RISING TIDES, RISING TEMPERATURES: GLOBAL WARMING'S IMPACTS ON THE OCEANS

HEARING

BEFORE THE

SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING HOUSE OF REPRESENTATIVES

ONE HUNDRED TENTH CONGRESS

SECOND SESSION

APRIL 29, 2008

Serial No. 110–35

Printed for the use of the Select Committee on
Energy Independence and Global Warming

globalwarming.house.gov

U.S. GOVERNMENT PRINTING OFFICE

61–725 WASHINGTON : 2010

For sale by the Superintendent of Documents, U.S. Government Printing Office
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CONTENTS

RISING TIDES, RISING TEMPERATURES: GLOBAL WARMING'S IMPACTS ON THE OCEANS

TUESDAY, APRIL 29, 2008

HOUSE OF REPRESENTATIVES,
SELECT COMMITTEE ON ENERGY INDEPENDENCE
AND GLOBAL WARMING,
Washington, DC.

The committee met, pursuant to call, at 1:36 p.m., in Room 2318, Rayburn House Office Building, Hon. Edward J. Markey [chairman of the committee] presiding.

Present: Representatives Markey, Cleaver, Sensenbrenner, and Blackburn.

Staff present: Ana Unruh-Cohen, Stephanie Herring and Morgan Gray.

The CHAIRMAN. Welcome, everyone. This is a hearing of the Select Committee on Energy Independence and Global Warming. We welcome you all to this very important hearing today.

Over the course of the past year the Select Committee has investigated numerous impacts of global warming, from the melting of the Greenland ice cap, to the drying out of the Amazon rain forest, to the sliding of Alaskan villages into the sea. But the impacts on land are only the tip of the melting iceberg of a potential climate catastrophe. Oceans cover 70 percent of our planet. And they are also feeling the heat of global warming.

Throughout Earth's history, the ocean and the atmosphere have worked together to regulate the climate. The ocean serves as a sponge, soaking up excess carbon and heat from the air above it. Carbon dioxide dissolves in seawater, where plants and animals of all shapes and sizes convert it into their own protective coverings. Although many of these creatures are too small to see with the naked eye, the result of their work can be monumental, as witnessed by the White Cliffs of Dover and the ancient reefs that are now the mountains of west Texas. But the burning of fossil fuels has released increasing amounts of ancient carbon back into the atmosphere, and the oceans are overworked.

During the past 40 years, the ocean has absorbed 90 percent of the estimated increase in the Earth's heat content from human activities. Like sweeping dirt under the rug, the oceans have protected us from feeling the full heat of global warming pollution. While many of the ocean changes may be out of our sight, we must not put them out of our mind.

Global warming is causing an underwater heat wave, and the rise in ocean temperature impacts sea life at all depths. Many marine species thrive in only a narrow temperature range, and this heat stress forces them to move away from their traditional feeding and breeding areas in search of cooler waters. But not all marine life can simply shift with changing sea temperatures. Coral reefs have nowhere to go when the water around them heats up. Instead, they expel their life-giving colorful algae. Once reefs experience such a bleaching episode, they often never recover.

Warmer oceans pose another threat, rising sea level. As water heats up, it expands. During the last 40 years, this expansion has contributed to 25 percent of the observed sea level rise. Rising sea levels already cause harm in coastal communities around the world, increasing their vulnerability to storms and threatening their drinking water. As global temperatures continue to rise, so too will sea levels, reshaping the contours of the world's coasts.

Impacts on the ocean go beyond warmer waters. The rising carbon dioxide concentration in the air alters the fundamental chemistry of the ocean. As sea water absorbs more and more CO_2, the water becomes relatively more acidic. This ocean acidification can prevent coral reefs from growing, stop shellfish from developing their protective outer layer, and inhibit the growth of tiny shell-forming plants and animals that form the foundation of much of the ocean food chain.

The oceans have been taking on the burden of the planet's fever. Recent evidence suggests that oceans are losing their efficiency as a sink for the carbon we admit. If we reduce the ocean's ability to help us handle the global warming burden, we may face the impacts of global warming sooner than predicted.

Today we hear from some of the world's foremost ocean researchers. They have seen firsthand many impacts from global warming that those of us above the surface will never see. Their testimonies will convey the consequences of our "out of sight, out of mind" strategy. Like an iceberg, most of the problem lies beneath the surface of the ocean. What lurks below holds serious consequences, and if we refuse to change course, we will run into a problem far larger than it first appeared. At this hearing we will demonstrate through our witnesses that we need a sea change in our energy and climate policy if we want to avoid an actual catastrophic change in our seas.

And now I would like to turn and recognize the ranking member, the gentleman from Wisconsin, Mr. Sensenbrenner.

[The statement of The Chairman follows:]

THE SELECT COMMITTEE ON
ENERGY INDEPENDENCE AND GLOBAL WARMING

Opening Statement for Chairman Edward Markey
Rising Temperatures, Rising Tides: Global Warming Impacts on the Oceans
Select Committee on Energy Independence and Global Warming
April 29th, 2008

Over the course of the past year, the Select Committee has investigated numerous impacts of global warming – from the melting of the Greenland ice cap, to the drying out of the Amazon rainforest, to the sliding of Alaskan villages into the sea. But the impacts on land are only the tip of the melting iceberg of a potential climate catastrophe. Oceans cover 70 percent of our planet, and they are also feeling the heat of global warming.

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But the burning of fossil fuels has released increasing amounts of ancient carbon back into the atmosphere, and the oceans are overworked. During the past forty years, the ocean has absorbed 90 percent of the estimated increase in the Earth's heat content from human activities. Like sweeping dirt under the rug, the oceans have protected us from feeling the full heat of global warming pollution. While many of the ocean changes may be out of our sight, we must not put them out of our mind.

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

The topic of today's hearing is yet another reason why I believe technological development is one of the most crucial steps in the effort to confront global warming. Rising CO_2 levels and increasing temperatures will have an impact on the oceans. Some prospects are unnerving, like the dying of the coral reefs. Others can be approached through adaptation, such as a rise in sea levels.

Energy is the life blood of our economy. Right now much of the energy that is generated creates CO_2, but there already exists some technologies that generate energy without emitting CO_2 into the atmosphere. And if Congress acts wisely, there could be more on the way.

One of these technologies is nuclear power, which generates great amounts of energy without producing any CO_2 whatsoever. Another technology that is on the horizon is carbon capture and storage, which has the potential to allow the U.S. to continue to use our vast coal reserves to generate energy but with only a fraction of the CO_2 emissions.

Renewable energy technologies and gains in energy efficiency also stand to reduce carbon dioxide emissions. And we should strive to achieve all of these key technological improvements. Nuclear power and carbon capture and storage are technologies that not only would go a long way toward reducing CO_2 emissions, but they will also help ensure the energy security of the United States.

And if the U.S. can't be secure in its energy supply, it certainly can't be secure in its economy. These days anyone pumping gas into their car knows this. That is why I don't support the array of policy proposals that unwisely seek to tax away carbon dioxide. This won't work, and it will slow the economy and eventually will end up being repealed.

The production of CO_2 through energy production is a factor in global warming, but it is not the only factor. There are many natural sources of CO_2 that are emitted into the atmosphere. There are still some scientific questions about how large a role humans play in global warming. It raises some questions as to how much humans can do to stop these changes in the oceans and in the atmosphere. Even if by some divine intervention humans were able to completely stop emitting CO_2 tomorrow, some of these changes would still occur. Therefore, in some cases, adaptation will be the only reasonable choice. And that is something that people all over the world need to be ready to handle. The witnesses today will present very interesting and well researched testimony on the scientific topic, which I am sure will not only help educate all of us but will also help to strengthen my belief in the need for the development and advancement of energy technology.

And I thank the Chair.

The CHAIRMAN. The gentleman's time has expired.

[The prepared statement of Mr. Cleaver follows:]

U.S. Representative Emanuel Cleaver, II
5th District, Missouri
Statement for the Record
House Select Committee on Energy Independence and Global Warming Hearing
"Rising Tides, Rising Temperatures: Global Warming's Impact on the Oceans"
Tuesday, April 29, 2008

Chairman Markey, Ranking Member Sensenbrenner, other Members of the Select Committee, good afternoon. I would like to welcome our distinguished panel of witnesses to the hearing today.

The world's oceans are critical to achieving a balance in the climate system, including the absorption of excess carbon dioxide in the atmosphere. Recently, specifically in the past decade, this balance has been threatened by the effects of global warming. Since oceans soak up most of the carbon dioxide released by living organisms, they have been particularly affected by increased emissions due to a growth in human activity. The world's oceans are adaptable up to a point, but they cannot sustain our current level of pollution and not be severely damaged.

The increased carbon dioxide in the atmosphere has lead to several negative effects on oceans such as water acidification and higher sea levels. The increased acidification of the seas has lead to the likely damage of coral reefs, such as coral bleaching. Rise in sea levels can affect ocean life and the life of organisms and humans on land as well. What is perhaps the most frightening is what we do not know. Is the damage that we have inflicted on our world's oceans irreversible? I hope the experts we host today can help us answer these questions and advise us on what we can do to stop or reverse this cycle. Our oceans are incredible and complex ecosystems, and they must be protected and enjoyed.

I thank all of our witnesses for their insight and suggestions, and I appreciate them taking the time to visit with our committee today.

Thank you.

[The prepared statement of Ms. Blackburn follows:]

Prepared Statement of Congresswoman Blackburn
House Select Committee on Energy Independence and Global Warming
Hearing, "Rising Tides, Rising Temperatures: Global Warming's Impact on the Oceans"

Mr. Chairman:

I want to thank you for holding this hearing, and I want to thank the witnesses for taking their time to come and testify before this committee.

Today, we will examine the impacts of global warming on the Earth's oceans and whether marine ecosystems are suffering from the effects.

The most common cited concerns on this issue are temperature and acidity increases in the oceans, destruction of coral reefs, and reductions in plankton populations.

Mr. Chairman, most available evidence from scientific studies show that these concerns are overblown. In some cases, the opposite is true.

First, climate change scientists state that 80 to 90 percent of global warming involves heating up the oceans. But over the past 5 years the oceans are actually cooling and releasing heat into the air.

Second, marine biologists state that coral reefs are bleaching and dying from CO2 concentrations and rising temperatures. But coral reefs are rapidly adapting to warmer temperatures and ocean acidification and flourishing by establishing new symbiotic relationships with algae and changing their use of minerals in seawater for skeletal growth.

The most cited concern is that plankton, the base of the ocean's food chain, is severely threatened by global warming and could lead to the ultimate demise of the ocean life. But plankton are thriving on increases in CO_2 concentrations, and their calcification rates are dramatically increasing from ocean acidification.

Mr. Chairman,

Before we invoke the global warming religion once again as the destroyer of our oceans, we should first look at all the scientific evidence right before our eyes and observe what is truly happening.

Recent observations indicate oceans are not warming and marine ecosystems are adapting and flourishing from CO_2 concentrations.

I look forward to hearing testimony from today's witnesses and offer copies of articles from science journals to be included in the record.

The CHAIRMAN. We will now turn to our witnesses.

STATEMENTS OF SYLVIA EARLE, EXPLORER-IN-RESIDENCE, NATIONAL GEOGRAPHIC SOCIETY; JANE LUBCHENCO, DEPARTMENT OF ZOOLOGY, OREGON STATE UNIVERSITY; JOAN KLEYPAS, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH, BOULDER, COLORADO; AND VIKKI SPRUILL, PRESIDENT AND CEO, THE OCEAN CONSERVANCY.

The CHAIRMAN. Our first witness is Dr. Sylvia Earle, Explorer-in-Residence for the National Geographic Society. For decades Dr. Earle has set herself apart as a world-renowned oceanographer, a pioneering explorer, and as the first female chief scientist of the National Oceanographic and Atmospheric Administration. Her incredible work understanding and protecting our oceans in more than 7,000 hours conducting underwater research have earned her the title "Her Deepness." She has been named a living legend by the Library of Congress and a hero for the planet by Time Magazine.

We welcome you, Dr. Earle. Whenever you feel comfortable, please begin.

STATEMENT OF SYLVIA EARLE

Ms. EARLE. Thank you, Representative Markey, for hosting us here, all of you. We were asked, those of us who have been invited to comment, to address several questions. And let me start with that.

The first was, what climate changes that we have personally observed. As one who splashes around in the oceans of the world as often as possible for a number of years, I have witnessed changes in the natural systems that have greatly changed over the period of time since I was a child. In projecting forward, if the pace of change continues, our children are not going to have much in the way of stable ecosystems in their future. Degraded systems are more vulnerable to climate change or any other factors, storms or diseases. And what we have caused in the last half century through our actions, what we put into the sea, what we take out of the ocean, is causing profound changes in the nature of the ocean itself.

