current knowledge, it appears likely that there will be ecological winners and losers, leading to shifts in the composition of many marine ecosystems.

4. The Committee finds that the Federal Government has taken positive initial steps by developing a national ocean acidification program. The recommendations in this report provide scientific advice to help guide the program.

5. More information is needed to fully understand and address the threat that ocean acidification may pose to marine ecosystems and the services they provide. Research is needed to assist Federal and state agencies in evaluating the potential impacts of ocean acidification, particularly to:

- understand processes affecting acidification in coastal waters;
- understand the physiological mechanisms of biological responses;
- assess the potential for acclimation and adaptation;
- investigate the response of individuals, populations, and communities; understand ecosystem-level consequences;
- investigate the interactive effects of multiple stressors;
- understand the implications for biogeochemical cycles; and
- understand the socioeconomic impacts and informing decisions.

6. The national ocean acidification will need to adapt in response to new research findings. Because ocean acidification is a relatively new area of research, the Program will need to adapt in response to findings, such as the identification of important biological metrics, analyses of the socioeconomic impact of ocean acidification, and inclusion of concerns from stakeholder communities.

7. A global network of chemical and biological observations is needed to monitor changes in ocean conditions attributable to acidification. Existing observation systems were not designed to monitor ocean acidification, and thus do not provide adequate coverage or measurements of carbon parameters, such as total alkalinity, pH, and dissolved inorganic carbon, or biological constituents such as nutrients, oxygen, and chlorophyll. Adding sites in vulnerable ecosystems, such as coral reefs or polar regions, and areas of high variability, such as coastal regions, would improve the observation system.

8. International collaboration will critical to the success of the program. Ocean acidification is a global problem that requires a multinational research approach. Such collaborations also afford opportunities to share resources, including expensive large-scale facilities for ecosystem-level manipulation, and expertise that may be beyond the capacity of a single nation.

9. The national ocean acidification program should support the development of standards for measurements and data collection and archiving to ensure that data is accessible and useful to researchers now and in the future. Steps should be taken to make information available to policymakers and the general public in a timely manner.

Senator CANTWELL. Thank you, Dr. Barry. And we'll look forward to asking you some questions about the recommendations from that report, and anxious to see those findings.

Dr. Everett, welcome, thank you for being here. We look forward to your testimony.

STATEMENT OF DR. JOHN T. EVERETT

Dr. EVERETT. Thank you, Madam Chair and members of the Committee.

Thirty years ago, I worked for the Committee, handling oceans and fisheries issues. I've sat behind you, and I've sat behind here for my other bosses, and this is the first time sitting at the table.

What I am going to present is swimming against the tide of what we're hearing; and so, I just want to make sure everyone knows, I'm not on anybody's payroll, other than my own. I have accepted no money from any groups that in any way influence my views on climate change.

My approach to the impact analysis is a product of my education and work at NOAA and for the Intergovernmental Panel on Climate Change. I led IPCC work on five impact analyses: fisheries, polar regions, oceans, and oceans and coastal zones, which was two reports. Since leaving NOAA, I have been an IPCC expert reviewer, and have maintained climate and other subjects in the U.N. Atlas of the Oceans, where I am the Chief Editor and Project Manager.

I am also President of Ocean Associates, Inc., an oceans and fisheries consulting business, with 70 people in six states. I also have a website called *ClimateChangeFacts.info*, where I try to keep track of and share all the latest information about climate change.

I have focused on seven concerns in my statement, including that marine life might lose the ability to make shells, and that existing shells will become weaker, and that the loss of shell-forming plants and animals will reduce food for those higher in the food chain; and there are about four others. These concerns are based on the work of respected scientists who believe increased CO_2 will dangerously increase acidification. They use IPCC scenarios developed in the early 1990s.

Other respected scientists believe that the scenarios have been overtaken by events; for example, the cost of fuels is rising, and the science shows the Earth's ability to absorb CO_2 has not diminished. And in my testimony, it also shows that the increase is a straight line, and may, in fact, be leveling off; still increasing, though.

Importantly, oceans are alkaline, not acidic. If all the CO_2 in the air were put into the ocean, the oceans would still be alkaline. We need to reassure bathers and scuba divers that when they put their feet in the water, they're not going to dissolve.

So, Madam Chair, a puddle of rainwater or a handful of snow is 100 times more acidic than the oceans will ever be.

I have reviewed the IPCC and more recent scientific literature, and believe that there is not a problem with increased acidification, even up to the unlikely levels in the most-used IPCC scenarios. This assessment is due to four primary factors.

First, laboratory work shows there is no basis to predict the demise of shell plants and animals living in the sea. The animals above them in the food chain will still find food. There are two noteworthy papers. In the first, Woods Hole Oceanographic researchers found that crabs, shrimp, and lobsters build more shell when exposed to acidification, and that hard clams and corals slowed formation of shells very—at very high CO_2 levels, while soft clams and oysters responded and—slowed at lower levels.

Second, the Iglesias-Rodriguez paper found that calcification and production in an important shell planktonic plant are significantly increased by high CO_2. Thus, the science actually indicates plants, crustaceans, and shelled algae plankton will be more successful. Since they are at, or near, the bottom of the food chain, this is good news.

Second, the Earth has been this route before. Whether or not laboratory studies provide the answers we think are reasonable, we need to look more broadly. Russian academicians—these are members of their Academy of Sciences that I worked with on IPCC—taught me to look at how the Earth responded in past eras when conditions were like those projected. They gravely distrusted computer models.

So, what can we learn from the past and what we see around us? The oceans have been far warmer and far colder and more acidic than as projected. During the millennia, that marine lift endured and responded to CO_2 that was many higher—many times higher than present. And it responded to temperatures that put tropical plants at the Poles or covered our land by a thick ice that was a mile thick. The memory of these events is built into the genes of all species, as Dr. Barry was talking about. Virtually all ecological niches have been filled at all times. If someone could demonstrate that there were no corals, clams, oysters, or shell plankton when there was double or triple the amount of CO_2, I would be concerned. The opposite is true.

Third, observational data show no harm. IPCC concluded, prior to the Iglesias-Rodriguez paper, that there is no observational evidence of oceanic changes due to acidification. There is also nothing conclusive in the recent research to indicate any reason for concern.

Last, natural changes are greater and faster than those projected. Major warming, cooling, and pH changes in the oceans are a fact of life, whether over a few years, as in an el Niño, over decades, as in the Pacific oscillation, or over a few hours, as a burst of upwelling appears or a storm bring acidic rainwater to an estuary and perhaps kills oysters and clams.

Despite severe and rapid changes that far exceed those in the scenarios, the biology adapts rapidly. The 0.1 change in ocean alkalinity since 1750 and the 1-degree Fahrenheit rise since 1860 are but noise in the rapidly changing system.

In the face of all these natural changes, whether over days or millennia, some species flourish while others diminish. With no laboratory or observational evidence of biological disruption, I see no economic disruption of the commercial and recreational fisheries, nor harm to marine mammals, sea turtles, or any other protected species.

Whichever response the U.S. takes, our actions should be prudent. Our research should focus on understanding those ecosystem linkages needed to wisely manage our fisheries and conserve our protected species. This includes research to explore further, the possible acidification effects, as wisely envisioned with the funds recently made available to NOAA.

I would be pleased to answer questions.

[The prepared statement of Dr. Everett follows:]

PREPARED STATEMENT OF DR. JOHN T. EVERETT

Mr. Chairman and members of the Committee, thank you for inviting me to appear before you today. I am John Everett. I am not here to represent any particular organization, company, nor special-interest group. I have never received any funding to support my climate change work other than my NOAA salary, from which I retired after a 31-year career in various positions. I was a Member of the Board of Directors of the NOAA Climate Change Program from its inception until I left NOAA. I led several impact analyses for the Intergovernmental Panel on Climate Change from 1988 to 2000, while an employee of NOAA. The reports were reviewed by hundreds of government and academic scientists as part of the IPCC process. My work included five impact analyses: Fisheries (Convening Lead Author), Polar Regions (Co-Chair), Oceans (Lead Author), and Oceans and Coastal Zones (Co-Chair/2 reports). Since leaving NOAA I have kept abreast of the literature, have continued as an IPCC Expert Reviewer, have talked to many individuals and groups and have maintained these subjects in the U.N. Atlas of the Oceans, where I am the Chief Editor and Project Manager. I own a fisheries and oceans consulting business called Ocean Associates, Inc. and a website ClimateChangeFacts.Info[1] that I try to keep unbiased in its treatment of conflicting science. This site is the number 1 Google-ranked site of many million for certain search terms. My approach to impact analysis is a product of my education and work experiences at NOAA and the work I led for IPCC. This statement provides my analysis of the effects of ocean acidification on our living resources and our economy.

All opinions are mine alone.

Background

I was assigned the climate change duties when I was the NOAA National Marine Fisheries Service Division Chief for Fisheries Development in the 1970s. The agency was very concerned about the impact of climate change on the United States fisheries and fishing industry. *Global cooling* would be devastating to our fisheries and aquaculture. About 1987, the momentum shifted to fears of *global warming* and with my background, and as Director of Policy and Planning for NOAA Fisheries, I was tasked to lead our efforts dealing with it. In 1996 I received the NOAA Administrator's Award for "accomplishments in assessing the impacts of climate change on global oceans and fisheries." In 2008, I received recognition from the IPCC for having "contributed to the work of the IPCC over the years since inception of the organization," leading to its Nobel Peace Prize.

I. The Concerns

There are several concerns about CO_2 entering the oceans and causing its pH to become lower. Their discussion in the press and among policy officials is at the foundation of this hearing. These concerns are:

1. Animals with calcium carbonate shells will lose the ability to make shells
2. Existing shells will become weaker
3. Loss of shell-forming animals will reduce food for those higher in the food chain
4. Many species will be gone in 30 years
5. Oysters and clams are dying
6. Jellyfish are increasing
7. Seagrasses will be injured

The concerns are based on the work of respected scientists who have shared the above beliefs or authored papers that argue the above points. They believe increased atmospheric CO_2 will increase the acidification of the oceans. The basis is largely a set of emission scenarios developed by IPCC in the early 1990s in an attempt to reign in the mass confusion about the future trajectory of CO_2 emissions. With this standard set of scenarios, climate modelers could then have a standard set of inputs in terms of what was broadly considered a primary determinant of climate—the proportion of CO_2 in the atmosphere. This proportion is based on new contributions after deducting removals by the Earth system and assumes a decreasing removal ability as CO_2 increases. For the first time, modelers around the world could compare results while impact assessment scientists and policymakers could look at points on which most models agreed. Standardization of scenarios allowed modelers to identify errors or alternative ways to predict or handle parameters, such as cloud cover. One of the scenarios became heavily used and is identified as IS92—Business

[1] *http://www.ClimateChangeFacts.Info*

as Usual. Nearly 20 years ago, it was a reasonable approach and pretty much in the middle range of alternative scenarios. It underpins much of the research findings I will present today.

There are other respected scientists who believe that the Business as Usual scenario has been overtaken by events. The cost of fossil fuels is rising, reflecting increasing scarcity and contributing to a slower CO_2 growth in the atmosphere and a lack of acceleration. New science shows the Earth's ability to absorb the same proportion of new CO_2 each year has not been diminished, removing a key underlying assumption. Importantly, oceans are alkaline—not acidic (much more so than rainwater), so use of the term "acidification" promotes fear. If all the CO_2 in the air were put into the ocean, the oceans would still be alkaline. With all this talk of acidification, we need to reassure bathers that their feet will not dissolve when they step into the ocean. Ocean water at the surface generally has a pH over 8 and neutral is 7.0 (pure water) while a puddle of rain water is far more acidic after having picked up CO_2 in its fall. Technically, we should say the oceans could become less alkaline, a term not so endearing to those trying to get attention.

II. The Physics

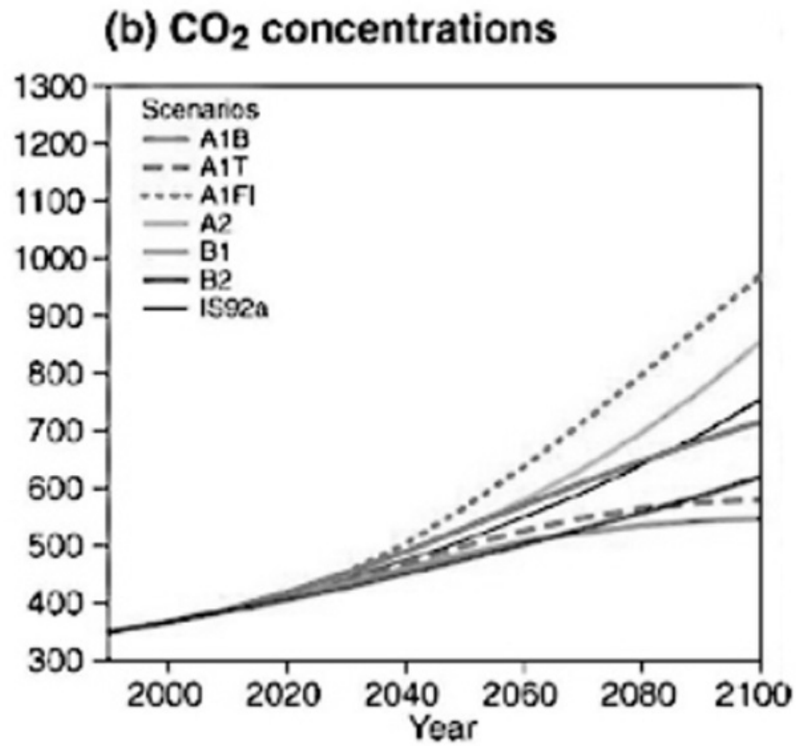
At the bottom of our inverted pyramid of climate science are a few good scientists working to improve our knowledge of how the Earth system operates, and then to project future possibilities. The physics are daunting. Similarly, the modelers must get observational input data from the physical world and from prognosticators about how many people will be born in future years and how they will get and use their energy. The number of scientists doing this work is small compared to the number who will use their information to analyze impacts and make policy recommendations to governments and industry.

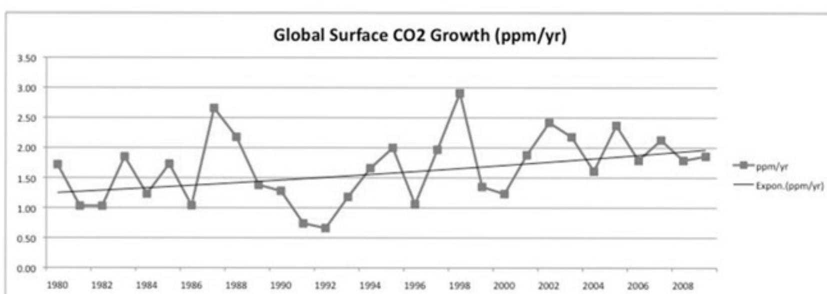
As a research manager much of my life, I have a healthy skepticism of things that underpin important decisions. Whether it is a column of numbers that will tie up a fishing fleet because of an addition error or a wiring harness on a manned lunar rocket that doesn't quite fit, I have learned to pause and check it out. There are some things at the bottom of the CO_2 pyramid that make it seem wobbly and in need of a check.