What are some of the initiatives we can take to conserve the oceans and work toward their long-term health? Well, look at what we are doing, what we have put into the ocean and what we are taking out of the sea, both in excess and both causing the destabilization of these natural systems, that if you really pull back and think about it, this is our life support system. The ocean governs climate and weather, governs climate and weather, churns out most of the oxygen in the atmosphere, governs the chemistry of the planet. It is the great thermoregulator for the Earth.

I gave a talk recently at the World Bank, and I chose as my opening image to make my point an image that all of us have now taken for granted owing to the observations of astronauts; that is Earth from space, the blue Earth. And I said there it is, the World Bank. That is it. Those are the assets. That is the source of all that we hold near and dear, our economy, our health, our security, actually the substance of life itself.

As to what we might be able to do about the situation, first I think the greatest concern about climate change is that many people aren't taking it seriously, and many others aren't taking it seriously enough. To deal with the problem, you first have to recognize that you have got one. And generally speaking, people are not acting or reacting as if we have got a serious problem. Well, we do.

Most worrisome perhaps is the accelerated warming trend caused by greenhouse gases. And you, Representative Markey, have articulated most of what I would have otherwise said and done it very well, putting on the balance sheet the issues that we now face, including the acidification of the ocean and the warming, the consequences of this warming trend with sea level rise.

But what can we do about it as a Nation? Well, one thing we can do is certainly to support policies to swiftly and sharply increase protection for natural systems on the land and in the sea. They are important for stabilizing the destructive trends that we are seeing. And of course, we should also start at the source of those destructive trends and modify our behavior. Certainly the upstream issues are important. Protecting forests benefits watersheds and rivers that inexorably flow into the sea. Healthier landscapes yield healthier seascapes.

The United States can help by acknowledging the importance of methane in global warming and recognize the need to view climate change with an increased and enhanced sense of urgency. In a little submarine, I have been out off the coast of Mississippi a hundred miles, down 1,800 feet beneath the surface and seen methane bubbles burbling up out of the sea floor. And I have wondered what would happen with even a modest increase in temperature, which would enhance the release of methane, which would increase the rate of global warming with a great and classic feedback mechanism.

Sadly, while the ocean provides the foundation for all of the planet's systems that I have already articulated, driving climate and weather and taking up and holding carbon dioxide from the atmosphere, shaping global chemistry, and providing home for most of life on Earth, the ocean nonetheless is being ignored by most of those who have been working on climate change issues of all things. It is baffling to me that with all the attention being given to climate change that you have to look pretty hard to find attention being given to what is happening to the ocean.

Another good reason for having this hearing. One of the most important and positive things that this country can do to prepare for the consequences of climate change is to recognize the role of the ocean and take all possible measures to protect that vast but vulnerable system that governs the way the world works. The blue heart of the planet, the ocean presently is choked with plastic and other debris. Even more troubling is that other big problem with carbon dioxide, the acidification issue that you will soon hear more about.

Yet there are many reasons for the United States to be optimistic, to consider the powerful influence that this country can have on the rest of the world by setting the right example as well as providing help in blunting the sharp edge of climate change impact. Many people who do know what is going on feel helpless and, therefore, hopeless.

There is time, but no time to waste. The next 10 years may be the most important in the next 10,000 years because of what we do or what we fail to do concerning climate change. Never again perhaps we will have a chance. And those of you who represent this country have a unique opportunity to promote actions that will protect all that we hold near and dear and that, again, are our wealth, our health, our security, and not only our lives but all the lives to follow. Thank you.

[The statement of Ms. Earle follows:]

STATEMENT BY SYLVIA A. EARLE
National Geographic Explorer in Residence

29 April 2008

FOR: SELECT COMMITTEE IN ENERGY INDEPENDENCE AND GLOBAL WARMING, U.S. HOUSE OF REPRESENTATIVES

First, to address the questions posed in the invitation to attend this hearing.

1. *What climate change impacts have I observed?* I have been tracking the research gathered over the years by scientists who were not looking for evidence of climate change, but who found it, anyway, in receding ice, rising sea level, changing distribution patterns of certain fish and marine plants. In a small submarine, I have personally observed bubbles of methane escaping from the seafloor in 1800 feet of water in the Gulf of Mexico, and have wondered what increased warming might do to accelerate the release of more methane, that in turn would accelerate warming, and so on.

I have also personally witnessed an increase in ocean pollution and the sharp decline in the abundance and diversity of marine life in many parts of this country and elsewhere in the world, and have wondered how degraded systems could cope with changes in climate that healthy, intact systems could more readily endure.

2. *Do increased concentrations of atmospheric carbon dioxide impact aquatic ecosystems.* Changes of any kind will have some impact, but the specific concerns about CO_2 relate to chemistry, especially the trend toward acidification when more CO_2 enters the ocean than can be accommodated. Increased CO_2 is likely to favor some species over others, with consequences that could include disruption of fine-tuned systems that have developed over thousands of millennia, systems that presently favor humankind.

3. *What are some of the initiatives we can take to conserve our oceans, and work towards their long term health?* What we put into the sea and what we take out are perhaps the two greatest causes of degradation. Regulations have improved but not enough to stop the flow of excess fertilizers and noxious chemicals as well as an avalanche of plastic and other debris that clogs the ocean and kills creatures that live there. Identifying and protecting large areas of the ocean from destructive fishing should be a high priority. Establishing true marine reserves, where only non-destructive uses are permitted is critically important. Large areas are needed, but even relatively small places can make a difference, especially to protect breeding areas, feeding areas, nursery areas, and regions of high diversity, linked with substantial corridors.

General Comments **Sylvia A. Earle**

Perhaps the greatest concern about climate change is that many people are not taking it seriously, and many others are not taking it seriously *enough.* To deal with a problem, it is necessary to first recognize that it exists. *The United States can help by making climate change issues priority issues, including actions that can help stabilize and reverse the troubling trends.*

Climate change is real, of course. Not only is change natural and inevitable, but owing to human actions over the ages, especially during the 20^{th} and now the 21^{st} centuries, the rate of change has accelerated significantly.

Most worrisome, perhaps, is the accelerated warming trend caused by excess greenhouse gases, notably carbon dioxide, that we have released into the atmosphere. *The United States can help by supporting policies that will reduce CO2 emissions sharply and swiftly.*

There should be a moratorium on cutting whatever old growth forests remain, wherever they are in the country, partly to maintain the irreplaceable diversity contained there. Maintaining the highest possible biodiversity is like writing an insurance policy against the negative consequences of climate change. The greater the diversity, the better the chances that some species will prosper and adapt to the new circumstances.

Protecting forests benefits watersheds and rivers that inexorably flow into the sea. Healthier landscapes yield healthier seascapes.

Moreover, intact forests store carbon; logged or burned forests release it to the atmosphere as CO2 and methane. The same is true of ocean ecosystems. Kelp forests and coral reefs sequester carbon; dead or damaged systems release carbon. Fish and other forms of ocean life are carbon-based units that represent an enormous living store-house for carbon – as long as it remains in the sea. Wildlife taken from forests as bushmeat and the hundred million or so tons of wildlife taken annually from the sea diminish the resilience of their respective systems and put stored carbon into play.

Increased temperature brings with it a host of concerns. Plants and animals typically occupy a fairly narrow span of temperature that is suitable for their particular species. Some like it hot; some like it cold. Even small temperatures can have profound consequences for organisms that do not have our capacity to modify the environment to suit themselves. Some can migrate, but the ecosystems upon which individual species depend cannot migrate enmasse. As migrating species move into new territories, they may displace and disrupt other species and undermine entire systems. *The United States can help by supporting policies to swiftly and sharply increase protection for natural systems, including forests and ocean ecosystems, and the diverse forms of life they support.*

\As the ocean warms, there is concern that frozen methane now abundant and widespread in the deep sea may be released, enhancing the greenhouse effect, and speeding up the warming trend, and thus increasing the release of more methane – a classic feedback loop. Moreover, increasing warmth will cause the release of methane from the now-frozen permafrost in the Arctic's tundra, with similar feed-back consequences. *The United States can help by acknowledging the importance of methane in global warming and recognize the need to view climate change with an enhanced sense of urgency.*

The results of global warming include the melting of polar and alpine ice leading to sea level rise, another natural process that is accelerating, with impact most obvious in densely populated coastal areas worldwide. Today's children and the majority of adults will experience the consequences. *The United States can take the lead in helping prepare people for how to deal with this in a timely manner.*

Sadly, while the ocean provides the foundation for all of the planet's systems – driving climate and weather, stabilizing temperature, taking up and holding carbon dioxide from the atmosphere, generating oxygen, shaping global chemistry, providing home for most of life on Earth – the ocean is being largely ignored by most of those who have been working on climate change issues. *One of the most important and positive things that the United States can do to prepare for the consequences of climate change is to recognize the role of the ocean, and take all possible measures to protect that vast but vulnerable system that governs the way the world works.*

Recognizing that the ocean's wildlife – the fish, the whales, the kelp, the crabs, the krill, the sharks, the urchins and starfish, the coral reefs and deep sea forests of coral – are all components of our life support system, it is truly alarming that in just a few decades, these vital natural treasures are in serious trouble.

Viewed from afar, Earth comes into focus as the one and only World Bank, the natural asset base that humankind relies upon for all that matters to us.

Our overfishing and use of trawls, draggers, longlines and other destructive gear have cost us dearly. Ninety per cent of the big fish are gone – sharks, swordfish, tunas, cod, marlin, groupers, snappers, and many more. Hundreds of thousands of marine mammals and seabirds as well as numerous sea turtles are killed as bycatch every year. Critical habitats, from mangrove forests to sea grass meadows to coral reefs and deep sea mountains have been devastated -- with perverse subsidies helping to underwrite the destruction.

The good news is that some coral reefs are still in reasonably good shape. There is still a chance for blue-fin tunas and blue whales, for cod and corals and deep sea crabs. But only if we understand that alive they are critically important to the health of the ocean, and therefore to our health. If the ocean is at risk – and it is – then so are we. If the ocean is in trouble, so are we. By taking care of the ocean, we are taking care of ourselves.

An opportunity was missed in 2007 when the United States joined with most other countries to establish a moratorium on bottom trawling in the High Seas, a recommendation to the United Nations that was narrowly defeated. How does this relate to climate change issues? It seems simple enough. During a time when the world is undergoing changes unprecedented in the history of humankind, the last thing that we should be doing is to go about disrupting stable, diverse, natural systems that may be critical in holding the planet steady as temperature swings, currents change, and living systems try to adapt to new circumstances.

Trawling the ocean floor is comparable to bulldozing forests for songbirds, Despite the Enormous destruction, most of the deep sea has been beyond our reach until now. There is only one chance to keep the deep sea ecosystems from severe trauma. Once trawled, the distillation of millions of years of fine-tuning is lost. *The United States could take actions necessary to stabilize ocean ecosystems: curb overfishing and destructive fishing practices, and stop using the ocean as a place to dump wastes.*

The blue heart of the planet is choked with plastic and other debris. Even more troubling is the other big problem with carbon dioxide. The ocean takes up a lot, but so much as been generated so fast that there is an excess of CO_2 in the ocean, CO_2 that converts to carbonic acid. The ocean has been trending toward acidification in recent years. That is bad for coral reefs, sea snails, clams, the planktonic young of many creatures, as well as the small green organisms with carbonate shells that dissolve in acidic water. No longer can they take carbon out of the atmosphere, generate oxygen, or produce food for other creatures.

There are many reasons for the United States to be optimistic, to consider the powerful influence this country can have on the rest of the world by setting the right example, as well as providing help in blunting the sharp edge of climate change impact. Many feel helpless and therefore hopeless.

There is time, but no time to waste.

The next ten years may be the most important in the next ten thousand years because of what we do – or fail to do – concerning climate change. As never again, we have a chance, and you who represent this country have a unique opportunity to promote actions That will protect all that we hold near and dear – our health, our wealth, our security, our very lives, and the lives of all who follow.

The CHAIRMAN. Thank you, Dr. Earle, so much for your testimony.

Our next witness is Dr. Jane Lubchenco, who is a professor at Oregon State University. She is also co-head of the Partnership for Interdisciplinary Studies of Coastal Oceans, a team of scientists that studied the marine ecosystem along the West Coast. She served on the Pew Oceans Commission, which made comprehensive U.S. ocean recommendations in 2003. And she now works with the Joint Ocean Commission Initiative that seeks to implement those recommendations.

For her work, Dr. Lubchenco has received numerous awards, including eight honorary degrees and a MacArthur genius fellowship.

So we welcome you, Dr. Lubchenco. Whenever you are ready, please begin.

STATEMENT OF JANE LUBCHENCO

Ms. LUBCHENCO. Chairman Markey, Ranking Minority Member Mr. Sensenbrenner, members of the committee, it is a great pleasure to be here with you today. Thank you very much for the invitation. As you mentioned in your opening remarks, oceans have indeed been out of sight, out of mind. And it is nice to have an opportunity for them to be front and center. I hope this is just the beginning.

My name is Jane Lubchenco. I am the Wayne and Gladys Valley Professor of Marine Biology at Oregon State University. And as you mentioned, I had the pleasure of serving on the Pew Oceans Commission, and now on the Joint Ocean Commission Initiative. I am here today as a marine scientist to describe some of the impacts of climate change on oceans and some of the implications that that has for us. I respectfully request that my PowerPoint images which I will use and a white paper on oceans and climate from the Joint Ocean Commission Initiative be entered into the record.

The CHAIRMAN. Without objection, it will be included.

JOINT OCEAN COMMISSION INITIATIVE

Addressing Oceans and Climate Change in Federal Legislation

July 2007

Introduction

The purpose of this paper is to provide Congress with information and recommendations to support the enactment of legislation that incorporates ocean science, management, and education into a national initiative to mitigate and adapt to climate change. This initiative must complement ongoing efforts to understand, monitor, and forecast changes associated with natural variability, such as El Niño and the Pacific Decadal Oscillation, since anthropogenic climate change will also impact the frequency, pattern, and severity of these natural processes. The goal is to improve our collective understanding of the role of the oceans in climate change in order to inform policies and strategies intended to reduce the vulnerability of and increase the resiliency of our economic and ecological systems to impacts associated with climate change. It is the Joint Ocean Commission Initiative's view that this goal can best be met through a broad national climate change response strategy that includes an emphasis on the oceans role in climate-related processes.

After consultation with leading experts in ocean and climate change science and policy, the Joint Ocean Commission Initiative suggests that Congress address the link between oceans and climate change by addressing needs in two key areas: governance reform and science. Clearly, additional funding will be necessary to make sustained progress in both areas. The actions recommended by the Joint Ocean Commission Initiative are summarized below and discussed in more detail in the pages that follow.

Governance Reform

1. Charge the National Academy with recommending a process and strategy to respond to climate change, including consideration of the organization and functions of a National Climate Change *Response* Office responsible for guiding federal programmatic and budgetary climate change activities.
2. Codify and strengthen the White House Committee on Ocean Policy, and give it a key role in supporting the activities of the Climate Change Response Office.
3. Codify and strengthen the National Oceanic and Atmospheric Administration (NOAA), realigning the agency's organizational structure to enhance and focus its capacity to provide climate-related services and improve ocean and coastal management.
4. Require a biennial *integrated* assessment of the nation's progress toward meeting its objectives to mitigate and adapt to impacts associated with climate change and variability.
5. Require the submission of an integrated budget to consolidate and highlight priorities established by the National Climate Change Response Office that would accompany the President's annual budget request

Science Requirements

1. Request prioritization of and provide funding to implement the Administration's *Ocean Research Priorities Plan and Implementation Strategy*, with a focus on developing a science enterprise that is responsive to societal and environmental concerns.
2. Enact legislation authorizing the implementation of an Integrated Ocean Observing System, incorporating both coastal and global components.
3. Fund major ocean observation research and monitoring infrastructure systems and supporting science and data management programs, such as an Integrated Ocean Observing System, the Ocean Observatories Initiative, research vessels, and remote sensing programs.
4. Enhance funding support for transitioning ocean and atmospheric data collection and synthesis programs from research to operational status, with ongoing engagement of the ocean science community in the operation, evaluation, and evolution of the programs.
5. Support research to evaluate the impact of greenhouse gas mitigation policies on coastal and ocean processes and ecosystem health (e.g., oceanic carbon sequestration, biofuel production).

THE ROLE OF OCEANS IN CLIMATE CHANGE

Increasing awareness and concerns about climate change have elevated the urgency to take action to mitigate its causes and make preparations to adapt to its anticipated economic and environmental impacts. At continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in arctic temperatures and ice, as well as widespread changes in, ocean salinity, wind patterns, the quantity of precipitation, and various aspects of extreme weather.[1] As Congress moves forward in developing climate change policies, the accompanying legislation should recognize the fundamental role oceans play in governing climate change and Earth-related processes. Some important facts regarding the relationship between oceans and climate change include the following:

- Oceans cover 71 percent of the Earth's surface and average over 12,200 feet in depth.
- Water holds approximately 1,000 times the amount of heat as air, and the interaction between ocean circulation and the global distribution of heat is the primary driver of climatic patterns.
- The oceans are warming, particularly since 1950s, with global mean sea surface temperature having increased roughly one degree Fahrenheit in the 20th century.[2]
- Sea levels rose 7 inches during the 20th century and nearly 1.5 inches between 1993 and 2003 alone.[2]
- Oceans are a major carbon sink and have absorbed fully half of all fossil carbon released to the atmosphere since the beginning of the Industrial Revolution.[2]

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[1] Intergovernmental Panel on Climate Change. 2007. Report of Working Group I *The Physical Science Basis*.

[2] Doney, Scott. 2006. *The Dangers of Ocean Acidification*. Scientific American (March).

- The absorption of carbon has resulted in increasing ocean acidification, impacting the health of marine ecosystems and species, including, but not limited to, those with carbonate-based skeletons (e.g., corals), as well as influencing the important role ocean plays in the global cycling of carbon.
- Little to no Arctic sea ice is expected in the summers by 2100.[2]

GOVERNANCE REFORM TO ADDRESS OCEANS AND CLIMATE CHANGE

Climate change involves complex and dynamic interactions of the atmosphere, ocean, land, their related ecosystems, and human activities. The complexity and breadth of issues associated with efforts to understand, mitigate, and adapt to climate change, the scale of its impacts from the local to the global level, and the need to understand the relationship between natural variability and climate change make it essential that the nation have a coherent and comprehensive strategy to address this new challenge.

Unfortunately, there is general agreement in the scientific community that the current federal climate change governance regime is too limited in scope and must be expanded if it is to be truly comprehensive. A Climate Change *Response* Office is required to guide the development and implementation of a National Climate Change Response Strategy. Such an office must have the authority to direct the activities of multiple federal agencies and have a strong role in the budget formulation process. This will require designing and implementing a strategy that balances the need to conduct basic and applied research, monitoring and analysis, and modeling and forecasting, with the goal of translating data into information products that can be used to develop sound policies to mitigate and adapt to environmental and socioeconomic impacts stemming from climate change.

Ocean science and management must be recognized as key elements of a national response strategy. Thus, the existing interagency coordination process operating under the White House Committee on Ocean Policy[3] should be codified and charged with supporting the effort to institutionalize a broader National Climate Change Response Strategy. An additional action needed to strengthen the federal government's capacity to respond to climate change is to codify and strengthen the National Oceanic and Atmospheric Administration (NOAA). As a key provider of climate-related services and ocean management information, and as one of the principle agencies investigating the ocean's role in climate variability, NOAA plays a lead role in matters related to climate change. However, an outdated organizational structure and the lack of resources have limited NOAA's ability to fulfill its multiple mandates. The opportunity is ripe for Congress to reevaluate NOAA's organizational structure and realign programs along its core functions: environmental assessment, prediction, and operations; scientific research and education; and marine resource and area management. Strengthening NOAA and realigning its functions would greatly enhance its capacity to provide climate-related services and facilitate the implementation of proactive management measures to mitigate anticipated impacts on coastal economies and ecosystems.

Finally, Congress should require a biennial integrated assessment of the nation's progress towards mitigating and adapting to climate change impacts. An integrated assessment evaluating the collective effort of federal programs and activities will provide a baseline from which to measure progress and will help ensure the nation is maximizing the use of available data and information to improve the

[3] Executive Order 13366, 2004.

caliber of forecasts and to evaluate the effectiveness of management actions. An additional step that would facilitate better integration of federal programs would be a requirement for the submission of an integrated budget that clearly identifies priorities established by the proposed National Climate Change Response Office and how those priorities relate to and complement efforts directed at understanding the ocean's role in climate change. Congressional oversight the federal budgets is its most powerful tool, but Congress' capacity to help guide a response to an issue as complex as climate change is compromised when information is dispersed throughout the President's budget.

Ocean and Coastal Science Requirements

Credible and timely scientific information will be essential as the nation begins the process of responding to the challenges associated with climate change. Better science, when linked with improved risk management and adaptive management strategies, will help guide a process that must deal with the relatively high levels of uncertainty related to mitigation alternatives and the range of impacts associated with climate change and variability. A much more comprehensive and robust science enterprise that incorporates a better understanding of the ocean's role in climate change is required to forecast more accurately the magnitude and intensity of this change at multiple scales, as well as to evaluate options for mitigation and adaptation. This process must also include strengthening capacity in the social sciences, whose contributions will influence risk and adaptive management strategies significantly given the immense economic impact climate change will have on coastal communities.

Unfortunately, the existing ocean and coastal science enterprise supporting climate change research, observations, data management, and socioeconomic analysis is limited. Despite the unprecedented opportunities to capitalize on technological advances, future capacity is compromised due to a lack of fiscal support for key infrastructure and science programs. For example, the U.S. commitment to constructing an observing system focused on studying physical ocean processes is only half complete, while satellite systems responsible for generating invaluable data across large areas of oceans are aging. The construction of replacement systems are behind schedule, over budget, and as currently configured, may have less capacity than the systems they are replacing. The status of infrastructure supporting on and underwater ocean science, such as ship, buoys, cabled observatories, planes, and other underwater monitoring hardware, is bleak. Additionally, support for shore-side lab work, where data for the observing systems is analyzed, quality-controlled, synthesized, and integrated, has eroded. Further underlying these weaknesses is a lack of capability to transmit large amounts of ocean data in real time and a disjointed data management system that prevents scientists from fully utilizing the data that are being collected now. Stagnant funding supports only bare-bones research, monitoring, modeling, and analysis enterprises that have difficulty providing the quantity and quality of data needed to generate information with the relatively high levels of confidence demanded by decision makers facing difficult policy choices.

Congress can begin to remedy this situation by taking the following series of step. First, it should call on the administration to prioritize and request full funding to implement its *Ocean Research Priorities Plan and Implementation Strategy* (ORPPIS). ORPPIS provides a solid blueprint to guide research on the ocean's role in climate, including the development of a comprehensive observing system and other ocean-related research priorities that will improve our ability to enhance the resiliency of marine ecosystems and coastal economies to climate-induced changes. Particularly noteworthy in ORPPIS is its emphasis on using improved understanding to provide better and timelier policy and resource management decisions, relying on much stronger support for social and economic research. It is the first comprehensive research strategy developed by the Administration with input from the ocean community and should be used by Congress to guide its ocean science funding priorities.

Congress should also authorize and fund the implementation of an Integrated Ocean Observing System (IOOS). Support for the implementation of the coastal and global IOOS should be driven by a cooperative interagency process that incorporates expertise from outside the federal system. Congressional support should also extend to major observing initiatives supported by the National Science Foundation, as well as to remote sensing satellite programs supported by NASA's Earth Science program. As noted earlier, the loss or diminishment of remote sensing capabilities, in addition to the lack of support for transitioning ocean and atmospheric data collection and synthesis program from research to operational status, has significantly compromised our nation's capacity to monitor the vast expanse of the ocean. Sustained research and operational monitoring and analyses programs supported by enhanced data collection, management, and synthesis capabilities are the foundation of an observation system that can refine climate change models and reduce the level of uncertainty associated with their projections.

Finally, Congress should support research and science programs focused on analyzing the potential impact various greenhouse gas mitigation strategies may have on ocean and coastal processes and ecosystem health. Recommendations for carbon sequestration in the oceans will require particularly careful review, given our growing concern about the sensitivity of marine ecosystems to changes in the biogeochemistry of ocean waters as a result of increased absorption of carbon dioxide, in particular ocean acidification. Similarly, increased biofuel production will generate additional runoff of nutrients, herbicides, and pesticides, further exacerbating pollution and nutrient enrichment problems in coastal waters.

Given their immense size, fundamental role as a driver of climate processes, and critical social and economic importance, it is imperative that Congress focus greater attention and resources on improving our understanding and management of our oceans, coasts, and Great Lakes. The actions recommended above are important steps that will lay the foundation for making great advances in ocean science and allow meaningful progress toward improved stewardship of one of nation's greatest natural resources.