Physics tells us that increasing atmospheric CO_2 lowers oceanic pH and carbonate ion concentrations, thereby decreasing calcium carbonate. Surface ocean pH (a logarithmic measure of hydrogen ions) today is believed to be 0.1 unit lower than preindustrial values. The median value of ocean model runs projects that pH will decrease by another 0.3 to 0.4 units by 2100. This translates into a 100 to 150 percent increase in the concentration of H+ ions while carbonate ion concentrations will decrease. When water is undersaturated with respect to calcium carbonate, marine organisms can no longer form calcium carbonate shells. The model simulations project that undersaturation will be reached in a few decades.[1] The conventional wisdom also says that as CO_2 concentration becomes higher, saturation will mean that more of it will remain in the atmosphere each year, accelerating its accumulation.

However there are some major problems with the science. The wisdom at the time of the IPCC 2007 report was that half of CO_2 emissions would remain in the atmosphere and that we would have 712 ppm (IS92a) by 2100.[2] This would require the atmosphere to more than double the present rate of growth of CO_2 to 3.05 ppm, yet the growth rate seems to be leveling off. The meaning of this information (and the future of all climate models based on it) became VERY cloudy on 31 December 2009 with the ScienceDaily acknowledgment of a paper published by American Geophysical Union and authored by Wolfgang Knorr that shows "No Rise of Atmospheric Carbon Dioxide Fraction in Past 160 Years," despite the predictions of carbon cycle/climate models.[3] The implications of this have yet to be assimilated by the modeling community. This does not mean that CO_2 proportion is not rising but rather that the proportion not being assimilated has not changed since 1850. Importantly, it means that the rate of CO_2 cycling increases as it becomes more concentrated, and does not decrease as assumed in climate models. The rate of projected growth in CO_2 appears to be greatly exaggerated.

The CO_2 scenarios are literally falling flat and need revision. The observational trend line shows monotonic growth—pretty much a straight line as in the chart below of global marine CO_2 measurements (NOAA data),[4] while the IPCC scenarios used in most research rely on an accelerating growth. Certainly the predicted rapid acceleration of the IS92a model (see solid black line in middle of figure) is missing from the NOAA data plotted below. In fact, if we wonder if the last 8 or 12 years are representative of the future, we might imagine a downward slope in the growth rate. This could be real as rising prices cut usage and lead to economic distress. It could also mean that the ocean is absorbing more CO_2, which might not bode well in light of concerns over acidification. However, it may be that the ocean is converting and storing the CO_2 as calcium carbonate in the form of shells of oyster, clams and planktonic organisms. It is a complicated environment and there is much we do not know.





Using the average rate of increase for the past 10 years (1.87/year), and assuming a straight-line growth, my projection for 2100 is 560 ppm. I have great reservations about our ability to find the necessary amount of fuel even this would require, never mind enough to reach 712 ppm (IS92a) or higher.

Thus, if the projections we are concerned with today are based on the IPCC IS92a model, or one of its cohorts, and the concept of CO_2 sink saturation, we should give the information on its impacts a second look.

Further, if a model can't replicate the past by relying on principles of physics and mathematics, without "tuning" its parameters to reflect past variations, we must not trust that it properly represents the real world. Some important physics may be missing or misrepresented. This is particularly true of any model that failed to predict the present leveling of temperatures in the face of rising CO_2. I know of none that got it right.

Something is very wrong at the bottom of our inverted pyramid!

III. The Biology

The Concerns

Much of the concern flows form the latest IPCC report. The text from the Summary for Policy Makers states: "The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic with an average decrease in pH of 0.1 units. Increasing atmospheric CO_2 concentrations lead to further acidification. Projections based on SRES scenarios give a reduction in average global surface ocean pH of between 0.14 and 0.35 units over the 21st century. While the effects of observed ocean acidification on the marine biosphere are as yet undocumented, the progressive acidification of oceans is expected to have negative impacts on marine shell-forming organisms (*e.g.,* corals) and their dependent species" [5]

1. *Animals with calcium carbonate shells will lose the ability to make shells.* These animals include corals, coralline algae (*e.g.,* encrusting algae), and foraminifera, pteropods (swimming planktonic snails with aragonite shells), and mollusks (*e,g,.* clams and oysters).

2. *Existing shells will become weaker and even dissolve.* Dissolution of shells after death is the norm. Calcium carbonate flows back into the water wherever it is not saturated. In the deep ocean, this can happen rapidly to exposed shells.

3. *Loss of shell-forming animals will reduce food for those higher in the food chain.* Dissolved calcium and carbonate ions are used by ocean animals to produce their shells and skeleton. A lower pH can slow shell production by disrupting the supply of carbonate ions, thus slowing shell production and increasing the susceptibility to dissolution, early death and predation.

4. *Many species will be gone in 30 years.* This is founded in a belief in the IS92a emission scenarios and some research results.

5. *Oysters and clams are dying.* In the Pacific Northwest there are charges that an acidic ocean is to blame for extensive mortalities of young oysters and clams. Fears include the possibility that acidic upwelling waters will get even more so when exposed to high CO_2 air.

6. *Jellyfish are increasing.* Some have postulated that ocean acidification could open ecological space for noncalcifying species.

7. *Seagrasses will be injured.* Acid waters will disrupt life processes and slow growth.

Biological Considerations

There is limited research. I have reviewed the major papers and the critiques about the papers. Below are a few that I think merit bringing before the Committee. It is only a few that show no obvious bias. For example, it is quite common among researchers vying for scarce funding dollars to hype their findings or the importance of the problem. Whether it is the use of hydrochloric (HCl) acid to mimic CO_2 but which introduces other issues such as shell decay, or presenting the findings of grave consequences at high acidity while not mentioning the lack of change at lower levels, or not investigating whether low pH was due to degraded water quality from runoff and sewage, the real cause of reduced growth or mortality. In some cases a lower base year is chosen that exaggerates the percentage change, such as "pH levels will drop 30 percent from pre-industrial levels—when current levels are far less disputed, but the percent change is less."

Each study must be scoured for hints of inappropriate procedures and unfounded statements. None can be accepted at face value. The peer review process has warts. A good example is the dispute over whether acidification is good or bad for shell-forming plankton, a vital part of the ocean's biology and the ability to sequester vast amounts of CO_2. The first paper says more CO_2 is good, the second bad, and then the first successfully refutes the criticism and gets the last word, sustaining the positive assessment in great detail. All published in *Science*.

> "Ocean acidification in response to rising atmospheric CO_2 partial pressures is widely expected to reduce calcification by marine organisms. From the mid-Mesozoic, coccolithophores have been major calcium carbonate producers in the world's oceans, today accounting for about a third of the total marine C_aCO_3 production. Here, we present laboratory evidence that calcification and net primary production in the coccolithophore species *Emiliania huxleyi are significantly increased by high CO_2* partial pressures. Field evidence from the deep

ocean is consistent with these laboratory conclusions, indicating that *over the past 220 years there has been a 40 percent increase in average coccolith mass.* Our findings show that coccolithophores are already responding and will probably continue to respond to rising atmospheric CO_2 partial pressures, which has important implications for biogeochemical modeling of future oceans and climate.[6] "However, Riebesell *et al.,* vigorously attacked the paper, claiming that "shortcomings in their experimental protocol compromise the interpretation of their data and the resulting conclusions."[7] In rebuttal, also in *Science*, Iglesias-Rodriguez *et al.,* successfully demonstrate that the logic and methods of Riebesall *et al.,* are the ones that are flawed and the original findings of increased calcification are valid.[8]

Perhaps the most thorough review of the literature on acidification impacts is by Fabry *et al.,*[9] They found that little research was done on CO_2 concentrations that were relevant to answer today's questions. They express much concern that acidification will retard development of shells. They as do several other authors, note that studies have not been long-term enough to discover adaptations over multiple generations. I believe this is key because these genera have genetic information about past events and this may well take several generations for stabilization. In any scenario, there will be ample time for this to happen. In a laboratory it happens with the throw of a switch. If my family or its descendants needs to hold its head underwater for 5 minutes and they have a couple generations to adapt, it can be done. However, I can't do it very well today.

With respect to corals, Atkinson reviewed recent literature on . . . "how ocean acidification may influence coral reef organisms and coral reef communities. We argue that it is unclear as to how, and to what extent, ocean acidification will influence calcium carbonate calcification and dissolution, and affect changes in community structure of present-day coral reefs."[10] Also, the latest IPCC report (summary above) found no empirical evidence supporting effects of acidification on marine biological systems.[11]

Kurihara *et al.,* investigated the "effects of seawater equilibrated with CO_2-enriched air (2000 ppm, pH 7.4) on the early development of the mussel" and found that the mussels, as clams studied by them earlier, were significantly impaired when exposed to CO_2 over 5X! that of today.[12]

Marubini *et al.,* found that seawater acidification may lead to a decrease of tropical coral growth calcification. This effect is either mediated by a decrease in carbonate, in pH, or by an alteration of the internal buffering system leading to a disruption of carbon supply to calcification rather than by a direct effect of CO_2 or a change of HCO_3-concentration. Results showed that the negative effect of acidification may be counteracted by increasing the bicarbonate concentration of seawater, resulting in an increase in the carbonate concentration.[13]

Research in laboratories shows that shell growth is slowed in some animals and enhanced in others. Woods Hole Oceanographic Institution (WHOI) researchers found that 7 of 18 species of animals "such as crabs, shrimp and lobsters—unexpectedly build more shell when exposed to ocean acidification caused by elevated levels of atmospheric carbon dioxide (CO_2)"S.[14] They tested as high as 7 times present levels. They found that hard clams and corals slowed formation of shells but only above 1,000 ppm, while soft clams and oyster slowed formation at lower levels. Note that the shells did not dissolve, but only grew somewhat slower at 7X present CO_2 concentrations.

There is no basis to predict the demise of shelled animals living in the sea or the animals above them in the food chain at any likely level of CO_2 that might be put in the air by humans.

A study at the University of Hawaii found the olfactory-based homing ability of clownfish was disrupted at 1,000 ppm and non-existent at 2,000 ppm. The values of CO_2 acidification were high: "These values are consistent with climate change models that predict atmospheric CO_2 levels could exceed 1,000 ppm by 2100 and approach 2,000 ppm by the end of next century under a business as usual scenario."[15] This has implication for all fish that need to find their way back to natal streams, if we were ever to get to 1,000 ppm.

With respect to clam and oyster mortalities being caused by acidified water, it is unlikely that CO_2 deposition from the air is the culprit. Upwelling brings water from the depths to the surface. This water has been out of sunlight perhaps for centuries. There has been no photosynthesis for plants to turn the CO_2 into oxygen, and whatever oxygen there was, has been converted into CO_2 by animals. When this cold water reaches the surface, it is saturated with CO_2 and is acidic, plus it has little oxygen. This warming water will be outgassing CO_2, rather than picking it up as claimed by some. Acidic water is also symptomatic of coastal eutrophication, whether caused by runoff or sewage. The WHOI work cited above shows that the growth of clams and oysters can be slowed by CO_2-induced acidification. In their studies, the animals did not die even at rates several multiples of today's CO_2 levels and for clams, growth slowed only at the highest levels of CO_2.

Example of shell formation at 7X current CO_2. Source: WHOI 2009

Enlarge Image

The conch shell at left was exposed to current CO2 levels; the shell at right was exposed to the highest levels in the study. (Tom Kleindinst, Woods Hole Oceanographic Institution)

Enlarge Image

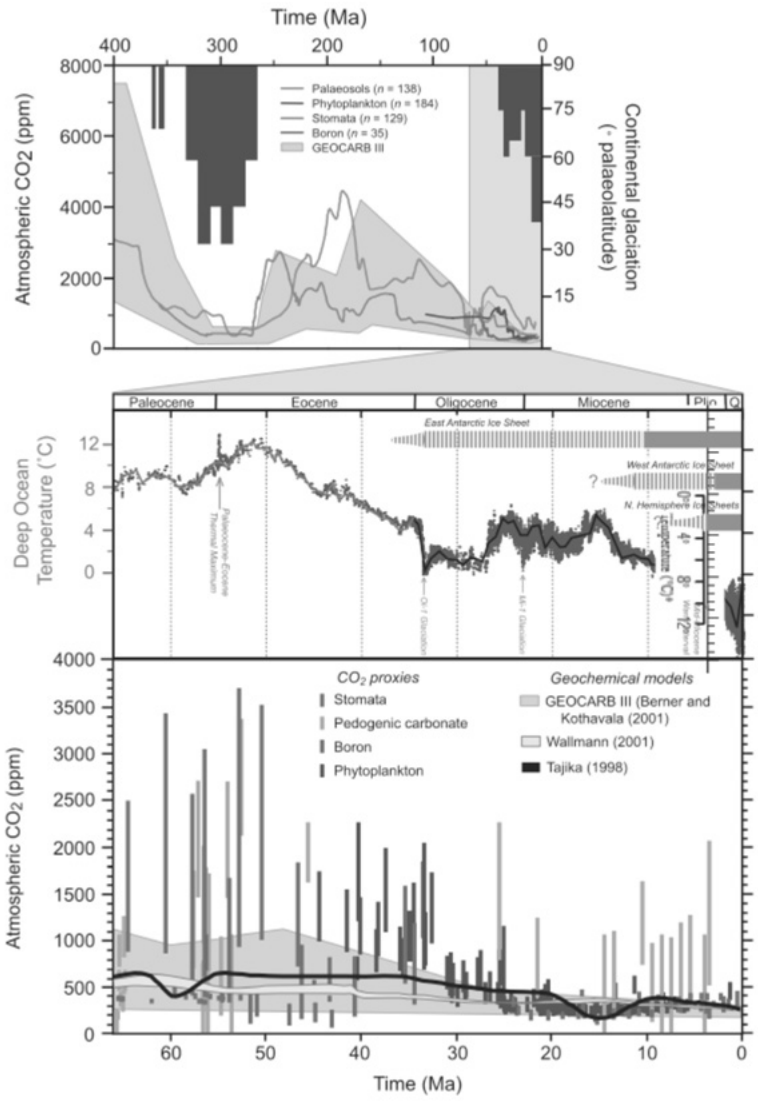
The larger of these two pencil urchins was exposed to currrent CO2 levels; the smaller was exposed to the highest CO2 levels in the study. (Tom Kleindinst, Woods Hole Oceanographic Institution)

With respect to being overrun with jellyfish, because ocean acidification could open ecological space for noncalcifying species. Richardson and Gibson studied the possibility that there were more noncalcifying jellyfish when conditions were more acidic (lower pH) in the Northeast Atlantic using coelenterate records from the Continuous Plankton Recorder and pH data from the International Council for the Exploration of the Sea for the period 1946–2003. They could find no significant relationships between jellyfish abundance and acidic conditions in any of the regions investigated.[16]

With respect to sea grasses, Zimmerman studied sea-grasses that form the bases of highly productive ecosystems ranging from tropical to polar seas. Despite clear evidence for carbon limitation of photosynthesis, seagrasses thrive in high light environments, and show little evidence of light-induced photoinhibition. Increasing the availability of dissolved aqueous CO_2 can increase instantaneous rates of light saturated photosynthesis by up to 4-fold. Prolonged exposure to elevated CO_2 concentrations increases the concentrations of non-structural carbohydrates (sucrose and starch), rates of vegetative shoot proliferation, and flowering, and reduces light requirements for plant survival. Consequently, seagrass populations are likely to respond positively to CO_2 -induced acidification of the coastal ocean, which may have significant implications for carbon dynamics in shallow water habitats and for the restoration/preservation of seagrass populations.[17]

IV. Has this Happened Before?

From 50–600 million years ago, CO_2 levels in the atmosphere were usually 2–20 times higher than at present. All the animals of concern evolved during this period. This included the age of the dinosaurs, when life was so prolific on land and in the oceans that we are still using the carbon (and chalk) deposited during those periods. The animals of concern all should have the innate genetic plasticity to quickly respond to the relatively modest changes of even the unlikely worst-case scenarios, none of which move our atmosphere's present concentration of CO_2 into the earlier range. The CO_2 we are putting into the atmosphere, originally came from it during the epochs when the species of concern flourished. The chart below compiles the work of several authors and methods. It is from the latest IPCC report, showing time in Ma (millions of years) before present. For comparison, the present CO_2 level is 388 ppm.