Ms. LUBCHENCO. Thank you very much. I intend to focus my remarks both on impacts and on implications today. And with respect to impacts, I want to talk about two different categories of impacts. One are those that have been predicted and in fact are happening. That includes warmer oceans. Sea level temperatures are rising around the world in every single ocean basin. Sea level is rising. And as Dr. Kleypas will describe, oceans are becoming increasingly acidic. And that has huge consequences for much of life in oceans and, in turn, for us.

I also wish, though, to focus on some surprises that are playing out that we suspect are related to climate change. And they really underscore how little we really understand about how the oceans work and how they will change in the future as these other predicted changes come about.

There is no doubt that ocean temperatures are increasing and that sea level is becoming more acidic and ocean levels are rising. It is worth noting that all of these are happening faster than originally predicted. Warming and acidification are particularly serious threats to marine life and to the benefits provided by ocean ecosystems. Rising sea level is a very real problem for many people in, especially in coastal communities and for coastal habitats. But by and large, on balance, the warming temperatures and increasing acidity are far greater threats for most of life in the oceans.

Turning now to consideration of some of the surprises that we are seeing in oceans, I draw your attention to the western sides of most of the continents in the world that are characterized by what are called coastal upwelling ecosystems. These ecosystems are particularly rich. They represent only 1 percent of the surface area of the oceans, but they have historically provided 20 percent of our global fisheries. Many of these systems are changing dramatically. And I would like to describe some of the ways that we are documenting.

The systems depend on winds that blow along the coast toward the equator. This in turn pushes surface waters away from the coast and brings up cold nutrient-rich water, which is why these systems are so incredibly productive. Off the Pacific northwest coasts off Oregon and Washington, we have a seasonal upwelling that appears in the summertime. It is intermittent, so it is upwelling alternating with downwelling, and our rich systems are legendary.

What we are seeing is a very significant perturbation of this normal upwelling, specifically the appearance of new dead zones. Now, these are different from the dead zones that you have heard of in the Gulf of Mexico and elsewhere around the world that are driven by runoff of nutrients from the land. This is a different type of dead zone. It is caused by changes in the coastal winds and in ocean conditions, both of which we believe are likely related to climate change.

We have seen a dead zone off the Pacific northwest coast now 6 years in a row; 2006 was the longest lasting. It was 4 months long. It occupied as much as two-thirds of the water column. This is a slice of the ocean where you see in colors different amounts of dissolved oxygen. On the far right of the screen is the land. And the bottom shows the coastal—the continental shelf getting deeper and deeper. And as much as two-thirds of the water column, the blues in here, are in fact too low in oxygen for most marine life to persist, and so they suffocate.

This image shows where the dead zone is. In blues and purples is the dead zone off the coast of Washington and Oregon in 2006. And you can see it is a very significant fraction of that shore line. Our research teams have in fact been working hard to figure out what is happening and why. We have pieced together a story that suggests that changes in the coastal winds and ocean conditions are the culprits here. There has not been a change in the runoff of land, so it is a different type of dead zone. But changes in ocean conditions and wind conditions are well described. We have images from remotely operated vehicles that have been driven along the sea floor showing what the sea floor looked like in normal years, for example in 2000, and then the devastation that has happened since then in 2002 and also 2006, the images that you see on the screen, with just massive numbers of dead crabs, dead sea stars, dead urchins on the ocean floor.

I had a movie to show you, but I am not going to have time. I want to switch quickly to the implications of this. Ocean ecosystems are already at serious risk. Many of the services that they provide to people are being threatened by overfishing, destructive fishing gear, runoff of nutrients, chemical pollution, and coastal development. The things that people want from oceans are in fact at risk. And if society wishes to avoid the most serious consequences that climate change is already bringing and that will get worse, we need to do a number of things: reduce greenhouse gas emissions very significantly first and foremost; secondly, avoid mitigation quote-unquote solutions that trigger serious unintended consequences; third, as you mentioned, prepare to adapt to changes.

But I believe we need to expand the way we think about adaptation. And it is not just adaptation of human systems, but in fact, we need to think about creating the conditions for nature to be able to adapt to the inevitable warmer waters and more acidic waters. If we have more funding for scientific research and monitoring, we can do a better job of helping to figure all this out. And of course, educating citizens is incredibly important.

Strategies to minimize impacts of climate change are both to reduce stresses that can be controlled and to protect as much biodiversity as possible. So, in summary, Mr. Chairman, oceans are in very serious trouble. Climate change will exacerbate them. We understand them relatively poorly. We need to reduce emissions. We need to make protecting ocean ecosystems one of the highest priorities, redefine adaptation to include creating the conditions for nature to adapt, increase funding, and educate citizens. Thank you very much.

[The statement of Ms. Lubchenco follows:]

CLIMATE CHANGE AND OCEANS: IMPACTS AND IMPLICATIONS

Testimony of
Professor Jane Lubchenco
Oregon State University

To the
U.S. House of Representatives
Select Committee on Energy Dependence and Global Warming
April 29, 2008
Washington, DC

Hearings on: "Rising Tides, Rising Temperatures; Global Warming's Impacts on the Oceans"

Chairman Markey, Ranking Minority Member Sensenbrenner, and members of the Committee: thank you for the invitation to testify today. My name is Jane Lubchenco. I am the Wayne and Gladys Valley Professor of Marine Biology and Distinguished Professor of Zoology at Oregon State University. I lead an interdisciplinary, multi-university research team called PISCO, the Partnership for Interdisciplinary Studies of Coastal Oceans, that studies the dynamics of the coastal ecosystem off Washington, Oregon and California. I had the pleasure of serving on the Pew Oceans Commission and I currently serve on the Joint Ocean Commission Initiative (JOCI) that seeks to implement the recommendations of the Pew Oceans Commission and the U.S. Commission on Ocean Policy. I also co-founded and serve as Vice Chair of Climate Central, a new nonprofit, non-advocacy organization that seeks to communicate scientific information about climate change and solutions in understandable fashion.

I am here today as a marine scientist, to share scientific information about impacts of climate change on ocean ecosystems and the implications of these changes for people and for U.S. policies and practices. I will focus on findings from the peer-reviewed scientific literature and relevant scientific assessments such as the Intergovernmental Panel on Climate Change (IPCC) the Arctic Climate Impact Assessment, and the Millennium Ecosystem Assessment, and also provide examples from my personal experiences and research.

I will use powerpoint images to illustrate some key information. I request that a copy of my powerpoint presentation be entered into the record, along with a copy of the JOCI white paper entitled "Addressing Oceans and Climate Change in Federal Legislation". Both are attached to this testimony. Thank you, Mr. Chairman.

IMPACTS

Predicted Impacts: Warmer water, rising sea level, more acidic seawater

I begin by summarizing three key impacts of climate change on oceans, all of which were predicted, based on scientific understanding of the climate system, then focus on another possible impact that has taken us by surprise. In each case, I'll describe the physical change first, then the biological and ecological consequences of the physical change. The three predicted impacts are: (1) increases in ocean temperatures, (2) increases in sea level, and (3) increases in the acidity of seawater.

(1) Warmer waters: There is unequivocal evidence that the oceans are warming. The temperature of every ocean basin around the world increased over the second half of the 20^{th} century. Taken as a whole, the ocean is now significantly warmer than it was in the middle of the 1900's.

Warmer waters have numerous consequences for life in the oceans: (a) Corals, when stressed by warmer temperatures, respond by expelling the microscopic plants they harbor – a phenomenon known as 'coral bleaching.' Although bleached corals do not always die, they often do. The incidence of bleaching events is increasing globally. Because coral reefs provide the three-dimensional habitat for millions of other species in tropical waters, their demise would have dire consequences for these rich oases of biodiversity. People who depend upon coral reef ecosystems for food, recreation and many associated livelihoods are already experiencing the consequences of disrupted and degraded coral reef ecosystems.

(b) Numerous species are shifting their geographic ranges, in response to changing ocean temperatures. In the north Atlantic, for example, herring, cod, capelin and mackerel are shifting poleward. In some cases, predators and prey shift differentially, with consequent disruptions to their ecosystems.

(c) Other species such as polar bears and other Arctic ice-dependent species face likely extinction as warmer waters melt the ice upon which they depend for food or shelter.

(2) Rising Sea Level: Sea level has risen steadily over the last century, on average about 6 inches, due to both thermal expansion and the melting of glaciers, ice caps and ice sheets on land. Sea level is expected to continue to rise, although the exact amount depends on a number of factors for which current information is insufficient for precise predictions. The consequences of rising sea level may be significant for people living on or near the shore, and significant for already-stressed coastal estuaries, salt marshes and mangrove ecosystems. On balance, however, the consequences of sea level rise are minimal for most marine species.

(3) Increasing acidity: Between 1/3 and ½ of the carbon dioxide that humans have released into the atmosphere has been taken up by oceans. When absorbed by oceans, $CO2$ is converted into carbonic acid, making seawater more acidic. Measurements indicate that the oceans are becoming more acidic. Experiments in the laboratory suggest that this increasing acidity is likely to be problematic for any marine species that makes a

shell or skeleton from calcium carbonate. The rate at which a new shell or skeleton is made depends on temperature and acidity. Likewise, the rate at which a shell or skeleton is dissolved depends on temperature and acidity. Hence a wide variety of life in oceans – ranging from corals to microscopic plants to snails, clams, mussels, oysters, sea stars, sea urchins, lobsters and crabs – is likely to be negatively impacted by an increasingly acid ocean.

I've summarized three major ways in which climate change is impacting life in the oceans: warmer waters, rising sea level and increasing acidity. Warming and acidification pose very serious threats to marine life and to many of the benefits that ocean ecosystems provide to people. It is important to note that although each of the three impacts was predicted, the *rate* of change for each has been faster than initially predicted. Most climate predictions have been conservative. In addition, these changes may interact with one another. A PISCO researcher, Dr. Gretchen Hofmann and her team at the University of California at Santa Barbara are finding that some species may be able to cope with changes in acidity alone or changes in temperature alone, but not the combination of the two.

A possible unexpected impact: Changes in coastal winds and circulation.
I will next describe a recently discovered perturbation of the ocean ecosystem off the west coast of the US, specifically along the coasts of Washington and Oregon. Beginning in 2002, our PISCO team has documented a new 'dead zone' that appears each summer. This dead zone is an area of the ocean where the levels of oxygen are too low to support most marine life. Fish and invertebrates suffocate if they cannot swim or scuttle away as the oxygen levels plummet.

This dead zone is unlike most of the other dead zones around the world, for example, the one in the Gulf of Mexico, that are driven by nutrient pollution coming from the land. The dead zone off the Pacific Northwest appears to be caused by changes in atmospheric and oceanic conditions, both of which are suspected of being related to climate change.

To understand how this dead zone develops, a little background information about normal upwelling dynamics is helpful. Around the world, on the western sides of continents, winds (driven by the differences in atmospheric pressure over the land and over the ocean) blow along the coast toward the equator. Because the earth is rotating, surface waters are pushed away from the coast and nutrient-rich but low-oxygen water from the dark, deeper portions of the ocean are pulled to the surface. This 'upwelling' of deep water brings nutrients to the surface and fuels the rich ecosystems typically found off these coasts. 'Coastal upwelling ecosystems' collectively represent about 1% of the surface area of oceans but they have historically provided about 20% of global fisheries, in large part due to this infusion of nutrients into sunlit, coastal waters. Other coastal upwelling ecosystems occur off the coasts of Chile and Peru, South Africa and Namibia, and Morocco.

In the Pacific North West, beginning in 2002, however, this normal pattern shifted slightly, but the slight shifts brought dire consequences. Suddenly fishermen were hauling up Dungeness crab pots only to find them full of dead crabs. Coastal residents and tourists reported mass numbers of dead fishes and crabs washed up on beaches. Recreational divers reported seeing huge schools of rockfish in unusual places. Scientists documented dead fish on the ocean floor and biological 'erratics': deep-dwelling fishes stranded in intertidal tide pools. Researchers with Oregon State University's Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) team figured out the cause of these anomalies: there was not enough oxygen in some of the water for most crabs and fishes to live, so they escaped or suffocated.

Since 2002, this dead zone has reappeared each summer: we've documented six dead zone events in six years. In a paper published in *Science* in February, we reported that these recent events are highly unusual compared to the last 60 years (as far back as reliable dissolved oxygen measurements go.) Hypoxia ('low oxygen') appears to have become the 'new normal' for summertime off our coasts.

2006 was the worst year on record: the low-oxygen water persisted for 4 months and occupied as much as 2/3 of the water column over approximately ½ of the continental shelves of Washington and Oregon. Moreover oxygen levels plummeted to near zero in 2006: seawater was not just hypoxic, it was anoxic (no oxygen). Mass die-offs of bottom-dwelling animals were documented. Some crabs and fishes escaped, and some of those have returned to the area, but the seafloor remains significantly depleted. The long-term consequences to fisheries of the region are not known.

Teams of researchers from OSU, the University of Washington, NOAA Fisheries, the Olympic Coast National Marine Sanctuary, the Oregon Department of Fish and Wildlife and Oregon Coastal Ocean Observing System have cobbled together resources to document these events and their consequences and to piece together the following understanding. Changes in both atmospheric and oceanic conditions are implicated in causing the dead zones. We have documented both changes in ocean conditions that set the stage for dead zones and changes in the coastal winds that trigger the events. Abundant nutrients from strong upwelling trigger explosive growth of microscopic plants in the surface waters. When these plants begin to sink and die, they are decomposed by bacteria that consume oxygen. Successive cycles of upwelling and decomposition result in lower and lower levels of dissolved oxygen in the water.

We cannot say definitively that these dead zones are caused by climate change, but we can say that they are consistent with our understanding of climate change dynamics. Moreover, there is no other obvious explanation for the appearance of dead zones off an open coast such as ours. This dead zone is a consequence of changes in oceanic and atmospheric conditions, not runoff of nutrients from the land.

This dead zone is a seasonal phenomenon. When coastal winds shift to a primarily poleward direction in October, downwelling conditions become dominant, the area is re-oxygenated and remains oxygenated until the following spring-summer when upwelling-favorable conditions develop and a new dead zone reappears. Some fish and crabs appear to venture back into the area during the wintertime, but come summer, they must again flee or die.

The consequences of the dead zone appear to be quite significant for the seafloor communities, with a number of longer-lived, large-bodied species disappearing from the system. Little is known about the impacts of repeated annual die-offs in these historically stable and rich communities.

In summary, fluctuations in the timing and intensity of coastal winds appear to be altering the dynamics of the historically rich ocean ecosystems off Washington and Oregon. These anomalies vary in intensity from year to year. These changes are unprecedented in this ecosystem relative to last 6 decades. Comparisons with other coastal upwelling ecosystems: off Chile and Peru, South Africa and Namibia, and Morocco would be useful. Further research will help determine ultimate causes and consequences.

IMPLICATIONS

The collective impacts of climate change on life in the oceans are serious and largely unappreciated. Moreover, they exacerbate a plethora of existing stresses on ocean ecosystems: overfishing, destructive fishing gear, unsustainable coastal development, nutrient and chemical pollution and introduction of non-native species. As reported in the Millennium Ecosystem Assessment and the reports from both ocean commissions, the wealth of benefits that humans derive from ocean ecosystems is already at risk due to these combined stresses, and climate changes will present even greater challenges.

Americans say they look to the ocean for healthy seafood, for abundant wildlife, for places to enjoy and be inspired, for their livelihoods, for vibrant coastal communities and in many cases for their identity. All of these benefits depend on healthy, productive and resilient ocean and coastal ecosystems. All are at risk in the face of a rapidly changing climate. If society wishes to maintain the above benefits and minimize the most serious consequences of climate change, it should

1. Reduce greenhouse gas emissions significantly
2. Avoid mitigation 'solutions' that trigger unintended consequences
3. Prepare to adapt human infrastructure to changes that are inevitable
4. Manage human activities to maximize likelihood that species can adapt
5. Invest in scientific monitoring and research to guide decisions, and
6. Educate citizens about options and consequences

Let me expand briefly on items 3 and 4. Most discussions about 'adaptation' focus on adapting human infrastructure to adjust to those impacts of climate change that are inevitable. I believe we should redefine 'adaptation' to also include managing human activities in a fashion that maximizes the likelihood that species can adapt to changes that are inevitable. The primary reason for expanding our thinking about 'adaptation' is the reality that human health, prosperity and well-being depend upon the healthy, productive and resilient ecosystems. Our future well-being depend not only on our ability to adapt, but on that of the millions of species that provide us with food, shelter, pollination services, recycling, climate regulation, flood regulation, shoreline protection, medicines, recreation, inspiration and much more.

Managing human activities to maximize the likelihood that species can adapt includes two general categories of actions: reducing other stresses and protecting biodiversity and habitats. (1) Reducing other stresses would entail reducing nutrient and chemical pollution, managing fisheries conservatively; eliminate use of destructive fishing gear, and controlling invasive species. (2) Protecting biodiversity and habitats to maximize likelihood of adaption would include establishing networks of no-take marine reserves and other protected areas and protecting coastal habitats.

All six of the items listed above have governance, management and funding implications. In my view, none of these is expendable. The recently released white paper entitled "Addressing Oceans and Climate Change in Federal Legislation" from the Joint Oceans Commission Initiative (JOCI) provides additional information about a number of these actions.

In summary, climate change is already impacting ocean ecosystems in U.S. waters and around the world. Climate-related stresses compound many previously existing stresses on ocean ecosystems. If society wishes to continue to benefit from the bounty and the beauty of the oceans, it will need to implement new and significantly more effective policies than currently exist. Ocean ecosystems are changing rapidly, sometimes in unexpected ways. Strong actions now will increase the likelihood that society will be able to benefit from and enjoy ocean resources and places for decades to come.

The CHAIRMAN. Thank you so much, Doctor. We very much very much appreciate your testimony.

Next we are going to hear from Dr. Joan Kleypas, an ocean scientist at the National Center for Atmospheric Research. Since joining NCAR in 2002, Dr. Kleypas has become a leading voice on the impacts of climate change, on the health of oceans and coral reefs. Her work has been featured in BBC News, Science magazine, Science Daily. A real expert in the field.

We welcome you, Doctor. Whenever you are ready, please begin.

STATEMENT OF JOAN KLEYPAS

Ms. KLEYPAS. Thank you, Chairman Markey, Ranking Member Sensenbrenner, and members and staff of the Select Committee.

Thank you for holding this hearing on such an important and urgent issue. And I will reiterate Dr. Earle's comment; we have a serious problem.

I am a scientist at the National Center for Atmospheric Research, and I have specialized on coral reefs for about 20 years. I thank you for this opportunity to discuss two serious consequences of climate change for coral reefs, ocean warming and ocean acidification.

Since the 1950s, the tropical oceans have warmed on average by more than half a degree Fahrenheit. This warming has caused a phenomenon called coral bleaching. Bleaching happens when a coral expels a colorful algae that lives within its tissues and provides that coral with most of its energy. Bleaching is often fatal. Coral bleaching has already destroyed about 10 percent of reefs worldwide and has weakened many more. The projections of bleaching patterns indicate that if ocean warming continues along its current path, we will lose this ecosystem. We hope that corals can adapt to the warming, but there is really very little evidence that they can do so.

The other problem I want to raise is something known as the other carbon dioxide problem. This is ocean acidification. The concept of ocean acidification can be explained with a bottle of carbonated water. So that water was carbonated simply by adding CO_2 or carbon dioxide to it. And carbonated water is more acidic than just regular tap water. And anybody can test this with litmus or pH paper. The oceans have already absorbed about a third of the carbon dioxide released into the atmosphere by man's activities. And this really is a natural gift, because it lessons the impact of climate change, but it is changing ocean chemistry. Although we can't feel the change, we can measure it, and measurements are confirming that ocean acidification is indeed happening.

So there are two main ways that ocean acidification affects marine organisms. First it can stress the organisms physiologically, such as increasing its respiration rate, lower reproduction, and lower survival. And second, what we know the most about, too, is that acidification impacts the ability of marine organisms to secrete their skeletons or their shells. This includes many important groups of marine organisms, from microscopic algae at the base of the food chain to familiar organisms like clams, starfish and corals.

Corals are the best studied of these. And there is strong evidence that their calcification rates will decline by 10 to 50 percent within the next 40 to 50 years. They simply won't grow as fast or they will grow more fragilely. And you can think of it as osteoporosis.

This slide shows a dramatic example of a coral cultured in normal versus acidified sea water. Ocean acidification not only slows skeletal formation, but at some point, it actually dissolves it. So what does this mean for the coral? Organisms that produce shells do so for a reason, for protection, for example. Even if this naked coral in this slide could somehow survive in the real world, it would be living as an anemone, not as a coral, and it wouldn't be producing coral reefs.

In fact, reefs themselves exist because corals and other organisms build the reef faster than it is eroded. Ocean acidification attacks a reef's structure itself by increasing the rate at which it dissolves. And if reefs erode away, we will lose many of the valuable services that they provide. And that includes high biodiversity, fisheries, and shoreline protection.

So what can be done about ocean acidification and warming? Obviously, reducing greenhouse gas emissions tackles the root cause of both. And we need to reduce those emissions aggressively. Given that coral bleaching is already so widespread, we may already be above the threshold for that ecosystem. For acidification, certainly we need to find a way to keep carbon dioxide levels below 500 parts per million because, above that level, some reefs will start to erode away.

It is worth noting here that geo-engineering solutions to reduce warming, such as putting dust into the atmosphere or sun shades in space, do not solve the problem of ocean acidification because those solutions don't reduce carbon dioxide concentrations in the atmosphere. I want to also stress that ocean acidification affects not just coral reefs, but it affects all marine ecosystems. And I really feel that this may be the greatest environmental threat that we face this century. It is a new issue, and we have our hands full just trying to understand the scope of the problem. We need to know how much carbon dioxide is too much carbon dioxide, but we also need to know what we can do to help marine ecosystems make it through this difficult time.

So I urge you, first, to take on the task of reducing greenhouse gas emissions and, second, to pass the FOARAM Act, which is an act to increase research on ocean acidification. And I just want to sign off on a comment that, 25 years ago, we thought that global warming was going to be good for reefs because, like warm water, they would expand. Well, now we, you know, now we know about coral bleaching. We know about ocean acidification. Climate change is not good for coral reefs. And what is at stake if we lose them is the most biodiverse ecosystem of the ocean. It is one that supports major fisheries and economies of the U.S. States and territories. It protects many shorelines. And of course, this is a masterpiece among God's creations.

Thank you very much, and I am happy to answer questions.

[The statement of Ms. Kleypas follows:]

Statement of

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National Center for Atmospheric Research

Before the

U.S. House of Representatives Select Committee on Energy Independence and Global Warming

29 April 2008

Hearing on

"Global Warming's Impact on the Oceans"

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

Introduction

I thank Chairman Markey, Ranking Member Sensenbrenner, and the other Members of the Select Committee for the opportunity to speak with you today about global climate change and its effects on our oceans. My name is Joan Kleypas. I am a Scientist at the National Center for Atmospheric Research in Boulder, Colorado. My research has focused on the interactions between marine ecosystems and climate change, with particular emphasis on the impacts of climate change on coral reef ecosystems. I have authored or co-authored more than 40 peer-reviewed scientific journal articles, book chapters, and technical documents, and have presented more than 40 invited talks worldwide. I have co-organized several international workshops on issues related to climate change and marine ecosystems. I currently serve on three committees related to carbon and the oceans: the Ocean Carbon and Biogeochemistry Scientific Steering Committee, the European CarboOcean International Advisory Board, and the European Program on Ocean Acidification (EPOCA). You have asked me to provide insights on issues related to the impacts of climate change on coral reefs. My testimony will focus on two major factors that affect coral reefs: ocean warming and the emerging problem of ocean acidification. I have worked on these issues for more than 10 years, and on coral reefs for more than 20 years.

Background

What are coral reefs? Coral reefs are geological structures built by biological communities dominated by corals. Coral reefs are quite unique in that they are literally defined by the rock – calcium carbonate – that the organisms produce during skeleton and shell building. A coral reef can be 30 meters thick and cover many square kilometers, essentially built over time by the thin veneer of organisms that live on the reef surface. The main organisms that build coral reefs are corals, animals related to sea anemones but which secrete skeletons. Many other organisms are also important in reef building: certain algae that secrete calcium carbonate, as well as mollusks, echinoderms, and many lesser-known groups of organisms. Even though corals are animals, their ability to grow quickly and build reefs is due to their symbiotic relationship with microscopic algae ("zooxanthellae") that live in their tissues. The symbiotic algae produce nutrients and energy via photosynthesis, which allows the corals to live in rather nutrient-poor regions.