V. Is this Bad or Good or Just Different?

We and all other animals use oxygen and expel CO_2. Plants do the opposite. CO_2, combined with light and nutrients is their food. We must not lose sight of the fact that plants have consumed once-abundant CO_2 to the point that it is 0.000388 of the atmosphere. Many greenhouse operators pump CO_2 into their buildings to enhance growth, indicating plants evolved during higher concentrations of CO_2. Plants in the ocean also rely on CO_2. There is a high ability to move the excess out of circulation, turning it into oxygen (by plants) or calcium carbonate (by animals-mostly). A view of the CO_2 growth chart and analyses such as that of Wolfgang Knorr cited above show this has not been adequately taken into account by climate modelers or those who provided their inputs.

We know that the Earth has seen these conditions before, and that all the same types of animals and plants of the oceans successfully made it through far more extreme conditions. Virtually all the ecological niches were filled at all times. If someone could demonstrate that there were no corals, clams, oysters, or shelled plankton when the Earth had double or triple the amount of CO_2 in the air, we would have reason for concern. Just as IPCC has concluded, there is no observational evidence that things would be better or worse, or even different. Similarly, there is nothing conclusive in the very recent scientific literature to indicate any reason for concern. If anything, the science indicates plants will be more successful, and since they are the bottom of the food chain, this cannot be totally bad.

VI. What Can Be Done about It?

Oceans are actually alkaline with a surface pH of around 8.1. But it can vary from higher levels in shallow areas, where CO_2 and hydrogen ions are consumed by plants, to relatively acidic areas in eutrophic estuaries. Upwelling areas are also less alkaline, as cold bottom waters are brought into sunlight near the surface where algae use the deep-water CO_2 and nutrients to create a productivity boom that sustains fisheries production in several areas of the world. There are no long-term data, using similar instruments that provide a real clue as to global trends in alkalinity. There are only a few data sets of over a decade, such as that of the Monterrey Bay Aquarium. The variability, because of nearby ocean currents and upwelling shows the difficulty in portraying a global average value.

Some pundits have argued that we could add limestone to the oceans to make them more alkaline, but this has little merit due to costs and the fact that the oceans already contain immense buffering capability. We should bear in mind that this limestone and chalk for the most part came from the shells of plankton as they fed on the CO_2-laden ancient seas.

VII. Research Suggestions

There are some items that would go a long way toward establishing the likely effects of an increased CO_2 world.

1. Develop a CO_2/temperature timeline based on extant research on past climates, at least back to about 600 million years before the present. This effort would provide a critical review of candidate papers and unpublished work that goes well beyond a typical peer-reviewed journal publication, or prior summary reports of the IPCC.

2. The acidification debate has showed us we lack a sufficient understanding of some fundamental chemical and biological processes. The research to resolve these questions should continue and perhaps centrally coordinated so that scarce dollars are targeted at real and important knowledge gaps.

3. Examine the growth rates, densities, and shell thicknesses of clams, oysters, or other mollusks from Indian middens and sediments to determine if any changes can be detected and if they correlate to any known changes in the oceans or atmosphere, including pH and CO_2 levels.

4. Before the next IPCC assessment begins, assemble a USA review team and nominees for the IPCC writing and Chair assignments that make up a cross-section of scientific viewpoints. There are qualified scientists in agencies, industry, and among the citizenry who can contribute. Just as we shouldn't have too many from the energy industry, the same goes for the agencies, universities, and NGO's. We all have biases, even if we think it is the other person who is the one with an agenda. We cannot afford to have only people with the same agenda, no matter how righteous they might think it to be.

VIII. Concluding Remarks

There is no reliable observational evidence of negative trends that can be traced definitively to lowered pH of the water. If there were, it would be suspect because there is insignificant change relative to past climates of the Earth. Scientific studies, and papers reviewing science papers, have similar messages. Papers that herald findings that show negative impacts need to be dismissed if they used acids rather than CO_2 to reduce alkalinity, if they simulated CO_2 values beyond triple those of today, while not reporting results at concentrations of half, present, double and triple, or as pointed out in several studies, they did not investigate adaptations over many generations.

The oceans and coastal zones have been far warmer and colder and much more acidic than is projected by climate models. Marine life has been in the oceans nearly since when they were formed. During the millennia life endured and responded to CO_2 levels well beyond anything projected, and temperature changes that put tropical plants at the poles or had much of our land covered by ice more than a mile thick. The memory of these events is built into the genetic plasticity of the species on this planet. IPCC forecasts are for changes to occur faster than evolution is considered to occur, so impacts will be determined by this plasticity from past experiences and the resiliency of affected organisms to find suitable habitats.

In the oceans, major climate warming and cooling and pH changes are a fact of life, whether it is over a few years as in an El Niño, over decades as in the Pacific Decadal Oscillation or the North Atlantic Oscillation, or in a few hours as a burst of upwelling moves into an area or a storm brings rainwater into an estuary. Upwelling and rainwater each have pH values that are dozens or orders of magnitude lower than in any scenario.

Currents, temperatures, salinity, pH, and biology change rapidly to the new state in months or a couple years. These changes far exceed the changes expected with human-induced climate change and occur much faster. The estimated 0.1 change in alkalinity since 1750 and the one degree F. temperature rise since 1860 are but noise in this rapidly changing system. Sea level has been inexorably rising since the last glaciation lost its grip a mere 10,000 years ago. It is only some few thousand years since trees grew on Georges Bank and oysters flourished on its shores. Their remains still come up in dredges and trawls in now deep water, with the oysters looking like they were shucked yesterday. In the face of all these natural changes, and those we are here to consider, some species flourish while others diminish.

I do not know whether the Earth is going to continue to warm, or that having reached a peak several years ago, we are at the start of a cooling cycle that will last several decades or more. I think carbon-based fuels will continue to increase in price and become scarcer as reserves are depleted even though I am an optimist about our technological advances in helping us find and exploit additional reserves. Nevertheless, our consumption is more likely to fall than to rise. In any case, I am optimistic about our ability to deal with the consequences.

The most important approach in determining the impact of CO_2 on the oceans is to examine what happened during past times. The world has been down this path before and all the existing genera, and many species, endured. It has often been a difficult journey, with volcanism, meteoroid collisions, severe ice ages, and great heat, with many of these events causing mass extinctions. The ancestors of these animals were on Earth long before humans. They are the survivors of great disasters. The memory of these difficult times is in their genetic makeup. Adaptation will be swift, if needed.

Whichever response the U.S. takes, our actions should be prudent. Our fishing industry, maritime industry and other users of the ocean environment compete in a world market and are vulnerable in many ways to possible governmental actions to reduce CO_2 emissions. We already import most of our seafood and many of the nations with which we compete do not need further advantages. Our research should focus on those ecosystem linkages we need to understand in order to wisely manage our fisheries, and conserve our protected species.

I think it is important to do the necessary research to see whether my views or those who see impending doom are correct. The research is important, but actions that would decrease our Nation's ability to afford the research should not be taken on the basis of what I believe is unfounded fear.

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Senator CANTWELL. Thank you, Dr. Everett, and thank you for your views. And we're glad that you've made it to the witness table, so—a long journey, being in the audience and back here.

My colleague from Alaska has joined us.

Do you want to make any kind of statement, Mr. Begich, before we go to questions?

Senator BEGICH. Madam Chair, no. We'll—I'll be happy to just go to questions, when that time is allowed.

Senator CANTWELL. Thank you, Senator.

I'm going to start off, and let's just jump right into it, Dr. Barry. And Dr. Everett claims that oceans will, you know, never truly become acidic, below a—a, you know, a pH below 7, and therefore, the term is somewhat misleading. But, isn't this really about, not the acidification level, but the chemistry of the oceans itself? And, as Mr. Waters correctly put it, why would we risk waiting to find out, when it's too late?

Dr. BARRY. Well, the pH of the ocean, or alkalinity or acidic—it's really just semantics. I think if we went to the newspapers and said, "The oceans are getting less alkaline," that's a little confusing. But, I think something about acidity is something that we can understand. So, when this term first came up, the idea that the ocean was acidic—it was understood, by all the chemists: 7.0 is considered neutral, and the oceans are about 8.1 in pH. There's really no thought in the scientific literature or community that the oceans are "acidic," by that standard. They're becoming more acidic, or less alkaline, but it's really a semantic term.

Now, what is going to go on in the future is really what's important. How much change have we seen, and how much will we see in the future? And all of the predictions that I have seen, even the most conservative models, suggest that we will see quite large changes in pH in the ocean in the future.

Now, think of it this way, in temperature, because acidity's a little difficult to understand. But, let's say that the range—because Dr. Everett talked about the natural range of variability, and he's correct that there is quite a wide variety—or quite a wide range of variability in some habitats in ocean acidity. And I'll say two things about that.

Number one, what if we took the temperature range that we live in—let's say, 50 degrees to 100 degrees—and we decided, we're going to now move that range by 50 degrees. Now we live between 100 degrees and 150 degrees. That would be quite stressful for humans, to live under those conditions.

So, we are basically asking organisms that live in the ocean, if all of the best science is correct about where we're going in the future, we're going to ask them to live in an ocean that has a range in pH that is, in many cases, outside the entire range that they have seen throughout much of their recent evolutionary history.

The second point I guess I'd like to make with this is that Dr. Everett is correct, environmental conditions change, and animals survive that. But, they—it doesn't mean that they perform at their optimal point throughout that period. So, animals might survive el Niños, but their performance, their survival, their growth, and their reproduction may be impaired during periods of their normal range that are stressful. If we shift that entire range over to a period where maybe they can tolerate the lower acidity—I'm sorry, the—say, the warmer part of it, but when it gets really hot, they're going to die, we have a real problem. So, when we started shifting the entire environmental range, that's where we get into trouble, I think. And that's the comment I have for that.

Senator CANTWELL. And what do we do about that change in chemistry? I mean, I think your example is a good one. We, in the Northwest, always talk about this impact, because we're a hydro system—you know, all of—you know, 70 percent of our electricity comes from hydro, which means snowpack matters to us. One degree change in the temperature means millions of dollars difference in the cost of electricity—1 degree. And so, what—when you have this chemistry change, what does it mean for the uncertainty, and what can we do to address that? What are the recommendations?

Dr. BARRY. Well, in the report, we recommend a program that begins with many of the recommendations that came from the FOARAM bill and the scientific community, and builds a framework of research that includes a variety of themes, running from basic physiology—How do organisms make calcium carbonate shells?—because we need to understand some of the basic mechanisms, as well as trying to understand, from the top down, How do—will these changes in the performance of individual organisms scale up to what goes through food webs and eventually provides ecosystem services?

And I can go into many more details, if you like. I'm not sure I answered this question entirely for you yet.

Senator CANTWELL. Well, I think the panel has done an excellent job. I wanted to ask Ms. Weaver about how she, you know, got involved in this issue, as it related to, you know, to acidification, you know, from the perspective of explaining it. But, I think you've all done a—you know, a fabulous job of talking about where we are today, in the graphics of that food chain and what's at risk, and yet doing nothing and saying, "Well, let's just see what happens"—it's just unacceptable.

Dr. BARRY. I agree with you.

Senator CANTWELL. It's just unacceptable.

So, Ms. Weaver, did you want to comment on your—I mean, were you surprised, when you got more involved with this, at the level of impacts to our ocean? Was it something you had been——

Ms. WEAVER. I think that I—oh, thank you. I should know how to do that.

I think that—you know, I consider myself a fairly well-informed citizen, and, you know, someone who participates a lot in the water. And the fact that I knew nothing about the scientific data came as a—it came as a huge shock to me. And it seemed to me that if every American citizen were given—could hear the testimony today, and could see this film we made, and certainly include Dr. Everett's testimony in this, that this is not an area—this is an area where we really look to our leadership to be informed and to take steps.

I think that scientists are putting together different parts of the puzzle of climate change. We may not have absolutely all the pieces. There may be a couple under the sofa. But, we have enough of the pieces to be sending out a cry to face this. To see, you know, Mr. Waters' testimony is so moving, and it's a—it's very heartwarming to me, since I come from such a different world, to hear his testimony, seeing what's happening to his beloved finned creatures, you know, looking ahead and looking at their future, as a fisherperson, rather than as an eater and admirer, like myself.

[Laughter.]

Ms. WEAVER. And, you know, I just feel that—such power in this committee. Even if we disagree on some of the scientific data, we're all sending the same message, which I think comes from all of the citizens, which is, "We need your leadership, and we need your courage, and we need people to put aside whatever their partisan or regional view is and help each other pass this climate bill and get us toward a clean energy—clean and renewable energy future." You know, we just cannot take the chance that all four of us are correct. Only one of us is—has a different opinion.

So, thank you.

Senator CANTWELL. Thank you. Thank you.

Senator Snowe?

Senator SNOWE. Thank you.

Well, just to follow up, Ms. Weaver, because obviously I think anybody who sees this documentary can certainly appreciate it, because it graphically portrays the problem that we're presented globally. And it's a question of how to communicate that and make it more accessible to the public to enhance awareness, because that also generates public support for what we do.

In your travels around the country, or the world, do you sense that people understand this, in your discussions? If they have seen this video, for example, or if you've had a chance to have conversations with people, do you feel that they have a better appreciation or understanding? Are they surprised? Or do you think it generates support?

Ms. WEAVER. I think the audiences are very surprised. I think this is completely off their radar. There's been so much attention to climate change, global warming, and for many years people were—seemed to be happy that the oceans were absorbing so much CO_2, because it meant that things were not going to heat up quite as fast.

And now the science has—you know, the scientists have discovered that it's having this unseen, really devastating impact. And I respect Dr. Everett's, you know, statistics, but I have read that, for instance, if, in Antarctica, where there's so much plankton—the plankton now, they are 30 percent less strong. Their shells have been compared to the shells that were found in the very bottom of Antarctica, and their shells are 30 percent less strong. The coral is growing off of Australia at a 14- percent less growth. We have the oyster beds off the coast of the Northwest.

I mean, these creatures are like the canaries in a mine, and they are sending a message to all of us. And I think my job is certainly to try to reach out to, just, citizens and try to continue to carry this news, because, frankly, I think, if the man, the woman, and the child, certainly, on the street—children in classes—they're actually more hip to the danger we're facing than a lot of other people. They may not have the facts that this film can give them; and when they get these facts; they are alarmed; and they know that we can't afford to waste any more time. We have to face this, and act.

Senator SNOWE. I appreciate that. And it is true, because public education and awareness have to be such a big part of this. And you being a great communicator, along with Mr. Waters. Maybe you can make a duo.

[Laughter.]

Ms. WEAVER. We'll talk about it.

[Laughter.]

Senator SNOWE. OK. In any event, communication has to be part of it. Communicating what the problem is, in terms of, obviously, the solution.