Corals and reef-building algae thus require light to grow and are usually limited to waters less than 30m in depth; as such they are subject to atmospheric disturbances such as storms and hurricanes. The shallow-water restriction usually places them near land as well, and thus coral reefs occur at the triple-intersection of atmosphere-land-ocean. Most reefs therefore are quite accessible to man and have sustained human cultures for thousands of years, but they are also subject to multiple stressors from the nearby land, atmosphere, and the ocean.

Reefs in the U.S. and its territories. Coral reefs in the U.S. and its territories extend well beyond the familiar reefs of Hawaii, Florida, and Texas. Extensive coral reefs also exist in Puerto Rico, U.S. Virgin Islands, and in the Pacific: The Northern Mariana Islands, Saipan, Guam, Wake Island, Johnston Atoll, Kingman and Palmyra Atolls, Howland and Baker Islands, and Jarvis Island. The U.S. values its coral reefs and has a history of protecting them. In 1998, President Clinton issued an Executive Order establishing the U.S. Coral Reef Task Force, and in 2000 he issued an Executive Order to establish the Northwestern Hawaiian Island Coral Reef Ecosystem Reserve.

The value of coral reefs. Coral reefs occupy only about 1% of continental shelves, yet they support an estimated 25% of marine species. Coral reefs have the obvious economic value derived through fishing, tourism, the aquarium industry, etc. However, they also provide many hidden values that are often overlooked. Some of these include: 1) shoreline protection; 2) fish habitat; 3) beach sand supply; 4) potential pharmaceuticals and 5) biodiversity. Global economic valuations of coral reefs calculate the net economic benefit from reefs at about US$30 billion per year[1]. The economies of four Florida counties alone (Palm Beach, Broward, Miami-Dade, and Monroe) receive some US$4.3 billion in sales and $2 billion in annual income[2].

Current state of coral reefs worldwide and in the Caribbean. By several measures, the condition of coral reef ecosystems has declined worldwide. Two recent studies document large declines in the percent coral cover on coral reefs. Since the 1970's, the percent coral cover (the percentage of reef surface area occupied by corals) has declined from about 50% to 25%[3]; in the Caribbean, the decline has been from about 50% coral cover to 10%[4]. Worldwide, about one-fifth of all reefs have already been destroyed with low prospects for recovery[5]; about half of this is due to the phenomenon called "coral

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[1] Cesar H, Burke L, Pet-Soede L. 2003 *The Economics of Worldwide Coral Reef Degradation*, 6828GH Arnhem, The Netherlands

[2] Johns GM, Leeworth VR, Bell FW, Bonn MA. 2003. *Socioeconomic Study of Reefs in Southeast Florida. Final Report submitted to Broward County, Palm Beach County, Miami-Dade County, Monroe County, Florida Fish and Wildlife Conservation Commission, and NOAA, as revised April 18, 2003*

[3] Bruno JF, Selig ER. 2007. Regional decline of coral cover in the Indo-Pacific: Timing, extent, and subregional comparisons. *PLoS ONE* 2: e711. doi:10.1371/journal.pone.0000711

[4] Gardner TA, Côté IM, Gill JA, Grant A, Watkinson AR. 2003. Long-term region-wide declines in Caribbean corals. *Science* 301: 958-60

[5] Wilkinson C, ed. 2004. *Status of Coral Reefs of the World: 2004*, Vols. 1. Townsville, Queensland: Australian Institute of Marine Science

bleaching" (described below). Of the remaining reefs, about half are considered critically threatened (24%) to threatened (26%)[6].

How climate change affects coral reefs. Coral reefs are particularly vulnerable to climate change because they already suffer multiple direct impacts from human activities such as overfishing and poor land-use practices. Climate change encompasses an array of changes that can directly or indirectly affect the coral reef environment, e.g., global warming, sea level rise, changes in storm intensity or storm tracks, changes in river runoff from land, etc. The root cause of climate change – increases in atmospheric CO_2 – also causes "ocean acidification," which presents an additional health challenge to coral reef ecosystems. I address below the two main challenges facing coral reefs today: ocean warming and ocean acidification.

Ocean warming

Coral bleaching. Coral bleaching is a phenomenon whereby a coral expels the algal symbionts that live within its tissues. This can occur when a coral becomes stressed by one of more of a number of factors such as sudden changes in salinity, disease, or changes in temperature. Coral bleaching incidents were relatively rare and local until the 1980s, when large-scale "mass bleaching" events were first identified in association with anomalously warm waters during warm-phase years of the El Niño-Southern Oscillation (ENSO). Coral bleaching has become increasingly common and widespread since then, with almost all events linked warmer than normal ocean temperatures, regardless of the ENSO state[7].

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[6] Ibid.

[7] Hoegh-Guldberg O, Mumby PJ, Hooten AJ, Steneck RS, Greenfield P, et al. 2007. Coral reefs under rapid

The tropical oceans have warmed an average of 0.3-0.4°C since the 1950s[8]; in many regions, temperatures have occasionally spiked by 1-2°C or more above the normal maximum temperature in that region. On average, corals will bleach if temperatures exceed the normal maximum by 1-2°C, even if for only a few weeks, but the temperature tolerance varies with region, species, and the baseline health of the corals.

The level of coral mortality following a bleaching event varies greatly with the severity and duration of the warming. In some regions, the corals have recovered completely (e.g., the Great Barrier Reef) while in others the entire coral community has died (e.g., Maldive Islands). Bleaching also increases vulnerability to diseases that contribute to coral mortality[9-10].

In 2005, a large-scale bleaching event in the Caribbean affected many reefs, particularly in the southern half of the basin and including reefs in Puerto Rico and the U.S. Virgin Islands. The same, unusually warm waters that fueled Hurricanes Katrina and Rita caused this mortality.

Coral disease. Coral disease has also increased in the last few decades, and dramatically so in the Caribbean[11]. The two most important Caribbean reef-building species (*Acropora palmata*, Elkhorn coral; and *Acropora cervicornis*, Staghorn coral) have been particularly affected by disease. These two species have declined dramatically, and in 2006 both were listed as "Vulnerable" under the Endangered Species

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climate change and ocean acidification. *Science* 318: 1737-42

[8] Kleypas JA, Danabasoglu G, Lough JM. 2008. Potential role of the ocean thermostat in determining regional differences in coral reef bleaching events. *Geophysical Research Letters* 35: L03613, doi:10.1029/2007GL032257

[9] Harvell CD, Mitchell CE, Ward JR, Altizer S, Dobson AR, et al. 2002. Climate warming and disease risks for terrestrial and marine biota. *Science* 296: 2158-62

[10] Wilkinson C, Souter D. 2008. *Status of Caribbean coral reefs after bleaching and hurricanes in 2005.* Townsville: Global Coral Reef Monitoring Network, and Reef and Rainforest Research Centre

[11] Porter JW, Dustan P, Jaap WC, Patterson KL, Kosmynin V, et al. 2001. Patterns of spread of coral disease in the Florida Keys. *Hydrobiologia* 460: 1-24

Act. Increasing ocean temperatures are hypothesized to increase disease by decreasing host resistance, and/or by increasing pathogen ranges, growth, virulence, or infectivity[12].

Ocean acidification

What causes ocean acidification? A large proportion of the carbon dioxide (CO_2) released to the atmosphere is absorbed by the ocean. A recent inventory of carbon in the oceans estimates that by mid-1990s, the oceans had already taken up nearly half of the total carbon dioxide released by human activities between 1800 and 1994[13]. Without this process, the atmospheric concentration of carbon dioxide would have risen from 280 ppmv (pars per million volume) to about 435 ppmv rather than the current concentration of 380 ppmv. The natural sequestration of carbon dioxide by the oceans thus slows down the build-up of greenhouse gases in the atmosphere.

However, the additional CO_2 in the water column is resulting in "ocean acidification," the progressive shift of ocean pH toward more acidic conditions. This shift is occurring because carbon dioxide combines with seawater to form carbonic acid, which lowers the pH. Once the concentration of carbon dioxide in the atmosphere reaches twice that of preindustrial times (560 ppmv), the pH of the surface ocean will have decreased from a preindustrial average of about 8.16 to about 7.91[14]. Because pH is reported on a logarithmic scale, this small change in pH represents a rather large increase (78%) in hydrogen ion concentration, with clear implications for biological processes. These

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[12] Harvell CD, Mitchell CE, Ward JR, Altizer S, Dobson AR, et al. 2002. Climate warming and disease risks for terrestrial and marine biota. *Science* 296: 2158-62

[13] Sabine CL, Feely RA, Gruber N, Key RM, Lee K, et al. 2004. The oceanic sink for anthropogenic CO_2. Ibid.305: 367-71

[14] Kleypas JA, Feely RA, Fabry VJ, C. Langdon CL, Sabine CL, L.L. Robbins. 2006. *Impacts of Increasing Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research, report of a workshop held 18–20 April 2005. St. Petersburg, FL*: sponsored by NSF, NOAA, and the U.S. Geological Survey. 88 pp. http://www.isse.ucar.edu/florida/

changes will also cause shifts in the relative concentrations of other dissolved carbon species in the ocean. Notably, the concentration of the carbonate ion, which is a major building block for the skeletons and shells of many marine organisms, will decrease by about 34%[15]. Ocean acidification leads to slower and/or weaker coral reef growth. The consequences of this are analogous to severe osteoporosis in humans, and are described in detail below under "*Effects of ocean acidification on marine biota.*"

Even though the process of ocean acidification was predicted since the 1970s, only recently has this process been verified by large-scale measurements of carbon in the ocean through programs such as the World Ocean Circulation Experiment and the Joint Global Ocean Flux Survey. Based on what we know about ocean pH in the past, the seawater chemistry of the surface ocean is already altered to a state that is considerably outside the range of conditions of the past several hundred thousand years and possibly twenty million years. The surface ocean is everywhere experiencing a decline in pH ("acidification"), which is causing changes in associated seawater properties such as the calcium carbonate saturation state. Today, the surface ocean remains saturated with the calcium carbonate minerals aragonite and calcite. The "saturation horizons," below which these minerals will dissolve, are becoming shallower as the oceans take up more CO_2. Within this century, it is predicted that the saturation horizon for aragonite will reach the surface near the poles, particularly in Antarctica and the North Pacific Ocean. Those organisms that secrete aragonite shells will thus be subject to undersaturated waters, which will restrict their ability to maintain shell building. It is unlikely that tropical surface waters will be become undersaturated in the future. However, many corals and coral communities appear to shift from net calcification to net dissolution at

[15] Ibid.

values well above aragonite saturation[16-17]; that is, these systems may experience net decline even in waters that remain saturated.

Effects of ocean acidification on marine biota. The potential effects of ocean acidification on marine biota were not recognized until about a decade ago, when experiments indicated that changes in ocean pH could cause significant responses in major groups of marine organisms. Ocean pH is a fundamental property of seawater that affects almost every aspect of biochemistry. It can affect organisms physiologically; that is, such basic life functions such as photosynthesis, respiration, growth, etc.; but it also affects the ability of "marine calcifiers" to form their calcium carbonate shells or skeletons. The latter is particularly important to coral reef ecosystems, and for this testimony, I will concentrate on the impacts of ocean acidification on corals, coral communities, and coral reef structures. Most of the information I present here draws from a U.S. report jointly funded by the National Science Foundation, the National Oceanic and Atmospheric Administration, and U.S. Geological Survey[18].

Effects on reef calcifiers. So far, experiments have been conducted on at least six major groups of calcifying organisms: coccolithophores (microscopic algae); foraminifera (microscopic protozoans); coralline algae (benthic algae); echinoderms (sea urchins and starfish); mollusks (snails, clams, and squid); and corals. While the responses vary both between and within these groups, nearly all experiments on corals

[16] Yates KK, Halley RB. 2006. CO_3^{2-} concentration and pCO_2 thresholds for calcification and dissolution on the Molokai reef flat, Hawaii. *Biogeosciences* 3: 357-69

[17] Langdon C, Takahashi T, Sweeney C, Chipman D, Goddard J, et al. 2000. Effect of calcium carbonate saturation state on the calcification rate of an experimental coral reef. *Global Biogeochemical Cycles* 14: 639-54

[18] Kleypas JA, Feely RA, Fabry VJ, C. Langdon CL, Sabine CL, L.L. Robbins. 2006. *Impacts of Increasing Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research, report of a workshop held 18–20 April 2005, St. Petersburg, FL*: sponsored by NSF, NOAA, and the U.S. Geological Survey. 88 pp. http://www.isse.ucar.edu/florida/

show a decrease in calcification rate under lower pH conditions, indicating that calcification rates will decline by 10–50% if atmospheric CO_2 concentrations reach double the preindustrial concentrations[19-20]. Calcification rates in multiple massive coral colonies of the Great Barrier Reef show that calcification rates declined 21% between 1988–2003[21]; this decrease exceeds that expected from lowered saturation state alone, and probably reflects the composite effects of a suite of changing environmental conditions (e.g., saturation state, temperature, water quality).