In Maine, we have the Gulf of Maine Research Institute, which is a fabulous institution. I know the NRDC has worked with them, and they just screened this video, as a matter of fact, and they bring in schoolchildren from around the state to have a chance to understand and appreciate marine life, and the maritime way of life.

Ms. WEAVER. Yes. I actually was at Brooklyn Tech, in New York last Saturday, where some of us on "Avatar" were giving out ecowarrior awards, and the children spoke so passionately about our environment. One little boy said that we are the predators, now, and nature is our prey.

Senator SNOWE. Yes.

Ms. WEAVER. And I think the kids are really very concerned about what's going on, not only under the water, but all over the world and in our atmosphere, and we owe it to them to come up with answers now.

Senator SNOWE. Absolutely.

Thank you.

Dr. Barry my question is on public policy. I think, indisputably, there is a chemical reaction. I mean, the link is indisputable. And the real issue now is the implications of that and what we do, in terms of enhancing the certainty about the direction we take.

At NOAA, can you comment on what you think the policy should be? Whether it's on the research, on the monitoring devices, or the biological assessments, for example. What are the issues? Do you think they're moving in the right direction? Because now we really have to refine and modify our policies, and I think we need to make sure exactly what direction we should be taking at as a committee and as a Congress.

Dr. BARRY. Well, I'll comment based on the report, because what the summary report has—is—that came out just this morning—recommends is a national ocean acidification strategy that is really a fairly large program that includes monitoring of conditions throughout areas in the ocean, and especially those that we don't—we're not certain about right now, as well as a program of research to try and understand, especially, areas of uncertainty.

I think that the steps that NOAA has taken with the FOARAM Act is a perfect framework to begin with. And this program that the Committee is recommending leverages, off ocean observing systems, just about anything that will fit the bill within this framework to try and address this issue. And there's a lot that can. All of those should be used to begin moving forward to try and narrow the uncertainties concerning a variety of areas of this research. I'm——

Senator SNOWE. Well, it's a 10-year strategy that you're recommending?

Dr. BARRY. The recommendation in the FOARAM bill is for a 10-year strategy that's—then is revised. And we—I would have to make sure that we follow the same—in the summary, I'm not—I can't recall, specifically, if we——

Senator SNOWE. You did.

Dr. BARRY.—call for 10 years, here, or if there is no timeline. This calls for a program that still will require contact with a variety of stakeholders to define exactly what the program would be, but it would certainly include characterizing ocean chemistry better than we have, as well as trying to figure out, How can we characterize the biology, without spending billions of dollars, so that we can document these changes as we move forward?

Senator SNOWE. OK, are there any areas that we should be prioritizing, for example, in all of this and in the areas that you have identified?

Dr. BARRY. Well——

Senator SNOWE. Because I think that's critical. And you mentioned the ocean observing system, which I do, as you know, repeatedly——

[Laughter.]

Senator SNOWE.—and, I don't know, it is moving in the wrong direction in terms of funding. This is an ideal network that we should be using for this purpose, but the funding recommendations are undercutting the system. It should be working in tandem.

Dr. BARRY. Well, the report in the Committee feels that we need to leverage off of just about any technology that's available and any system that's available. But, we did not set priorities for exactly which of these research tasks should be placed first. So, if—in number five, for example, we come up with eight research priorities that are unranked.

Senator SNOWE. Right.

Dr. BARRY. And so, the Committee did not rank those, at this point.

Senator SNOWE. OK. But, should they all happen at the same time?

Dr. BARRY. Well, in some cases, if you look through these, they do require some overlap, so they're—in some—some things, you would want to do in tandem. It makes no sense, for example, to characterize ocean chemistry without parallel biological studies going on at the same time.

I wish I could give you more clear guidance about the priorities, but that's something that we didn't cover.

Senator SNOWE. I appreciate it. Thank you.

Senator CANTWELL. Senator Lautenberg?

Senator LAUTENBERG. Thank you, Madam Chairman.

And thank each one of you for your testimony.

A couple things that are mystifying for me is the difference in perspective that we hear from Mr. Everett—Dr. Everett and the others of you.

And, Mr. Waters, don't dismiss your articulate skills. Don't underestimate your message, because it comes from the gut, and that's the kind of thing that we have to hear. And you're onsite, I mean, you're—you see the effects of problems that are developing in our oceans. And obviously we think that—in this particular hearing, that one the major ones is the acidification of the oceans and its effect on coral, coral being kind of the home place that fish can find refuge and procreate and do all of the things that we want them to do.

Dr. Everett, you're in business, am I correct? You said you had a consulting business?

Dr. EVERETT. Yes, in my—I come from a fishing family, and I just——

Senator LAUTENBERG. No, but——

Dr. EVERETT.—divested of all of that, but I do ocean climate consulting.

Senator LAUTENBERG. So, and you, therefore, have clients and——

Dr. EVERETT. Yes.

Senator LAUTENBERG. Yes.

Dr. EVERETT. And let me say, they're all public-sector, there are no private-sector clients.

Senator LAUTENBERG. Yes. What kind of clients might you have? Is it—can you tell us anything about——

Dr. EVERETT. Yes, mostly NOAA and United Nations Food and Agriculture Organization.

Senator LAUTENBERG. And do they give you opinions on your conclusions?

Dr. EVERETT. Not about this. I have no work on climate change with NOAA.

Senator LAUTENBERG. But, you know, you list the things that others are concerned about, in your testimony, about loss of shell-forming animals, reduced food for those high on the food chain.

Dr. Barry, do we have specific things? You know, I know we often, around here, wait for studies to be concluded, and so forth, and it—but, meanwhile, if there's a fire in the house, you don't have to start figuring out how the fire got started, you've got to figure out how to put the fire out.

Do we have things that you—using my analogy, do you have things that you would, say, tell us, "There is fire there," that these are things that we can see, these are things that we can feel, like Mr. Waters in his comments?

Dr. BARRY. I think I understand the question, and this would be my personal view of this, as a scientist. And I would say, yes, I think there are things that we need to be very concerned about. Just as—and let's say that there isn't a fire in the house. We would certainly insure against the case that we might have one, and that's something we are not doing well with our oceans.

Senator LAUTENBERG. Right.

Dr. BARRY. In this case——

Senator LAUTENBERG. That's part A. And part B——

Dr. BARRY. Right. And then, part B, there are some things that are going on, although—it's interesting to look at how organisms respond to changes in their conditions. And let's—just ocean acidification—it can affect your acid-based balance, but it might be—have a positive effect on calcification; or it could affect calcification, but at the expense of growth by tissues. And so, there is a lot of responses that organisms perform.

In general, organisms calcify less under a more—more acidic conditions. But, there are a few species that are anomalous in that way. There is a—Dr. Everett mentioned Justin Ries' paper, which surveyed 18 species, showing that several crustaceans, a couple of lobsters, actually grew quite a bit larger.

Now, I know Justin is now looking for funds to try and figure out what really happened there, because there have been a variety of studies that have shown—in cases where things have calcified more, which is not what you'd expect, they've actually found that they're—they had tissue loss or they had suffered some other problem, metabolically.

So, to get back to the point, I think that we have to be worried about these trends in ocean chemistry, and the future in ocean chemistry, coupled with the information that we have now about the responsive organisms. There's a fire there, or if it's—if it's not—it may not be a roaring blaze yet, but it's certainly—there's something starting on the curtains in the corner.

Senator LAUTENBERG. Right. Yes, but do we feel the heat? Do we see this—the reality of shells being too soft or even transparent in places? Is that there in any quantity that we can point to, that we—that reduce the supply of the numbers of crustaceans that we—that are out there?

Dr. BARRY. That's a tough one, because we don't have much of a context to measure that from. We have not been going along, measuring the thickness of shells for a variety of marine animals. There are now a few papers that have begun to come out to show that, in areas where we think there are some vulnerabilities—and in polar areas, that Sigourney mentioned, the calcification of marine terrapods, which are an important prey species for a variety of animals—they're little snails that live and float through the water, beautiful little things—their shells are affected by ocean acidification.

And in the Antarctic—in polar regions, in general, the water's colder, it absorbs more CO_2, it's naturally more acidic. And when you add the extra burden of CO_2 from the atmosphere, it makes it that much more acidic, and it's a more difficult place, in general, to make shells. There's evidence, there, that shell formation is decreasing.

On—in the Great Barrier Reef, there's a paper recently that came out to show that there has been a reduction in the rate of calcification on the reefs itself. And it's difficult to attribute it to either—only to ocean acidification; it may be an acidification and global warming or water temperatures rising.

So, the problem with multiple stressors is that it may be—there's an effect of ocean acidification plus there's an effect of global warming plus there's an effect of pollution, but we don't really understand how those multiple stressors will work. It may not be A plus B plus C, it could be A plus B times C; it could be nonlinear. So, there are some real problems that we're not sure of.

Senator LAUTENBERG. Dr. Everett, do you see any warning signs that concern you about the condition of the ocean's ecology?

Dr. EVERETT. Well, sir, if you had asked me, say, 2 weeks ago, before this hearing, I would say that one of my primary concerns in the climate change area was ocean acidification. In the preparation of this, 2 weeks, perhaps 10 days of—this is pretty much all I did, and, one staff person, all that she did, poring over the literature, getting everything together, the—I changed my testimony from being of great concern to being as I testified. And so, that's——

Senator LAUTENBERG. What was—just in short form, repeat for me the conclusion you've come to, that things are—that's life and, you know—let me not speak for you, let me——

Dr. EVERETT. No, I think what Dr. Barry said is—I agree, 100 percent, and we need to find out whether the conclusion I came to, which says it's—acidification is important, but doesn't look like it's a problem. But, we need to find out, it—you know, am I wrong? And let's follow the research protocol being laid out for NOAA and others, and let's get at the bottom of it.

I come from a fishing family, as I said; and my father could also, as Mr. Waters, speak very eloquently. And my father didn't go to college, but he spoke from the heart. And we're very much in favor of the clean environment. Let's clean up our act. OK? That's the important thing. I'm not a CO_2 advocate. I'm just saying that I don't see damage.

Senator LAUTENBERG. Well, you had a quick study, there, obviously. You've been—10 days, 2 weeks. You——

Dr. EVERETT. Oh, I—but, I've done it for close to 30 years. This was a brush-up.

Senator LAUTENBERG. So, then you were a slow study for a lot of years——

Dr. EVERETT. Yes.

[Laughter.]

Senator LAUTENBERG.—before that.

Dr. EVERETT. That's right.

Senator LAUTENBERG. The—we're not fishing families, but we are fish-eating people, and I thank you all for your testimony.

Sigourney, you look like you want to say something. And I don't have the—I'm the seniority in the Committee, as you see, to cut you off, so—[Laughter.]

Ms. WEAVER. I hope that Dr. Everett watches our documentary. It's not fiction. And certainly I've done enough science fiction to know that the Earth can survive, in various forms, through lots of different nightmarish scenarios. But, again, that's sort of entertainment. And, as a citizen, I think that we simply cannot take the chance. We have to be on guard. We have to see these warning signs and act, and be able to look in our children's eyes in 20 years and say, "Yes, we did the right thing when we got these early reports. We acted. We didn't have all the information, but we had enough to know which direction we should go in."

Senator LAUTENBERG. I thank the Chair——

Senator CANTWELL. Thank you. Thank you.

Senator LAUTENBERG.—colleagues for the——

Senator CANTWELL. Thank you.

Senator Begich?

STATEMENT OF HON. MARK BEGICH, U.S. SENATOR FROM ALASKA

Senator BEGICH. Thank you very much, Madam Chair. And I'll try to go through my questions, here, and then I've got to get back to another committee. I have some amendments pending.

Let me ask, just first off, from Alaska, you know, we have—62 percent of the fresh-caught fish in the country comes from Alaska, so we have a huge interest in the issue of climate change or acidification of waters, as one element of it. We also see the greatest impacts. There's no other state that sees it, compared to us. So, I want to—most of you already know that.

But, as I look at the document I have here, which is the draft—and I know you're going to have a much more formal, probably much thicker, nicer-looking, glossy top to it or whatever—but, let me ask you—when I look at the recommendations—and you have several through here—I think it was asked a little bit—are you going to—and I try to be realistic in all the work we do here, and

I'm probably more aggressive now than ever before. I—we just had broadband, and a presentation on that last—a week or so ago, but presented a nice, big plan. I know enough that—serving in public office for almost, now, 20 years, that I've learned one thing, that a lot of plans end up on a great many shelves, and they look great, 20 years later, when we review them and find out what we didn't do. So, are you going to, in your recommendations, prioritize, recognizing the resources of this country are limited?

Now, I will say this, saying that I do believe this is an important issue. I can tell you, the fishermen I talk to on a regular basis—just like Mr. Waters—on a regular basis—we have the best-managed fisheries in the country, if not, in my belief, in the world, when it comes to Alaska fisheries. But, the greatest threat is acidification, because it can't be managed by the fishermen, by themselves. And so, by that fact, after managing for more than 20, 30 years—and we've gone through the catch shares and all that, and we're glad we've done everything we've done. We still have our fish wars, but they're not like they were in the 1970s, and because of that we have an—incredibly successful fisheries. But, the piece that is the most dangerous, even if we believe a little bit or a lot, between the two doctors, it is a threat that cannot be managed after the fact.

So, can you tell me, as you look at this, are you prioritizing to where we need to hone in resource-wise and subject-wise? I think that was one of the questions on policy. Because all of us will love to do everything in the report—who believe in this—but we have to be realistic of what we need to do first and how it has the longest impact. Are you going to do that? I know it's tough in a lot of these reports. Because they like to just give the recommendations and say, "You're the policymakers, you figure it out." But we're all in this ship together.

Dr. BARRY. Agreed. We were tasked with saying, What do we need to do about this problem?—in a nutshell. So, we don't have a series of priorities for you, but what we do state is that, in order for this program to move forward, we must get together repeatedly with a variety of stakeholders, certainly the sponsors, and design explicitly what this is going to entail.

At that point, what I would anticipate, is the starting point for where these priorities are going to start to fall out. Who's going to ocean observing? What piece of the pie must that be? Where are the highest research priorities, or where's the most economical place to start? Those are the sorts of considerations that the Committee was not tasked with. But, I can certainly see how that would start to play out once you really sat down and said, "OK, let's get moving on this."

Now, getting moving on this is something that has already started to happen through the FOARAM Act, and, in part, the stimulus money. So, there——

Senator BEGICH. Sure.

Dr. BARRY.—there's a lot of traction, I guess, is what you use here, for this. And so, I—although I can't tell you where those priorities lie, I think there is a mechanism by which those will be defined.

Senator BEGICH. Very good.

Let me ask both of you, Dr. Barry and Dr. Everett, do you think we have—this may be a very leading question, but do you think we have enough resources at this point to really understand what acidification of the waters means? To either one of you first, whoever wants to go first.

Dr. BARRY. Well, I guess I'll go first.

Senator BEGICH. Do the Federal agencies, not necessarily—just so I—because that's what we deal with.

Dr. BARRY. I mean, that's a little bit of an ambiguous question, so I can't really answer that in the context of the report, but I will answer that personally. And my view of this is—the first thing I'd say is that what we think is going to happen is that the oceans are going to be different. They're not going to die, life will continue, the oceans will thrive, but they're going to be different, and that may be quite disruptive for humans and society—societal economies.

I'm not sure if we have the funds to understand everything, or the support to understand everything, about ocean acidification, but we can certainly make significant progress. We've already done this. This is a new field, the term was coined maybe 5 years ago.

Senator BEGICH. Right.