At some point growth is slowed to the point where a marine animal may no longer be able to maintain its skeleton, and the skeletal material will dissolve. This has been demonstrated in both mollusks and corals. A dramatic example of this is the work by Fine and Tchernov[22] in which two species of corals that were cultured in highly acidified water (equivalent to atmospheric CO_2 levels around 1200 ppmv) completely lost their skeletons; then re-grew them after being returned to seawater of normal pH. These species may not be typical of most reef-building corals, and indeed appear to be closely related to those few species that survived the Cretaceous-Tertiary extinction (65 million years ago) and later gave rise to modern-day corals (over time spans of millions of years). Nonetheless, the experiment highlighted three important points: (1) coral calcification rates can essentially stop or reverse in lowered ocean pH conditions; (2) the naked, anemone-like coral polyps remained healthy, but the fitness of the organisms overall

[19] Langdon C. 2002. Review of experimental evidence for effects of CO_2 on calcification of reef builders. *Proceedings of the 9th International Coral Reef Symposium* 2: 1091-8

[20] Langdon C, Atkinson MJ. 2005. Effect of elevated pCO_2 on photosynthesis and calcification of corals and interactions with seasonal change in temperature/irradiance and nutrient enrichment. *Journal Of Geophysical Research-Oceans* 110: art. no. C09S7

[21] Cooper TF, De 'Ath G, Fabricius KE, Lough JM. 2008. Declining coral calcification in massive *Porites* in two nearshore regions of the northern Great Barrier Reef. *Global Change Biology* 14: 529-38

[22] Fine M, Tchernov D. 2007. Scleractinian coral species survive and recover from decalcification. *Science* 315: 1811

would change because of the loss of the protective skeleton; and (3) reversing the acidification process results in a reversal of the skeletal loss.

Fewer studies have been conducted on coralline algae, another major reef-builder. Certain species of coralline algae are able to calcify under extreme conditions, such as in the polar regions. However, recent studies conducted with Hawaiian crustose coralline algae showed that under acidified conditions they calcify more slowly and their larvae have lower settlement rates on reef surfaces[23]. The latter is important because coralline algae are an important colonizer of damaged reef surfaces and prepare the surface for later colonization by corals. Indeed, the effects of ocean acidification on other life stages of reef organisms are still minimally researched and poorly known.

Ocean acidification will not likely affect all species equally – indeed, as with most environmental changes, there will be winners and losers. For example, a recent study on microscopic plankton suggests that some species may have the capacity to adapt to ocean acidification. Studies on corals have not illustrated this capacity; corals and coralline algae that have been grown under decreased pH conditions for a year or more do not show signs of adapting[24].

Effects on organism survival and ecosystem functioning. There is essentially no information regarding how changes in calcification rate will affect the ability of organisms to survive in nature, and most of what we know is based on assumptions that organisms grow shells and skeletons for a variety of reasons, such as: protection, gathering light for photosynthesis, competing for space, anchoring to the substrate, and

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[23] Kuffner IB, Andersson AJ, Jokiel PL, Rodgers KS, Mackenzie FT. 2008. Decreased abundance of crustose coralline algae due to ocean acidification. *Nature Geoscience* 1: 77-140

[24] Langdon C, Broecker WS, Hammond DE, Glenn E, Fitzsimmons K, et al. 2003. Effect of elevated CO_2 on the community metabolism of an experimental coral reef. *Global Biogeochemical Cycles* 17: art. no. 1011

reproduction. Just as bone loss affects human fitness, it is likely that suppressing skeletal growth in a marine organism will affect its fitness and ability to function within its ecological community. Also, the function of the calcium carbonate may change over the lifetime of an organism. For example, calcium carbonate in a larval echinoderm provides the ballast that allows the larvae to settle onto suitable substrate, but later provides its protective exoskeleton.

Changes in the physiology and calcification rates of reef organisms will undoubtedly affect reef ecosystems and food chains. Non-calcifying species, such as fleshy macroalgae, may become more competitive for space if corals can no longer 'hold their ground' through calcification. Many species live directly within coral skeletons, and some of these in turn protect the corals from predators (e.g., feather duster worms that live in massive corals have been known to dissuade predation on their host by crown-of-thorns starfish). There have been several recent calls to reef researchers to take up the task to understand how reduced calcification on coral reefs will affect reef ecosystem functioning and reef ecosystem services, because there has yet been little research on this.

Effects on coral reef structures. Coral reef ecosystems are defined by their ability to produce a net surplus of $CaCO_3$ that produces the reef structure. Under increasing ocean acidification not only will coral community calcification decrease, but dissolution rates will increase [25-26], with a net decrease in reef building and a probable shift toward net dissolution in those reefs that are already near the limit for reef growth (e.g. higher latitude reefs). Interestingly, even though global warming will probably allow corals to

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[25] Langdon C, Takahashi T, Sweeney C, Chipman D, Goddard J, et al. 2000. Effect of calcium carbonate saturation state on the calcification rate of an experimental coral reef. Ibid.14: 639-54
[26] Yates KK, Halley RB. 2006. CO_3^{2-} concentration and pCO_2 thresholds for calcification and dissolution on the Molokai reef flat, Hawaii. *Biogeosciences* 3: 357-69

inhabit higher latitudes[27], the decrease in reef $CaCO_3$ production is likely to shift the limit of reef development to lower latitudes[28-29].

Coral reefs exist simply because corals and other organisms secrete calcium carbonate faster than it is removed. During the repeated glacial to interglacial sea level transgressions of the past 3 my (million years), reef ecosystems thrived because their rapid accretion rates migrated the coral community upward and maintained them within the minimum light levels for continued growth. The structural complexity of coral reefs allows them to support high marine biodiversity. The structure also shapes and protects shorelines because it acts as a natural barrier to waves and currents. It is also the foundation for atoll and cay development. If calcium carbonate production decreases, then reef building and the constant supply of coral sediment will also decrease. Mass coral die offs in recent years has led to considerable erosion on some reefs; the Galápagos reefs, for example, were formed over several thousand years, but were eroded away within a decade following the 1982-1983 coral bleaching event that killed off 95% of the corals. Ocean acidification not only decreases calcification rates on reefs, it also increases dissolution rates, so that net reef building declines. Any reduction in calcium carbonate increases the potential for reef erosion, particularly in the face of rising sea level.

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[27] Precht WF, Aronson RB. 2004. Climate flickers and range shifts of reef corals. *Frontiers in Ecology and the Environment* 2: 307-14
[28] Kleypas JA, Buddemeier RW, Gattuso JP. 2001. The future of coral reefs in an age of global change. *International Journal of Earth Sciences* 90: 426-37
[29] Guinotte JM, Buddemeier RW, Kleypas JA. 2003. Future coral reef habitat marginality: temporal and spatial effects of climate change in the Pacific basin. *Coral Reefs* 22: 551-8
[30] Kleypas JA, Buddemeier RW, Gattuso JP. 2001. The future of coral reefs in an age of global change. *International Journal of Earth Sciences* 90: 426-37

Paleontological Perspective.

Periods of high atmospheric CO_2 concentrations are common throughout the geologic record. Some of these high-CO_2 periods, e.g. Cretaceous Period 65 million years ago, include massive shallow-water $CaCO_3$ deposits, including reef structures. Initially this appears to be a conundrum: if high atmospheric CO_2 concentration produces acidic seas, why was $CaCO_3$ production and preservation so prevalent in these earlier high-CO_2 periods? The short answer to this question is that the carbonate saturation states were almost certainly maintained during those periods despite the high pCO_2 levels. This is possible because, with increases in atmospheric CO_2 and decreases in ocean pH, another part of ocean chemistry, total alkalinity, will increase. This increase occurs because increased atmospheric CO_2 causes rainfall to be more acidic, and increases weathering rates on land; this increases the alkalinity of river runoff. Also, as ocean pH decreases, more deep-sea carbonate dissolves and adds alkalinity to the ocean. Both of these processes take thousands of years to bring the carbonate system back to equilibrium. Ocean acidification today is occurring because the rate of CO_2 increase in the atmosphere is much faster than the rates at which the negative feedbacks of weathering and carbonate dissolution act to restore ocean pH. Indeed, there is evidence of a sudden input of carbon into the atmosphere or ocean some 55 million years ago; concurrent with that is evidence that of a major marine carbonate dissolution event[31].

[31] Zachos JC, Rohl U, Schellenberg SA, Sluijs A, Hodell DA, et al. 2005. Rapid acidification of the ocean during the Paleocene-Eocene thermal maximum. *Science* 308: 1611-5

Deep-water corals and carbonate mounds

Shallow-water tropical ecosystems are not the only coral community threatened by ocean acidification. Deep-water scleractinian corals lack the algal symbionts of their tropical counterparts, and thrive in the subphotic zone waters of continental slopes, usually in depths of 200–1000 m. They grow slowly and can live a long time, up to 1500 years old. The distribution and environmental needs of deep-water corals are quite poorly known, but they are of particular interest because of they support high biodiversity and fisheries. The maximum depth of these communities, particularly of the aragonitic scleractinians corals, appears to be limited to the depth of the aragonite saturation horizon[32], which reaches an average depth of > 2000 m in the North Atlantic, but can be as shallow as 200 m in the North Pacific ocean. Like their tropical counterparts, deep-water corals can produce large mounds of calcium carbonate, albeit much more slowly[33]. Nonetheless, these deep-water structures also support high biodiversity, and elevate the associated communities above the substrate. Similar to tropical coral reefs, ocean acidification is expected to contract the geographic range of deep-water coral communities, but in contrast to the equatorward contraction of tropical coral reefs, it is the depth distribution of deep water coral communities that will contract, with the deepest communities being the first to experience a shift from saturated to undersaturated conditions.

Both coral reefs and deep-water corals are the foundation of the productive coral communities they build. Just as a forest does not exist without trees, a coral reef cannot exist without corals. Tropical coral reefs are well known for the many symbiotic

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

[33] Roberts JM, Wheeler AJ, Freiwald A. 2006. Reefs of the deep: The biology and geology of cold-water coral ecosystems. *Science* 312: 543-7

relationships that have developed between species, and given the relatively few years we have observed these underwater wonders (essentially since SCUBA was invented in the 1950s), there are many more such relationships are yet to be observed. The impacts of ocean acidification on coral reef food chains, biological and chemical cycles, and ultimately our fisheries are certain. The loss of the reef structure alone will have tremendous impacts on local shorelines, infrastructure and adjacent ecosystems, as well as on the economies and livelihoods of millions of people that are served both directly and indirectly by the reef.

Solutions and Future Research

Ocean acidification will be one of the greatest environmental risks we face if we continue to allow CO_2 to build up in the atmosphere. The obvious solution is to reduce CO_2 emissions; this will not only decrease ocean acidification, it will decrease many of the other problems associated with climate change. The positive news is that stabilizing atmospheric concentrations of carbon dioxide would halt further acidification almost immediately (compared to the considerable momentum in ocean warming). Furthermore, with new technologies to not only slow atmospheric CO_2 increases, but to actually remove CO_2 from the atmosphere, the current acidification of the upper ocean would be reversed. It is true that much of the carbon absorbed by the oceans will eventually be transported by ocean circulation to deeper depths, and will remain in the ocean for hundreds of years. The upper ocean, however, is in near equilibrium with the atmosphere, and removing CO_2 from either the ocean or the atmosphere causes CO_2 to diffuse across the air-sea interface (gas diffuses from the region of high concentration to low concentration). Thus, restoring the atmosphere to its preindustrial state would restore the surface ocean to its preindustrial pH.

It is tempting to recommend some limit to how warm and/or acidic the ocean can get before irreparable damage will occur. The "safest" value would be the maximum values experienced during the glacial interglacial cycles (essentially the preindustrial levels). At the current atmospheric CO_2 concentration of 382 ppmv, coral reefs are already considered near their threshold for survival[34]. At CO_2 levels between 450 to 500 ppmv, coral reefs would experience significantly more bleaching events[35], and some reefs will begin to experience net dissolution[36]. At CO_2 levels above 500 ppmv, analyses indicate that coral bleaching and ocean acidification to be prohibitive to normal reef functioning[37]. However, for many other ocean ecosystems, the CO_2 threshold may be much lower. We do not have a good understanding of the CO_2 concentrations that will: 1) impact fish species or their food resources, 2) impact larval survival and recruitment of important species of fish and shellfish, and 3) cause changes in community composition in ways that affect the ability of the oceans to recycle important nutrients such as carbon, nitrogen, and phosphorus. In reality, there are likely to be a continuum of thresholds, and predicting these is complicated by the problem of "multiple stressors" on marine ecosystems, such as pollution, poor land-use practices, and overfishing.