Dr. BARRY. And so we're moving fast, now. There's a lot that we can make—make hay with right now.

Senator BEGICH. Dr. Everett?

Dr. EVERETT. Yes, I agree. And the—as perspective, I perhaps have, at this moment, maybe 60 or 70 contracts of—working on fisheries and oceans, none of them are on acidification.

Senator BEGICH. None are.

Dr. EVERETT. None at all.

Senator BEGICH. That's very interesting. Well, thank you very much.

And, Ms. Weaver, thank you for putting your voice to the message. As the fishermen—I love your—I love that we picked Mr. Waters to be here to represent the fishing community, because the name is appropriate.

[Laughter.]

Senator BEGICH. But, I think that putting the voice to the struggles of what I see—not necessarily in the Gulf that you fish, Mr. Waters, but the Gulf of Alaska and throughout Alaska—putting a voice to it and helping advocate, I really appreciate that, because, I think, if you asked me, 4 or 5 years ago, I wouldn't have much knowledge on acidification.

When I was Mayor of Anchorage, I became more and more aware of it, because our city had the largest amount of commercial fishermen licenses there, even though they fished the whole state. And then, as I traveled, especially in southeast Alaska, I really started to hear the issue more and more. So, thank you for your willingness to kind of step to the plate, put your voice to it.

And, Mr. Waters, I think you did great today. You know, fisherman, usually the meetings I'm in—and, I'm sure, my colleagues are in—usually they're yelling at each other. So, I appreciate your passion, directed in a way that is going to have, hopefully, some positive results. So, thank you very much.

Senator CANTWELL. Thank you, Senator Begich. He did mention Magnuson-Stevens, so—I mean, he did preface——

[Laughter.]

Senator CANTWELL.—his——

Senator BEGICH. I wasn't sure if he was going to go somewhere there on that, so——

[Laughter.]

Mr. WATERS. Keep it closed.

Senator CANTWELL. So, one of the things that—we're going to do one more round. And I know—then we're going to let our panelists go. But, one of the things—we've talked a lot about fish, but I—if we could go back to the coral reef situation for a second, because obviously not only does acidification affect that, I'm concerned that it might prevent the coral reefs from even—that, you know, that initial damage might prohibit it from regrowing. And as people have explained to me, this is almost like our rain forest, if you will, for the species that live in that particular environment, so if you could talk about that.

And then I want Mr. Waters and Mr. Ingram to talk about, Well, what are the kind of early warning systems that you see, that you think we should be doing as part of solutions?

Dr. BARRY. Well, concerning coral reefs, coral reefs are certainly dependent upon calcification.

Senator CANTWELL. And I should just mention to people, we have many coral reefs in the Northwest, and my colleague from Alaska can tell you about the coral reefs in his areas, so——

Dr. BARRY. Well, you also have them offshore, in deeper waters, too. I'm a deep sea ecologist, so I have a little bias toward the things that live in deep waters. But shallow-water reefs certainly depend upon calcification. And when you couple calcification with—I'm sorry—ocean acidification with warming, we've seen coral bleaching, just due to warming; and if that persists for a couple weeks, the corals die. The reefs will remain intact until they dissolve. As we make the oceans more acidic, then—or less alkaline—then they certainly could begin to erode more quickly.

And the tropical Pacific—actually, if there is a—if I could get a slide up, this shows the change in the aragonite saturation state, how much saturation of carbonate minerals are in the ocean. And this is a little bit complicated—whoops—well, this is a movie, produced by Sarah Cooley at WHOI, which is—the reds are areas—you can see the scale, going from purple to red. Purple means that—4.5 means there's a lot of carbonate minerals around to make their shells. And as things get lower—and corals when they get to around 2.2, 2.3—below that, it's becoming hard to calcify. If you go below 1, into the red, exposed carbonate minerals will dissolve, just because the ocean is sufficiently acidic at that point.

So, as we move from 1900, at the beginning of this slide, to the right, at 2100, we see that the red starts to take over, and the purples and dark blues disappear. And I think this will stop, after this last one, and you'll see, at the end, toward the end of this century, the conditions for creating calcium carbonate are much, much weaker, and that the chemical conditions are not as appropriate as they are now or as they were in the past.

Now, what happens in the long run? In the long run, when we make this ocean more acidic, that makes it harder to make the skeletons. There's evidence from different areas that are either more acidic or less acidic now. In areas where corals are living where it is now more acidic, they cement that calcium carbonate more weakly, so they have more fragile skeletons, which allows more rapid coastal erosion, et cetera.

And as you move into the future, if all of the areas that are creating corals are more fragile cementation of that calcium carbonate, that means that they're much more susceptible to erosion if they die or when they die. And so, if you add warming on top of the story, all of a sudden we have a bunch of reefs that are now dead, that could be eroded.

Now, I can't—there's no certainty that that's going to happen. But, it—there's quite a bit of worry in the scientific community, particularly about shallow water or tropical coral reefs.

That being said, once you change that reef structure, because they're such an important structure-forming part of the community, everything else can change with it. So, instead of a coral-dominated community, with all the animals that you have now, and plants, you start to algal-dominated community, which has a whole different suite of things that may be completely different, in terms of its ecology, completely different for the services it provides, in terms of scuba divers, fishing, coastline protection, or even as a source of biodiversity that we—that pharmaceutical companies are interested in, to try and look for new medicines.

So, in a kind of a wide-ranging tome, there's my answer for you.

Senator CANTWELL. Thank you.

Mr. Waters, early warning systems. What should we be doing, or what do you think the fishing industry sees as ways to participate in helping with this information?

Mr. WATERS. Yes, ma'am. Well, so far, I only know of one thing, where the Coast Guard wants to do some baseline studies in the Gulf of Mexico. And our biggest threat is considered hypoxia, which is the nutrients coming down the Mississippi River, creating dead zones where we're at. But I think these baseline studies would be just a pure minimum for the monitoring of the Gulf of Mexico. I would like to see some funding for some more active and more proactive monitoring to see if we having any kind of acidity change in the Gulf of Mexico. Because, like all these doctors are saying, the colder waters absorb the carbon faster than the warm waters.

So, I can't really sit here and tell you that I'm watching my fish die or my oysters die from acidification, but I also want to keep my eyes open. I don't want to turn my back on it, and I don't want to—I'd love to believe in Dr. Everett, and I'm scared to death of Dr. Barry. And——

[Laughter.]

Mr. WATERS. So, I mean, I've really—you know, my whole life, my family's life, is all in a fishing community. And even though we fish hard against other fishermen, and they don't seem to be your friends, if you ever holler "mayday," they are your friends. So, at this time, we just—we really need to keep our eyes open and have some fundings to monitor this in the southern regions, and I believe a little more proactive in the northern regions, and really see what's going on in this.

Thank you.

Senator CANTWELL. Thank you.

Mr. Ingram?

Mr. INGRAM. I guess this—this seems to me like the proverb of boiling a frog. We don't really know precisely that somebody's turning up the heat on us just yet, because we haven't really felt it. And if we were that frog in water that was being increasingly heated, we would, sooner or later, find ourselves in deep trouble.

We, in the diving industry—you know, there are three and a half million active divers in the United States. And some of those people are scientists, and some of them have been able to help us to understand what's going on around us. We have a couple of environmental organizations that are very tightly tied to the diving industry—the Reef Environmental Education Foundation, the Coral Reef Alliance, and the Project AWARE Foundation. And they do help us to understand what's going on. They very frequently provide us with information that helps to educate all of our constituents about what's going on.

But, I think, for us, the biggest issue that we would need is to work with somebody like Jim Barry, like Dr. Everett, to help us to understand what those early warning signs could be. There's a lot of signs that we see firsthand, as I mentioned before, that are signs that there is something wrong. There's coral bleaching that's taking place. We see, unfortunately, trash on the bottom of the ocean. We see all sorts of different things, from pollution, that probably should not be there. And so, when we do see those things, we try to do our best to clean that stuff up and get it off the bottom, and also report it to those organizations that can help us to keep our area clean.

So, I think, for us—from the diving industry's perspective, the thing, for us, that would be the most critical would be for us to continue our education toward understanding, so that we can help to provide as much information as we possibly can on reporting what's happening as the heat gets turned up on our frog.

Senator CANTWELL. Well, thank you, Mr. Ingram.

And I will just say, I—you know, I know, Mr. Waters, you're saying, you know, this event has, you know, worried on one side or listening to the results. I mean, my—you met one of our Northwest shell growers, and you saw what he was going through. And I can tell you, we don't want that to continue or to broaden to a larger group and classification of either the shellfish industry or the fishing industry. And that's why I think this letter from the shellfish growers and the commercial fishermen, today that we received, about how important this is, and making sure that we come up with answers.

That's—I can't say to shellfish growers who've been in Washington State for 126 years, "We're going to do nothing." I simply can't. So, we're going to get answers, and we want to work with you.

Senator Snowe, do you have any——

Senator SNOWE. Thank you, Madam Chair. Just briefly.

Mr. Waters, certainly we want to prevent any trauma to your industry. I know, speaking firsthand, in my own state, many of our sectors in the fishing industry, particularly the groundfish industry, is faced with tremendous challenges, the reduction of the number of days at sea, and enormous Federal regulations are a result of what has happened in the past, in losing so much of their fisheries, and trying to rebuild it now. That's what we've got to avoid and to prevent and preempt. It's always a delicate balancing act about whether you do too much or too little, and that's the debate that even is reflected here today, in some senses, in how far we go.

And also, from my standpoint of the fishing community in Maine, a couple of things that are really important. The credibility and the integrity of the science is so important to the outcome and the decisions that have to be made as a result and collaboration should exist between the scientists and the fishermen.

Think about the Gulf of Mexico. I mean, talk about a dead zone—7– to 8,000 square miles literally described as a dead zone because of hypoxia. I have introduced legislation that has passed out of this committee to assist in that effort, but as you mentioned, acidification cannot be considered in a vacuum. There are so many other aspects that are affecting, and could affect, your livelihood.

So, do you see your fishing community with whom you work, recognizing that this is a serious issue, and that fishermen can play a vital role in helping in this process of scientific research?

Mr. WATERS. Ms. Snowe, it's—we've had so many fires in our cabin with fighting catch share—or not fighting against catch share, as we've come to you before—or I have visited your office and had help from you and other things with Magnuson and Stevens. But, there are so many fires in the fishing industry. As you know, I spent last week with some of the monk fishermen in Galveston with the Fishermen's Exchange. It—it's—you know, it just hasn't been brought forward.

I mean, we're having a presentation in Tampa by an organization for—The Gulf of Mexico Shareholders Alliance. The Alliance signed off—you know, I was the founding president of the Alliance, and they signed off on this, and they're becoming aware. And this is a new topic. I mean, we've had so many battles. And how many battles can you fight? You, yourself, know of how many issues you have to deal with in 1 day. How many issues can you deal with as a person? And a lot of our fishermen don't have staffs as intelligent or as responsible as your staffs, relaying information to you.

So, I believe it's going to come to the forefront, it's coming very quickly. And, like I said, the news is just reaching our fishermen. And talking to some of the fishermen from your area last week, you know, it's concerning them. I mean, when you start getting other fishermen, and you sit down and have your discussion, and they say, "Well, it's killing us. Our oysters are dying," and stuff like this. So it's, you know, we—we've had the issues of management and turf wars, the days at sea, the sectors, and on and on and on and on and on. And I mean, it's just——

Senator SNOWE. I know.

Mr. WATERS.—we've got to go fishing sometimes.

[Laughter.]

Senator SNOWE. I know. I couldn't agree with you more, you're right on. You're absolutely right. I think people would be surprised to what degree the fishing industry is regulated by the Federal Government. I sympathize and empathize.

Mr. WATERS. But, I do thank you for your support.

Senator SNOWE. But, your eyes and ears are on the water, and you can share firsthand information, so that's what's important. My fishing industry asked for us to be part of the process and to make sure we're doing our part and investing in quality research so that whatever emerges from that research and the decisions that are made, they are ones that they can accept and embrace.

Mr. WATERS. Yes, ma'am, and I do appreciate your concerns. And mostly my cries have been from other fishermen warning me of what's coming to my area, from their heart, just as I have spoke to you from my heart. And I appreciate your help with us.

Senator SNOWE. We thank you for giving your time, your precious time, away from your work. So, we thank you very much.

Mr. Ingram, your clients as well, do they recognize this issue? Because coral reefs are very integral to the diving industry. So, do you see a general awareness?

Mr. INGRAM. Well, as Dr. Barry indicated, the term was only coined about 5 years ago, so it is—it's just coming to the forefront. We have seen a number of articles that have been posted within our industry to start to educate. And the fine film, "Acid Test," has really been kind of making its way through the diving industry here, of late. And I think that that is a key to this, because, as I said before, we have 3 and a half million divers out there that are watching what's going on with the coral reefs. And they can be a wealth of information to everyone here at this table. So, I think it's an important thing for us to continue to be involved, as well, to be able to help the scientists, as best we can, but also help from the standpoint that I think we can look at this from an economic standpoint, as well, just as Donny has indicated.

Diving feeds our families, and we want them to be able to do that. And we have to do that for the long haul. It's not just for the short run. It's for both, actually; both are critical.

Senator SNOWE. Thank you.

Dr. BARRY AND DR. Everett, on the issue of research versus mitigation, the question is, first of all, How much research is necessary to determine whether or not mitigation steps are essential? Are we doing enough research, at the Federal level right now, that is sufficient to warrant steps to be taken? How much research and how much funding should we be spending on research? I think that's the real question, because, obviously, between you, Dr. Barry and Dr. Everett, there are some differences and questions on not—whether or not there is sufficient science. That's what I'm hearing from Dr. Everett and that would suggest that there is a real problem.

On the other hand, do we know that we're spending enough money on sufficient research to document the problem, and whether or not we should take the next step for mitigation or adaptation, whatever the case may be?

Dr. BARRY. I think—so, there are a couple questions here really. One of them, Is there—are we doing enough right now? This committee was charged with defining, What do we need to do, as a Nation, to get a grip on this problem? And so, the report that was released today really does outline what this committee feels are the necessary steps that we should take in order to find out what's going on, get to the bottom of this science, so that we can understand what's going to happen in the future, much—or at least constrain the range of possibilities so that it will give us some power to adapt, as a Nation, as a society.

How much money should we put into this is something that the scientific community would love to tell you. I'd love to help you say that we should do this or that, but that's not something that we were charged with, and it's probably good to separate that. Just as we would love to say, as a committee, here's what the priorities should be, because we have—each have our own key ideas of what we think should be done. But, that's also not really appropriate, and that's not something the Committee addressed.

Senator SNOWE. Dr. Everett, what are your views?

Dr. EVERETT. Well, one of the ways to look at it is—as I said, presently I'm not involved in any of the work. It's highly likely I would be. And so, the—there's very little being done.

Now, if the—one of the ways that I always looked at it, when I was head of policy and planning at the Fishery Service, was to—you know, how important is the problem, OK?—and—versus the amount of money being spent on it, versus the other problems? You know, it—does it merit just a fraction of 1 percent, or, you know, is it fundamental, and therefore, it ought to be several percent? And when you look at it, I think the funding now is below 1 percent, even in the plans. And so, if it's a bigger problem, then guidance is needed from you all. So——

Senator SNOWE. Thank you.

Thank you.

Senator CANTWELL. Thank you.

Thank you. And I want to thank Dr. Everett, Dr. Barry, Ms. Weaver, Mr. Waters, Mr. Ingram, for your testimony today.

Senator Snowe and I and Senator Lautenberg, along with 20 of our colleagues, are calling for Fiscal Year 2011 funding for ocean acidification and monitoring and research. So, we are going to be proceeding, moving ahead on this issue. So, we thank you.

We want to, specifically, thank you, too, for being here on the 40th anniversary of Earth Day. I think we all helped make sure that the oceans got their fair due in this big debate about our planet, that—70 percent of our Earth's planet being oceans, that not all is well underneath those waters, and we need to be good stewards of that part of our planet, as well.

So, thank you for helping us illuminate that, and for your testimony today.

The hearing is adjourned.

[Whereupon, at 11:54 a.m., the hearing was adjourned.]

A P P E N D I X

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. OLYMPIA J. SNOWE TO THOMAS INGRAM

Question 1. When we're faced with scientific uncertainty about how present actions will impact the future environment, it makes decisions to permit or prohibit certain actions more difficult. Because your industry is likely to be affected by whatever regulatory action is taken to deal with this issue, how do you feel that public participation should be incorporated into the policy-making process to minimize negative impacts on your industry today and in the future?

Answer. Thank you for the opportunity to respond to your thoughtful questions. We appreciate being included in this discussion.

There are a number of ways that public participation should be incorporated into the policy-making process to minimize the negative impacts on the diving industry, both for today and for the future.

a. I recommend strongly that such active participation and discussion continue through DEMA. We are eager to assist, and can continue operating as a conduit of information and feedback for this government body from both the professional and consumer perspective.

As the trade association for the Recreational Diving Industry DEMA has members encompassing the five different active major stakeholder groups in the industry; equipment manufacturers, training organizations, retail dive centers, travel/boat operators, non-retail services and the media. Any legislation enacted will have an impact on one or more of these stakeholder groups. As DEMA's Board and staff can provide information and help facilitate communication with members of the industry, we are glad to offer our assistance and play a continuing role in the process. In addition, several diving-related NGO's also exist with which DEMA interacts, such as the Project AWARE Foundation and the Reef Environmental Education Foundation. These NGO's can assist with policy input and communications to the general public.

DEMA can provide business-related information to this Senate Committee as well as operational details needed to help this body understand the long term impact of legislation for the industry/professional diving community. DEMA has the capability and expertise to make general recommendations on methodologies to protect this important resource and soliciting the input of business professionals. Working directly with the professional diving community as we do, DEMA will assist by keeping this issue in front of the professional audience.

DEMA is positioned to assist this body in reaching the diving consumer to bring Ocean Acidification and any legislative activity to their attention.

b. In addition to utilizing DEMA's resources to reach the professional and consumer audience, we believe the best way to incorporate public participation in policy-making is to bring the proposed policies before this intelligent audience in a series of face-to-face meeting opportunities, as well as to provide access to the information through government and private websites and other communication means. By working through DEMA, through the environmental NGO's and though members of the professional dive community, meeting notifications, explanations of the pros and cons of proposed legislation and ample time for analysis will provide the kind of transparency needed to develop agreement within this diverse but involved community.

Question 2. As you pointed out in your testimony, divers can act as stewards of the marine environment, and their contributions to coastal economies are substantial. Coral bleaching events and die-offs as a result of ocean acidification and rising sea temperatures have already affected your industry, and the downturn in the economy seems to be affecting your industry as well. Overall, ocean acidification has the potential to impact your business on an even broader scale. What kinds of monitoring data or other research activities would most benefit industries like yours that support coastal communities while simultaneously building public appreciation for the oceans?

Answer. It appears that a need exists for accurate, readily available, and easily understood baseline information regarding the health of aquatic resources which may be impacted by ocean acidification. Developing consumer-friendly baseline information for such resources as coral reefs, current ocean pH, marine life activity and growth, and other biological factors should make it easier for the professional and consumer diving communities to observe and provide feedback on advancement of the phenomenon and on its correction should legislation be enacted. As previously mentioned, the diving-related NGO's such as the Project AWARE Foundation and Reef Environmental Education Foundation, along with DEMA, can assist in developing and dispersing such baseline data to the diving community.

In addition to baseline scientific data that provides references for the biological processes impacted by ocean acidification, it is also important to develop and use baseline economic data for the diving related businesses that may be impacted by any enacted legislation. These small (and sometimes micro-sized) businesses depend on the availability of inexpensive energy, in the form of fuel for diving vessels, electricity to run their land and electronic operations and easy, inexpensive, and unfettered access to diving locations. Direct and indirect jobs as well as induced jobs and the tax-revenues generated by them, are likely to be impacted by any legislation which restricts or otherwise impairs the diving business community. While DEMA has provided some of this current economic data as part of our Senate Committee testimony, this data should be considered when legislation is proposed.

In summary, divers want to be involved. A clear set of economic and biological baselines and guidelines to monitor changes will help keep divers involved and will help divers advocate for economic and biological resource protection.

Question 2a. In your interactions with your clients, do you get the sense that the general public awareness of ocean acidification is growing?

Yes, but public awareness still remains somewhat limited. Using vehicles such as the video presentation "Acid Test" has been helpful in generating public awareness. The opportunity for DEMA to testify before this committee was also helpful in bringing the issue to the attention of the professional members of the diving community. The DEMA Board of Directors has also indicated their desire to provide more economic information to assist in educating the professional diving stakeholder groups.

Question 2b. How can your industry contribute to, and benefit from, increased public awareness of this issue?

There are three means by which this industry can contribute to public awareness of ocean acidification:

1. Professional members, environmental NGO's and consumer participants in the diving industry have the unique opportunity to observe first-hand any impacts or changes in the close-to-shore aquatic environment. Divers can contribute to the body of directly observable information available to this committee and any scientific or economic group involved in the future.

2. DEMA, the organization, and diving's environmental NGO's, can contribute to public awareness through the use of published papers written by qualified member groups, through the educational component its annual trade-only convention, by disseminating information directly to its professional members for further distribution to diving consumers, and by disseminating information directly to diving consumers through videos, articles and other means, such as the consumer diving website, www.BeADiver.com.

3. Because diving has a high level of visual media appeal, the diving industry can continue to offer its resources to groups that provide science-based and economics-based information for media dissemination. DEMA has made such an opportunity available for showing the previously mentioned "Acid Test" video during the annual trade-only DEMA Show, and invited Sigourney Weaver to participate. As you well know, such opportunities draw media attention to these issues, helping to increase public awareness.

The diving industry will benefit from increased public awareness of this phenomenon in several ways:

1. Senate Committee involvement and concern with this issue brings aquatic resources and diving to attention of the general public, generally having a positive effect on diving participation.

2. Protecting our aquatic resources is absolutely necessary to health of the recreational scuba diving and snorkeling industries. Without a healthy aquatic en-

vironment and ease of access to that environment, these industries cannot exist. As we have seen in the last few weeks, even the suggestion of aquatic resource degradation can have a devastating effect on these industries. When we consider that diving businesses in Florida, Alabama, Mississippi, Louisiana and even Texas are being impacted by the mere publicity surrounding the current Deepwater Horizon oil spill, the economic damage that could be caused to these industries by ocean acidification, true oil spill damage, and other real environmental problems should be apparent.

3. Bringing attention to this issue provides the industry with a better understanding of the governmental role in protecting these resources, and provides an opportunity to demonstrate DEMA's role in assisting these businesses by helping to protect them. It also provides an opportunity for stakeholders in the diving industry to develop a greater understanding of the economics of the diving industry and provides them with guidelines for operating using long and short-term objectives that preserve this industry.

Ranking Member Snowe, we again applaud the efforts of this committee. Your willingness to solicit input from a variety of sources in the professional and lay communities is a good example of private industry and government working together to understand the issues and bring them to the public for their careful consideration. Thank you for your service and your continued interest.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. OLYMPIA J. SNOWE TO DONALD A. WATERS

Question. When we're faced with scientific uncertainty about how present actions will impact the future environment, it makes decisions to permit or prohibit certain actions more difficult. Because your industry is likely to be affected by whatever regulatory action is taken to deal with this issue, how do you feel that public participation should be incorporated into the policy-making process to minimize negative impacts on your industry today and in the future?

Answer. Thank you for asking about this, Senator Snowe. After reading your question I think it's possible that we share some of the same hopes and concerns. And I do have some ideas about how to make a public process that might help us find a good, balanced way to move forward.

We Need Balanced Solutions

I'm happy to see your interest in dealing with ocean acidification, because it looks like a problem for fishermen and shellfish growers. I'm also happy to see that you aren't rushing into radical measures to eliminate carbon emissions no matter what the consequences. I support your effort in the Senate to cap carbon emissions from utilities. It's a step in the right direction. If it reduces the amount of acid going into the ocean, I can live with a small increase in my utility bill. Once I get used to that, I might be ready to go the next step. You've already got power companies in the Northeast working in a regional emissions-reduction program that shows they can do this without breaking the economy. To scale that up sounds like a practical way to go.

Use Public Involvement For Science

You asked about public process, and as far as fishermen are concerned I can tell you that's a very welcome question. From talking to fishermen I know around the country, I can tell you the stakes are high and the knowledge about ocean acidification is low. There aren't many of us who really know a lot about what carbon emissions do to our fisheries. There are a lot of rumors and fears out there about what it might cost to solve this problem. We need to understand the problem better, and we also need to understand the solutions better.

I also want to suggest that a really good public involvement program might help the whole country deal with this problem. Ocean acidification could be a problem for the whole nation. The oil spill in the Gulf has made it pretty clear that when the ocean gets messed up, the consequences reach a long way from the coast. When it stays healthy, there are benefits for everyone.

A good public process on the waterfront might help at both ends of this problem. There's the science end where we need to understand what's happening to the ocean, and there's the policy end where we need to do something about it.

I'll start with the science. We all need to understand the problem of ocean acidification better. There are a lot of us who spend our working lives on the water. We can help the scientists look in the right places. This problem of acidification is important to fishermen, even though we don't know much about it yet. It has the potential to affect our livelihood. We don't now how yet, but we need to find out.

Consulting with fishermen and aquaculture people and divers can help scientists deliver a good, focused research and monitoring program on acidification. Scientists are gearing up the national research program on acidification under the FOARAM Act that you helped to pass in 2009 (and thank you for that, it was a good first step).

I know the funding for the research and monitoring is modest, because there's a real need to control Federal spending. In April several Senators on this subcommittee mentioned this when they asked how to prioritize investment in research and monitoring. That's a good question to put to a combined group of scientists and user groups, and I know you're going to be hearing some ideas about that soon from people who are already pulling some of those groups together. Those of us who work on the water, fishermen and divers and growers, can help figure out where to get the best bang for your buck. We can point scientists to the places that produce the most seafood, and together we can pinpoint the resources that might be affected the most or the soonest. We can also help by working with scientists to collect data and water samples and provide boats for at-sea research.

We might even be able to help work out ways to duck some of the damage that acidification may cause to fisheries and aquaculture. I'm not saying we can live with an ocean that doesn't produce fish any more. I do not buy the idea that we just have to accept destruction and "get used it." The oyster hatcheries on the West Coast aren't waiting around for the world to stop emitting carbon dioxide. They've already taken some hard punches from corrosive water that dissolves their oyster larvae before they can grow. They're trying to find ways to protect their oyster larvae by monitoring chemical changes in the seawater. They are timing when they try to grow larvae so they can take advantage "good water" periods. They are doing broodstock research to try to improve the oysters' resistance to low-pH seawater. They are at the front line, and the rest of us should be learning from them and teaming up to help them beat this problem.

Go Local and Regional

If you really want to get people prepared to deal with this problem, it will probably take a lot of meetings. Fishing is local, and the knowledge that fishermen can offer is local. It's a big job, but you could do a lot of good by reaching out to fishermen and seafood growers and other users in the bayous, in the little bays up the coast of Maine, in the ports where they fish in Alaska—all around the country.

Public Involvement For Policy

Senator Snowe, you're absolutely right that anything you do to reduce carbon emissions is going to affect fishermen. Doing nothing will affect us too, if this problem turns out to be as serious as most of the scientists say.

It's fairly obvious that fishermen are going to see changes in the ocean. For example, back in the 1970s in the Gulf of Mexico I used to pull up a very thin-shelled, delicate thing called a paper nautilus, and I hardly ever see them now. If you ask, fishermen might give you a lot of observations like that, and maybe scientists can use that information to understand what's happening.

Fishermen have a stake in both sides of this problem. Whatever you do, we want it to work. We need the sea to be healthy so it still produces lots of fish. At the same time we need to run boats so we can go out and bring that food home from the sea. We need affordable fuel to do that.

If you can find a way of reducing carbon emissions that fishermen can live with, then the odds are good that most other people can get comfortable with it too.

I understand that one of the ways to reduce emissions is to put a price on carbon emissions, and maybe at some point we'll have to live with higher costs at the fuel pump. We hear reports that the EPA is taking steps to regulate emissions from fishing boats and other commercial marine vessels. We know that fishing vessels are a tiny source of emissions, but if it is done fairly, a lot of us will probably be willing to do our part, especially if there is help available to fishermen for the investment that may be required to make boats more fuel-efficient.

I make my whole living from the ocean. As long as it doesn't drive me broke, I'm more than willing to pull my share of the load to keep it healthy.

I think a good public process might ask people how to encourage more fuel efficiency. In fishing, those who can afford the investment can cut fuel use by repowering, or putting in more efficient generators, pumps, and other things. There are also some out-of-the-box approaches like changing the way fisheries are managed and regulated so they can become more fuel-efficient. This isn't for everybody, but one example is the Gulf of Mexico reef fish fishery, where we went to a catch-share system. It reduced the fuel each of us burns to catch a fish, and it also led to fleet reduction. Put the two together and you see a drastic reduction in the amount of fuel used in our fishery. Now, I don't want to force catch shares on fisheries that don't want them, and I'm not saying the same approach will work everywhere. But if the goal is to help people reduce emissions, it's not just about equipment. Sometimes it's about the way regulations define how efficient a guy can be in his operation.

These are the kind of questions that you can bring up in a good public process on the waterfront. If you ask people first, you might get some good options on the table for dealing with this carbon problem. Should the government help people invest to become more fuel-efficient? How much? What are the best ways to do it?

An Independent Process

Getting scientists and fishermen to work together isn't always easy, as you know. It takes a lot of skill, communications expertise, and a pretty good understanding of how to herd cats.

I think it would be good to do this through an independent organization instead of a Federal agency. Getting the right outfit to put all this together is important. It's probably going to vary from one area of the country to another. In some places, like in the Gulf of Mexico where I'm from, the Sea Grant programs are good at creating ways for scientists and the user groups to work together. In some places, the best organizers for this might be fishing associations, or really well respected nonprofit groups or university people who can build a trust between the fishing communities and the scientific community.

Some of this is already going on. The oyster growers, Sea Grant, some of the fishing groups are working with the Sustainable Fisheries Partnership, other groups and universities and so on. They have been putting together some regional workshops about acidification. It's a good model.

User Advisory Group

It would also be good to find some smart fishing, aquaculture, and diving leaders and form a user advisory group to consult with the scientists about the research and monitoring on acidification.

Oil Industry Should Help Pay

Down on the Gulf coast before the oil spill, it was hard to believe we could have such incredible consequences. Now we know, and we've begun to push BP to pick up the tab for the cleanup and for research and monitoring so we can understand what the spill is doing to sea life and to the ocean's chemistry.

Maybe the oil industry should do more. If you're going to have some public participation, you could ask people if they think the oil business should pay for a lot of the science to understand what all that carbon does to the ocean. Maybe the oil industry should be picking up their fair share of the long-term research and monitoring costs, not just for spills but to show the effects of all the carbon emissions that get into the sea. I saw a report that says oil and gas are responsible for about half of all the carbon dioxide produced by the world's energy economy. (*http://www.eia.doe.gov/.../emissions.pdf*). So maybe they should pay for half the science on this even though these cost will probably be passed on to the consumer. Senator Snowe, I know that you've been pushing to create an ocean endowment for marine research. I think if you had a string of meetings around the coasts you might find a lot of support for making the oil companies pay their fair share.

Once again, thanks for your leadership on this issue, Senator Snowe. It means a lot to those of us who make our living fishing.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. OLYMPIA J. SNOWE TO JAMES P. BARRY, PH.D.

Question 1. A recent study published in the journal of the Geological Society of America, found that when 18 different types of marine organisms were exposed to seawater with four different levels of partial pressure of carbon dioxide the calcification rates of those organisms did not all respond the same way. In fact, three species had their highest calcification rates at the highest level of CO_2: species of crabs, lobsters, and shrimps. What does this study tell you about the ability of some species to adapt to or perhaps even be genetically predisposed to thrive in oceans that experience higher degrees of acidity?

Answer. The recent paper by Justin Ries (Ries *et al.,* 2009) demonstrated that calcification rates among 18 marine organisms responded in different ways to simulated ocean acidification. While it is widely expected that calcification rates of marine organisms would decrease in more acidic waters with low saturation states for calcium carbonate, Dr. Ries found that some organisms studied increased their production of calcium carbonate skeletal material under even very high simulated atmospheric CO_2 levels. In particular, the crustaceans studied (crab, lobster, shrimp) increased skeletal production as the acidity of waters was increased, while most in most other species, calcification declined.

What does this tell us about the effects that future ocean acidification might have on these animals or on marine ecosystems in general? First, let's consider what changes in calcification may mean for the lives of these animals. To be successful, organisms must survive, grow, and reproduce. For organisms forming calcium carbonate skeletons or shells, calcification is one of many important processes that contribute to successful growth, survival, and reproduction. As Dr. Ries notes, we do not know how ocean acidification waters might have affected physiological processes other than calcification in these organisms, or how lifelong immersion in acidified waters would affect their growth, survival, and successful reproduction. This is a critical observation because calcification alone may not be a good indicator of success.

The exact mechanisms of calcification are not understood for all organisms, but research to date indicates that forming calcium carbonate in acidic waters is energetically more costly for organisms than in normal seawater. In a sense this is saying, "There is no free lunch." If it is costs (energetically) more to make either the same or a larger skeleton in acidified waters, where does the extra energy come from? The crustaceans studied by Ries may have had plenty of extra energy available (food) to support the extra cost of calcification. Could animals in the wild respond similarly? Will they be able to simply feed more to compensate for the presumed higher costs of shell formation in more acidic waters, or might there be energetic tradeoffs? For example, would they grow more slowly or produce fewer young to support high skeletal growth?

Crustaceans are also very different physiologically than many of the other organisms studied and Dr. Ries' results pose several questions concerning factors influencing growth and shell formation in these animals. Crustaceans increase in size by molting (shedding their shell) periodically, since they cannot make their shells larger once it is formed. Molting involves very complex changes in hormonal and internal chemistry that may actually favor larger new shells during molting in acidified waters. As they begin to molt, crabs inflate their bodies with water as much as possible, to maximize their size while the new shell is hardening (calcifying). This hardening process occurs over days. One the new shell is formed, tissue grows in slowly to fill the now larger shell, followed by another molt cycle. Could higher acidity slow the process of calcification during molting, allowing the animals to inflate to a greater size before hardening occurs? Does the larger shell also allow more rapid tissue growth leading to faster growth rates and larger individuals?

At this point, we do not know how immersion in acidified waters will affect the lifelong survival, growth, and reproduction of any of the species studied by Dr. Ries. His study provides some tantalizing evidence that there are likely to be winners and losers as ocean chemistry changes in the future. However, his work and that of others looking at the short-term physiological performance of animals under ocean acidification cannot tell the whole story. We need to understand how these physiological changes (and others) will affect lifelong performance for individuals, which in turn scales up to populations (population growth rates, reproductive rates, and productivity). Ultimately, changes in populations and species due to ocean acidification can affect entire ecosystems. These are the sorts of questions we need more information about to understand the comprehensive effects of ocean acidification.

A second aspect of Dr. Ries' study that is important to consider is how the differing effects of ocean acidification on many species will affect marine food webs and ecosystem processes. Let's assume, perhaps incorrectly, that higher calcification is good and reduced calcification is bad, in terms of the growth and survival of animals. If so, then crustaceans will benefit (*i.e.,* live longer, grow faster or larger), than most of the other animals studied, including most mollusks, which appear to be the losers in a high-CO_2 ocean (based on calcification rates). These differences alone could lead to a disruption of marine food webs due to the reduction in some prey or predators and increase in others. If the abundance of important prey or predators changes greatly due to the direct physiological impacts of ocean acidification, this could indirectly affect many other species due to shifts in prey and predator abundance. Ultimately, changes in the performance of even a relatively small number of species due to ocean acidification could modify energy flow through marine food webs and drive important changes in the function of ecosystems.

Dr. Everett testified at the Ocean Acidification Hearing, cited Dr. Ries' paper as one piece of evidence to conclude that there is little concern that ocean acidification is a serious problem. Dr. Ries, along with Dr. Iglesias-Rodriguez (whose paper (Iglesias-Rodriguez *et al.,* 2008) was also cited by Dr. Everett as evidence to alleviate concern about ocean acidification) submitted a rebuttal to the Senate, objecting strong to what they felt was Dr. Everett's serious misinterpretation of their studies.

Question 1a. What do studies such as this one say about the future of the science of ocean acidification and where we should be focusing our efforts?

Answer. Dr. Ries' study is one of many excellent efforts to understand how ocean acidification will affect marine organisms and ecosystems. Society needs to know how changes in ocean chemistry due to ocean acidification will affect the growth and productivity of species, their interactions with other species, and other processes that may in turn affect a wide variety of ecosystem services we depend upon. Will fisheries production change, and if so, how? How will the biodiversity of marine ecosystems change, if at all? These are important but difficult questions that cannot be addressed easily. The scientific community has started where it can—what is the physiological response of organisms to future conditions for short periods? While these sorts of studies will continue to be important, we need to be able to scale up the results of these studies to the level of populations and ecosystems over longer time scales. How will ocean acidification affect the growth, survival, and reproductive rates of organisms over their entire lives? How will changes in individuals affect populations, in terms of productivity or resilience to disturbance? How will changes in individual species affect food webs from phytoplankton and algae at its base to top predators such as salmon and tuna?

Scientific inquiry concerning all aspects of ocean acidification is developing rapidly. While we still need more studies just like Dr. Ries', he and many others are already working to broaden the scope of these studies to address some of the more difficult longer-term and broader scale questions mentioned above. Scaling up from single organism studies to populations and ecosystems is difficult and will require innovative approaches and sustained effort. It is important to remember that our activities are changing the chemistry of the ocean faster and further than is thought to have occurred for many millions of years, with unknown consequences for ocean ecosystems. Just as we wouldn't drive down a dark road without headlights, we should not forge ahead into a future within some insight into where we are going.

References

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RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. ROGER F. WICKER TO JAMES P. BARRY, PH.D.

Question 1. You discussed in your testimony that research concerning ocean acidification's impact on marine life is limited, particularly on populations and ecosystem dynamics. Can you please describe other areas of study which lack sound scientific research that would provide better understanding of this issue?

Answer. The field of ocean acidification is quite new, and important questions concerning how populations and ecosystems will respond to future ocean acidification are the tough questions we face. These are difficult questions, but they lie at the heart of what society needs to know to plan for the future and adapt (as a society) to potential changes in resources and ecosystem services provided by the oceans. There are research programs underway now (European Project on OCean Acidification: EPOCA), Biological Impacts of Ocean ACIDification (BIOACID)—the German National program on ocean acidification, the UK Ocean Acidification program, and now the National Research Council has published its report on a U.S. National Strategy for Ocean Acidification Research. Each of these program outlines a series of efforts to investigate the effects of ocean acidification, often in combination with other climate-related stressors (warming, hypoxia), on marine organisms, including efforts to "scale-up" our understanding of individual effects to populations and ecosystems.

Regarding ocean acidification research, we need to understand not only the effects on individual organisms, but also require a much broader understanding of future changes in ocean chemistry, from the scale of entire ocean basins to the apparently more complex coastal and inshore areas. Ocean chemistry in these areas are also affected greatly by other factors such as nutrient loading. Within this context of anthropogenic influences on ocean chemistry, we hope to gain an understanding of the effects of changing chemistry on ecosystems. Thus, ocean chemistry is one area where we require much more information before we can predict changes in marine populations and ecosystems.

Because society acts in many ways to affect ocean ecosystems (fishing, habitat degradation, pollution, climate change, ocean acidification (Jackson *et al.,* 2001), it may be difficult to determine the relative roles of various anthropogenic influences and natural factors in the trajectories of marine ecosystems. Knowledge of the influence of each of these factors can be of obvious importance, and efforts to integrate information concerning the influence of human stresses on the performance of species from the level of individual physiology up to populations and eventually to ecosystems will be a key to predicting future ecosystem changes in response to our activities.

Question 2. I understand it is estimated that average pH of ocean surface waters has decreased approximately 0.1 pH unit, from 8.2 to 8.1, since the beginning of the industrial revolution. Estuarine and tidal creek organisms, such as oysters, shrimp, and blue crabs in the Gulf and Southeast U.S. undergo daily shifts in pH that can range above 8.2 and down to 7.0. How does the current estimated shift in pH of 0.1 impact these organisms given their adaptability to routine naturally occurring shifts in pH?

Answer. This is an excellent question that relates to the potential effects of an anthropogenic shift in the mean pH of a natural ecosystem with a large range of natural variation in pH. The short answer is that we do not yet know if, or how much, the current shift in ocean pH (-0.1 units in the open ocean) is affecting estuarine and tidal creek organisms. The long answer involves the details of carbonate chemistry in estuaries, any effects of fossil fuel CO_2, and the physiological tolerance of estuarine species, including all life history phases (eggs, larvae, juveniles, adults), to variation in pH (and other potential stress factors).

First, some background on estuarine pH variation. The pH in tidal creeks and estuaries is naturally variable due to diurnal and seasonal shifts in the balance between photosynthesis and respiration in the environment. During the day, especially during Spring and Summer, high rates of photosynthesis by plants, algae, and phytoplankton consume CO_2 and produce O_2. This typically dominates over respiration by all organisms, leading to higher O_2 levels, lower CO_2, and consequently, higher pH. During night (especially during Winter), photosynthesis effectively ceases and respiration dominates, consuming oxygen and releasing carbon dioxide, leading to low O_2, high CO_2, and low pH. The magnitude of these changes can be affected by many factors, such as the abundance of habitat with plants/algae versus mudflat and animal populations, as well as water depth and tidal flat exposure during night and day. This natural variability is modified by anthropogenic nutrient loading in the coastal zone (primarily agricultural runoff), which can influence the balance between photosynthesis and respiration—high nutrient loading often increases primary production, followed by higher net respiration rates, reduced oxygen levels (dead zones in some cases), where CO_2 is high and pH is low (*e.g.,* Diaz *et al.,* 2008).

Ocean acidification (OA) due to fossil fuel emissions can modify the natural pH variation in coastal and estuarine areas even further, either from the inflow of acidified waters into estuaries (Feely *et al.,* 2010), or by direct CO_2 influx into estuarine waters from the atmosphere. However, during periods when the CO_2 levels in estuarine surface waters may be higher than the atmosphere, those waters would act as a source of CO_2 to the atmosphere, rather than a sink—that is, high atmospheric levels from fossil fuel emissions would may not increase the CO_2 levels of the estuary (and reduce pH further), but could impede CO_2 efflux to the atmosphere. The bottom line for this discussion is that: (1) the pH of coastal and inshore waters is considerably more variable than found offshore, (2) several human activities appear to be affecting inshore pH, and (3) we do not yet have a good idea of how human influences including ocean acidification have or will affect the carbonate chemistry of estuarine areas.

If estuarine pH is naturally variable, should we worry about the tolerance of estuarine organisms to what may be a relatively small additional pH shift? Common sense may say that since estuarine animals tolerate a wide pH range, then a 0.1 unit shift overall shouldn't make much of a difference. I expect that may be true for many organisms, particularly those with the physiological capacity to deal with CO_2-related stresses (*e.g.,* many fishes), but doesn't tell the whole story. Because organisms tolerate the entire natural pH range does not mean that they can "perform" equally well throughout the natural range or slightly outside it (the new range with ocean acidification), particularly marine larvae or other vulnerable life history phases. While it is clear that organisms inhabiting estuarine habitats must be tolerant of the conditions, it is also likely that their performance—survival, growth, and reproduction—is not the same at all locations or times and probably varies with pH. Therefore, diurnal or seasonal changes in estuarine pH may be quite important. Particularly during the more acidic periods or locations where minerals used for shell formation are low in abundance (low aragonite saturation state), it may be difficult or impossible for some species (*e.g.,* clams, mussels, oysters) to create calcium carbonate skeletons. This appears to be particularly important for oyster larvae as shown in one recent study. Miller *et al.,* (2009) measured the growth and survival of oyster larvae and modeled the carbonate chemistry of Chesapeake Bay, both under realistic current and future atmospheric CO_2 levels, to estimate how future changes in atmospheric CO_2 might affect oysters. Oyster larvae are expected to be more vulnerable than adults because their larval shells are made of aragonite, a form of calcium carbonate that is more easily dissolved than the calcite shells made by adult oysters. There is already a region in the upper bay where larval shells will dissolve (where the aragonite saturation is below 1.0), related to the temperature, salinity, and CO_2 content of the water (Figure 1). Their conclusions are that as atmospheric CO_2 rises, this zone will expand seaward, since the waters will become more and more acidic. Thus, although the Chesapeake, like many estuaries, has considerable pH variation, it appears that ongoing and future changes due to ocean acidification could have important effects. This process can be exacerbated by nutrient loading in the coastal zone, which can amplify the boom and bust cycle of estuarine primary production and organic consumption, leading to expanding zones of low oxygen or hypoxia and high acidity (low pH).

We need much more research to understand how these and other organisms will respond to shifts in pH as we move toward the future. Perhaps a 0.1 unit shift in the mean pH of a highly variable system will be tolerable, at least in currently marginal areas, but the much larger pH changes expected by the end of this century may cross thresholds leading to important ecosystem changes.

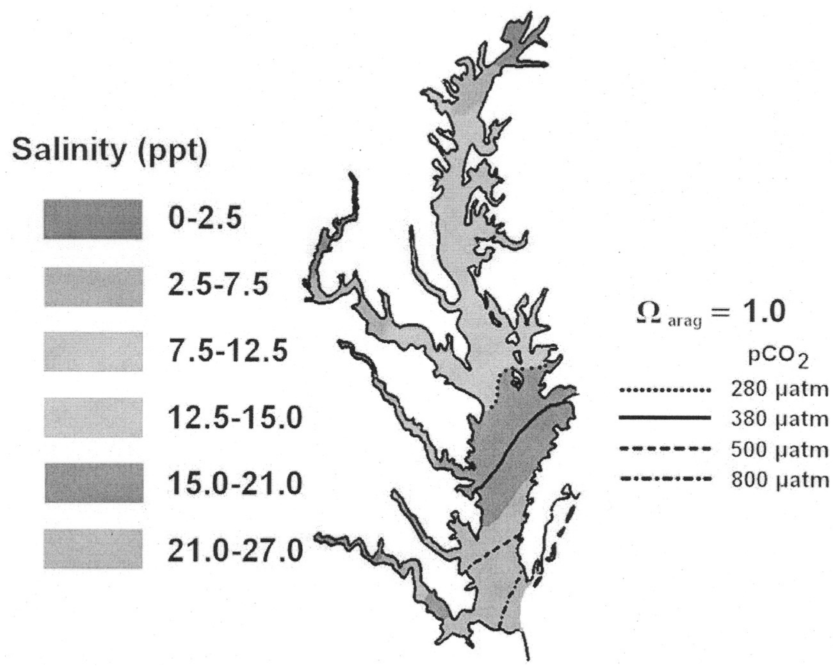

Figure 1. Map of Chesapeake Bay showing summertime salinity, and changes in the position of the aragonite saturation boundary—the point above (inshore from) which exposed aragonite (*e.g.,* shells of oyster larvae) will dissolve. The boundary moves seaward with increasing atmospheric CO_2 levels listed (280 to 800 ppm CO_2). From Miller *et al.,* (2009).

Question 3. How does seawater acidification through run-off and pollutant input compare to that caused by atmospheric deposition?

Answer. There are both similarities and differences between ocean acidification (changes in ocean chemistry driven by adding fossil fuel carbon dioxide from the atmosphere to the ocean) and acidification caused by coastal nutrient loading due to run-off and pollutant input. Here I consider pollutants as nutrient inputs (nitrogenous wastes and agricultural fertilizers) carried by rivers to the coastal ocean as well as nitrogenous aerosols deposited on the oceans from fossil fuel combustion

(Figure 2; Doney 2010). Ocean acidification affects the carbonate chemistry of the ocean, increasing CO_2 levels, leading to the formation of carbonic acid, which ultimately causes a rise in acidity (lower pH) and lower levels of carbonate ions—minerals used for the shells of many marine animals. This is a global phenomenon which occurs through most of the oceans, though in some regions where surface CO_2 levels are naturally high, the oceans are a source of CO_2, rather than a sink—there CO_2 degasses from the surface ocean into the atmosphere. Coastal nutrient loading increases the productivity of phytoplankton and algae in surface waters, particularly in nutrient poor regions. As this "extra" organic material sinks to deeper waters, it is consumed and degraded, which consumes oxygen and produces respiratory carbon dioxide. Overall, this process has increased the production of organic material in the oceans, and reduced oxygen levels and acidifying deeper waters to some degree. Where coastal nutrient loading is fairly intensive, oxygen levels near the bottom can drop to zero or nearly so, with simultaneous acidification of those waters. This process continues to expand and is causing the development of "dead zones" at coastal regions around the globe (Figure 3; Diaz *et al.,* 2008).

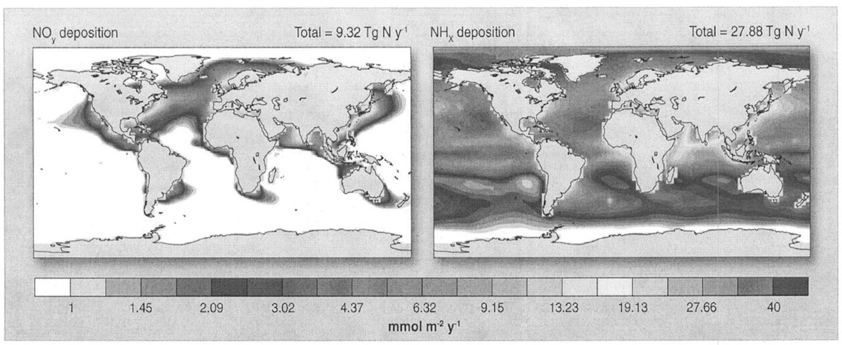

Figure 2. Estimated deposition of anthropogenic reactive nitrogen to the ocean surface for oxidized forms (NOy), mainly from fossil fuel combustion sources, and reduced forms (NHx) primarily from agricultural sources (from Doney 2010).

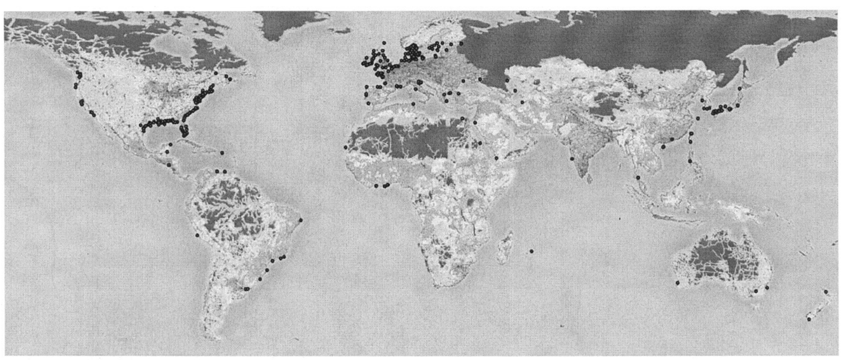

Figure 3. Global distribution of 400-plus systems reported to have eutrophication-associated dead zones. Their distribution matches the global human footprint in the Northern Hemisphere. Dead zones are only recently reported for the Southern Hemisphere. From Diaz *et al.,* 2008.

Unlike nutrient additions, ocean acidification does little to affect oxygen levels directly, though they may be affected by changes in the response of ecosystems. To date, nutrient loading is a more significant problem since it is driving oxygen levels to zero in areas, with important consequences for ecosystems (Diaz *et al.,* 2008; Doney 2010). As we move through this century, both processes are expected to increase their 'footprint' on ocean ecosystems.

Question 3a. Does this differ by region in the U.S.?

Answer. Ocean acidification probably does not vary considerably among regions in the US, other than its potentially synergistic interaction with other factors (nutrient loading, warming). For example, along the Pacific Northwest, the upwelling of acidified waters affected by ocean acidification, coupled with nutrient loading, is causing very low pH waters in areas of Puget Sound and the local region, with potentially important impacts on local ecosystems (Feely *et al.,* 2008; Feely *et al.,* 2010). Similar synergistic interactions among anthropogenic factors may also occur elsewhere, but may be milder than occurs in the already acidic, upwelled waters along the NW Pacific.

Eutrophication due to the input of nutrients is most severe in more urbanized coastal areas and at the outputs of major rivers with carrying large nutrient loads to the ocean (*e.g.,* Mississippi River). The eastern seaboard and the Gulf of Mexico coast have many more reports of hypoxic zones or events driven by nutrient loading. However, these events are increasing as well along the western U.S. coast.

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RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. OLYMPIA J. SNOWE TO DR. JOHN T. EVERETT

Question 1. A recent study published in the journal of the Geological Society of America, found that when 18 different types of marine organisms were exposed to seawater with four different levels of partial pressure of carbon dioxide the calcification rates of those organisms did not all respond the same way. In fact, three species had their highest calcification rates at the highest level of CO_2: species of crabs, lobsters, and shrimps. What does this study tell you about the ability of some species to adapt to or perhaps even be genetically predisposed to thrive in oceans that experience higher degrees of acidity?

Answer. This study tells us that we need to look carefully for the benefits just as we do for the harm from any change to the environment that concerns us. Since the crustaceans that did better with a higher CO_2 environment are not substantially different than the krill and small shrimp that feed on algae, which themselves do better in a CO_2-rich environment, we must be very cautious before we say that higher pH in the oceans will lead to the demise of all sea creatures. In terms of productivity, there could well be an increase, rather than decrease. Much of the coal and oil resources that we have available to us are the result of the tremendous productivity of the Earth during past times of high atmospheric CO_2.

Question 1a. What do studies such as this one say about the future of the science of ocean acidification and where we should be focusing our efforts?

Answer. Our research should focus on the likely changes in ecology as a result of more acidic water. A strong component in that research should investigate how we can take advantage of the opportunities and also deal with the problems. Things will be different, neither necessarily worse nor better. We should be preparing ourselves to make the most out of whatever conditions come to be—ready to take advantage of the opportunities and prepare for any disadvantages.

Question 2. Your testimony suggests a high degree of uncertainty remains even in what other scientists consider to be the relatively undisputable fact that the chemistry of our oceans is changing. Even the NRC report unequivocally asserted that the chemical changes are "well understood." You have also asserted that perhaps the terminology used to describe this problem—acidification—is inaccurate and intended to directly influence public opinion and draw attention to the issue. Your conclusion is that we should continue to carry out research on ocean acidification, but not take drastic action to address it. In your opinion, are the actions taken to date by NOAA and the scientific community appropriate, or should we scale back our efforts to investigate this potential area of concern?

Answer. Since the American public has been targeted with a great deal of fear mongering, it behooves us to determine whether there is really a problem or not. I think that the amount of funding provided by the Congress is about right. However, as I indicated above, I believe that we should be directing a reasonable amount of the total funding toward seeking out the opportunities and preparing for the negatives.

Question 2a. What degree of certainty in the research is sufficient to dictate additional actions, either regulatory or otherwise, to address ocean acidification as a real problem?

Answer. I do not have a problem with things that are different, provided that I am prepared for these changes and they are not harmful overall. I believe that under extreme ocean acidification things will be different, but not worse, for us and for the animals near the top of the ocean food chain. Under the relatively small amounts of being discussed, I don't see significant threat, nor even any measurable change. I am not an advocate of further regulations, particularly any that make our goods and services non competitive in the global market.

Question 2b. Should we even bother pursuing mitigation measures at this time?

Answer. We should not be pursuing mitigation measures if they place our country at a disadvantage relative to other countries with whom we compete in the world economy.

I wish to make it clear that I am addressing, with respect to this question and the others, only increases of CO_2 in the atmosphere and ocean. If the CO_2 comes with increases in heavy metals and other toxic elements, there is much more reason for concern. We and other nations of the Earth must work together to reduce the amount of harmful pollution reaching the oceans. I don't believe that CO_2 is harmful overall at the levels under discussion and should not be used as an excuse to stop the use of hydrocarbon-based fuels.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. ROGER F. WICKER TO DR. JOHN T. EVERETT

Question 1. You mention in your testimony that research concerning broad impacts of ocean acidification on marine life is limited. Can you please describe what areas of study lack sound scientific research that would provide better understanding of this issue?

Answer. There is a lot of good research that is being conducted. A major problem is that there also is a lot of bad research being conducted. Much of the research seems to be aimed at proving that ocean acidification is bad. This is evidenced by the use of hydrochloric and sulfuric acid (to simulate CO_2), by not allowing creatures time to adapt to major increases, by using unrealistically high levels, and in the narrative justification for the research, among other things. There is rarely an objective observation of the changes, only a search for the negatives. This makes it unlikely that positive effects will be observed and reported. Positives cannot be found when no one is searching for them as carefully as they are for the damage. To make matters worse, positives are not newsworthy and are not reported in the press whereas the negatives often make headlines, causing a distortion of the facts in the minds of the citizens.

The research items that intrigue me are finding an explanation for how we might actually get at the asserted damages from relatively miniscule PH changes. For example, how can mollusk larvae be damaged by a small change in acidification when their cousins that live in fresh water do just fine under actually acidic waters that are hundreds or thousands of times more acidic than the oceans will ever be? How can fisheries be destroyed by pH levels that are no worse than in upwelling regions that are the most productive areas for marine life of all kinds?

I would like to see more research that addresses true understanding rather than the fulfillment of an activist agenda of any flavor. It is difficult for scientists, no matter how objective, to receive funding for such research from philanthropic organizations and government agencies.

Question 2. There have been claims that oyster hatcheries in the Pacific Northwest have experienced effects of lower pH seawater on developing larvae stocks. Was this a result of upwelling cold deep water off the coast of Oregon and Washington?

Answer. The conjecture among many scientists not participating in the work is that any changes in pH of the level observed would have to be due to upwelling waters that moved into the area, or by rain, or by pollution. I do not have enough information to form an opinion of my own.

Question 3. Have similar acidification events occurred in other areas of upwelling around the world? In other words, is this a common event or isolated incident?

Answer. If a lowered pH was in fact the root cause of oyster larvae mortalities, it may well happen in other parts of the world. However the NW area in question is more susceptible to a deep water upwelling event than, say the Chesapeake Bay, where it would be virtually impossible from an oceanographic standpoint. In most areas of the world, the pH of the water is not routinely measured and would not likely be suspected if there were a mortality event of larvae or other organisms.

Question 4. What scientific evidence exists that suggests similar acidification events occurring in other regions of the U.S. are significantly impacting wildlife?

Answer. Much of the most thorough research on acidification occurred during the scare over acid rain a few decades ago. That research indicated that the makeup of the ecology could be quite different under acidic conditions that were hundreds of times more acidic than the changes we're talking about for the oceans. Levels practically reached the acidity of vinegar before life was severely compromised. Again, ecology was very different but the overall production stayed quite constant at any reasonable pH level.

The importance of this is when we are using the harm to marine mammals and fisheries as a research or mitigation justification. There will still be about the same amount of food available for the those animals even if it is a different form of a species or in fact a different species.

Question 5. What proportion of CO_2 in upwelled ocean water can be attributed to deposition from the atmosphere? What proportion can be attributed to biological processes?

Answer. Near the surface a high proportion of the CO_2 can be from the atmosphere because the exchange of gases is constant. However well below the surface, where the sunlight is dim or nonexistent, all the animals and bacteria are consuming oxygen and giving up CO_2 faster than algae and plants can convert it into oxygen. This and other processes cause the deep water to become high in CO_2 and thus more acidic. When the deep water rises to the surface as part of an upwelling current, it is often at a pH that is lower than is contemplated in the global warming scenarios for the future.

Question 6. Since ocean circulation and upwelling events occur on a global basis, what role do other countries play in contributing CO_2 to waters that impact the coastline of the United States?

Answer. All nations of the world contribute to the CO_2 reaching the coastal waters of the United States. The amount of CO_2 in the atmosphere that is the product of humans is contributed by each nation in proportion to its emissions. There are no boundaries slowing the mixing of CO_2 and it occurs rapidly and quite thoroughly. The CO_2 coming from the Chinese, Australian and American coal that is being burned in China has no signature different from used that in Australia or the US, or from any other country. It is also not generally distinguishable from that emitted by humans and other animals or volcanoes.

Question 7. How does lowering of seawater alkalinity through run-off and pollutant input compare to that caused by atmospheric deposition?

Answer. For the global ocean, deposition would be the larger contributor. However, in a localized area, such as a bay, pollution and rainwater, whether from run off or from rain falling on the water, would be the more important source.

Question 7a. Does this differ by region in the U.S.?

Answer. Yes, it varies by location because pollution and runoff vary, as does their mixing with the ocean water depending on whether they flow into a narrow bay or into a rapidly moving ocean current.

Question 8. Is there scientific research showing that ocean acidification may be caused by factors other than atmospheric CO_2, such as nutrient loading, pollution, or habitat degradation?

Answer. Yes, research shows that pH can be changed in a number of ways, but generally not at the global level. Research of the types presented, has been more localized such as in harbors, bays, and rivers. It would be very difficult to demonstrate that any of these factors were at play in the ocean as a whole.

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