In my opinion we know enough about the effects of ocean warming and ocean acidification to be extremely concerned about not only coral reef ecosystems, but all

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[34] Hoegh-Guldberg O, Mumby PJ, Hooten AJ, Steneck RS, Greenfield P, et al. 2007. Coral reefs under rapid climate change and ocean acidification. Ibid.318: 1737-42

[35] Hoegh-Guldberg O. 2005. Low coral cover in a high-CO_2 world. *Journal of Geophysical Research-Oceans* 110: C09S6

[36] Yates KK, Halley RB. 2006. CO_3^{2-} concentration and pCO_2 thresholds for calcification and dissolution on the Molokai reef flat, Hawaii. *Biogeosciences* 3: 357-69

[37] Hoegh-Guldberg O, Mumby PJ, Hooten AJ, Steneck RS, Greenfield P, et al. 2007. Coral reefs under rapid climate change and ocean acidification. *Science* 318: 1737-42

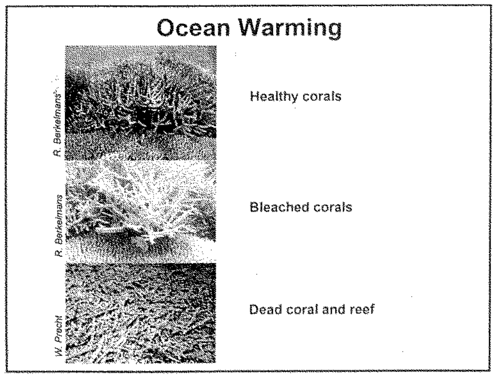
ocean ecosystems. Even at today's CO_2 concentrations, coral reefs will continue to experience bleaching for years to come. Corals and other reef organisms will almost certainly face the additional problems that ocean acidification poses for their ability to survive. And finally, coral reef structures themselves, which not only support coral reef biodiversity, but also protect shorelines and support valuable fisheries, are themselves threatened by ocean acidification.

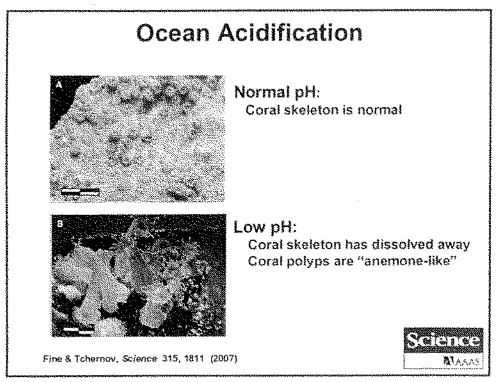
It is urgent that we improve our understanding of how ocean acidification will affect all marine life across molecular to ecosystem scales. Given the multiple stressors in our environment, actions should be taken to minimize additional stresses to organisms or ecosystems that are particularly vulnerable to ocean acidification. Acquiring the information needed to advise policy makers on these issues will require coordinated research across multiple institutes and government agencies. In some cases, even basic information on the distribution patterns of major groups of marine organisms is lacking and such information would greatly inform our ability to predict future biological responses. Existing efforts by NOAA and NASA should be expanded to improve monitoring and observations; but much of the key needed research is at the cellular to ecosystem levels and requires basic academic research through both NSF and EPA. To support ocean acidification research, the U.S. Senate passed the *Federal Ocean Acidification Research and Monitoring Act of 2007 (FOARAM)* in December 2007. I urge the House of Representatives to pass the companion legislation that has been introduced by Representatives Tom Allen (D-ME), Jay Inslee (D-WA), Wayne Gilchrest (R-MD) and nine other co-sponsors.

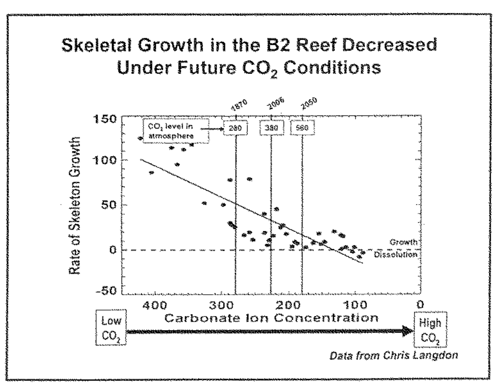
Conclusions

Ocean warming and ocean acidification is affecting all oceans and the organisms that live in them. The pH of the surface ocean, where the bulk of ocean production and biodiversity exist, is changing in lock step with changes in atmospheric CO_2 concentration. Evidence from multiple scientific disciplines points to the same conclusion: ocean life is sensitive to changes in ocean pH, and will be increasingly affected by ocean acidification. This is particularly true of coral reefs, an ecosystem that is defined by the large calcium carbonate structures that they produce. Corals and many coral reef organisms will be affected by a decreased capacity to grow and maintain their shells and skeletons. This will affect their ability to survive, but it will also affect reef structures that offer many valuable ecosystems services to man. Because ocean acidification is likely to affect such a broad array of marine organisms, we can expect to see significant changes in marine ecosystems, including those that support commercial fishing.

Ocean acidification is an emerging scientific issue, but it is also one of high environmental risk. Because of this, I am deeply grateful for this opportunity to address the Select Committee, and I look forward to answering your questions.


Ocean Warming
R. Berkelmans
Healthy corals
R. Berkelmans
Bleached corals
W. Precht
Dead coral and reef


Ocean Acidification
A
Normal pH:
Coral skeleton is normal
B
Low pH:
Coral skeleton has dissolved away
Coral polyps are "anemone-like"
Fine & Tchernov, Science 315, 1811 (2007)
Science
AAAS


Skeletal Growth in the B2 Reef Decreased Under Future CO_2 Conditions
1870
2006
2050
CO_2 level in atmosphere
280
380
560
Rate of Skeleton Growth
150
100
50
0
-50
Growth
Dissolution
400
300
200
100
0
Carbonate Ion Concentration
Low CO_2
High CO_2
Data from Chris Langdon

The CHAIRMAN. Thank you, Doctor, very much.

And our final witness is Ms. Vikki Spruill, who is the president and CEO of The Ocean Conservancy, where she leads the organization's efforts to promote healthy and diverse ocean ecosystems. She was also recently appointed to the Pew Fellows Advisory Committee. We welcome you.

Whenever you feel ready, please begin.

STATEMENT OF VIKKI SPRUILL

Ms. SPRUILL. Thank you, Chairman Markey, Ranking Member Sensenbrenner, and the committee, for your leadership in having this hearing. The committee has already done such a service to the country by moving us forward on the urgent issues of energy independence and climate change. Your effort today to focus on the ocean, the place where it all starts, and yet is often overlooked, is of enormous importance. It is a real honor to be on such a distinguished panel of women. I had to say it.

The ocean is essential to the health of everything on the planet, including our own. It covers over two-thirds of the Earth. It drives our climate. It provides much of the food we eat and the oxygen that is essential for our very survival. It is a source of renewal for the human spirit.

Fundamentally, as Sylvia says, the ocean is the life support system for our planet. Seafood is a major staple, in some cases the staple in this country and elsewhere. In the U.S., the contribution of the seafood industry exceeds $50 billion per year. A healthy ocean contributes to a healthy economy. The President's Commission on Ocean Policy reported that coastal communities generated over 10 percent of GDP. Three-quarters of those associated jobs are in ocean tourism and the recreation sectors alone.

The ocean, of course, also moderates our climate, absorbing over a third of the greenhouse gases that we produce. The dynamics of the ocean and the atmosphere are so tightly linked and so easily overlooked that we ignore the ocean's role in climate at our own peril. In 2005, millions in the U.S. and in the Caribbean experienced firsthand and quite tragically how the ocean's heat engine can drive violent storms, most dramatically, of course, Hurricane Katrina. Over 2,000 lives were lost and over $100 billion in damage occurred during that devastating season.

Fundamentally, the ocean is the basis of our ecosystem, with an incredibly diverse web of life that supports the planet. Of course, we are most familiar with the grand diversity of life at the margins, on coral reefs and in tide pools, where many of us saw our first mussels and sea stars, and maybe even a hermit crab looking back at us. The truth is that our essential and diverse ocean ecosystems cannot protect us unless they are healthy and resilient. Harmful impacts are exacting a toll on this web of life that frankly we can no longer afford to pay. Ocean Conservancy is working to make the ocean healthy by fostering sustainable fisheries, by protecting marine wildlife, and putting in place management plans for State and Federal waters, and preserving magnificent ocean places that we like to call "Yosemites undersea."

All of this work is vitally important, but the most sweeping and devastating threat to the ocean is global climate change. The planet has warmed in the last 100 years by nearly a degree. And over 80 percent of the excess heat produced by the greenhouse effect has already been absorbed by the ocean. Even if carbon emissions are substantially reduced, ocean warming will continue to increase for decades. Two or more degrees of warming, which is quite possible, will devastate many coastal communities, kill the world's coral reefs, and result in mass extinctions of marine life. Think about it, when our own temperatures rise 2 degrees, we have a fever.

So our ocean is sick. And if you are an Alaskan native whose people have lived in harmony with the Arctic Ocean for over 10,000 years and your village is falling into the sea, you know that climate change is happening and that our ocean is sick. If you are a fisherman in the Caribbean, where up to 90 percent of corals bleached and died in 2005, then you don't doubt that climate change is actually happening now.

The ocean is really where the rubber meets the road with climate change. It isn't decades of projections we are dealing with or ominous warnings about the future of the ocean. It is now. This is happening now. And if you detect a sense of urgency in my voice, it is because I believe that protecting our ocean from the onslaught of climate change is one of the greatest challenges of our lifetimes; 2008 is the "year of the reef," and I commend the committee for drawing attention to this fragile, yet critical ecosystem.

Coral reefs have long been threatened by over-exploitation and pollution, and now climate change adds another one-two punch, maybe the knockout punch for an already damaged system. Ocean warming has already increased coral bleaching and is a major threat to reefs worldwide. Let me put it this way, in 1998, we lost 16 percent of the world's coral reefs in a single year. If we lost 16 percent of the forests in the world, that would be the equivalent to losing all of the forests in North America in a single year.

Unless we change course, coral reefs, the entire ocean, and all of mankind are at the mercy of climate change. There are two essential ways we must address climate change. First, of course, is mitigation. We must substantially reduce greenhouse gas emissions, and we must do that now. And the second is adaptation. Simply meaning we have to strengthen the health and resiliency of our ocean ecosystems so they can better anticipate and adapt to the increased stresses of climate change while we work to reduce emissions. It is as if we have a patient who has already been suffering from the flu and high blood pressure and now has been given a diagnosis of serious but treatable cancer. The plan for recovery involves curing the patient of the flu and then taking some medication and adapting your lifestyle to lower the blood pressure. But of course fighting the cancer, in our case global climate change, is the goal. But the way to do that is to first make the patient healthy and strong to take on the much bigger challenges ahead.

To save our coral reefs, we must adopt adaptation strategies that build resilience and restore ecosystem function. We need to be protecting reefs from unsustainable fishing practices. We need to be reducing the inputs of pollution, such as fertilizers and sewage and sediments, and we need to be implementing a more comprehensive and stronger system of coral reef protected areas.

I know this committee and this Congress is working hard on mitigation solutions trying to cure the disease. I would respectfully urge you to follow your principles that you set forth last week on Earth Day and put as much effort into adaptation strategies to lessen the damage and pain as we seek to cure the patient. We simply have to do a better job of sustaining the life support system that sustains us. Our oceans are in trouble. And that means so are we. That is the sea change we are starting at Ocean Conservancy. And thank you for propelling that change forward with your leadership.

[The statement of Ms. Spruill follows:]

Testimony of Vikki Spruill
President and CEO of Ocean Conservancy

Before the

Select Committee on Energy Independence and Global Warming
U.S. House of Representatives

Hearing on

"Global Warming's Impact on the Oceans"

29 April 2008

INTRODUCTION

I thank Chairman Markey, Ranking Member Sensenbrenner, and other members of the Select Committee for the opportunity to talk with you today about global climate change and its impact on the ocean. My name is Vikki Spruill and I am the president and CEO of Ocean Conservancy, becoming just the fifth person, and the only woman, ever to hold that title. Prior to my appointment at Ocean Conservancy, I was president and founder of SeaWeb, a non-profit organization that uses strategic communications techniques to advance ocean conservation. I also led a team there that in eleven years designed and executed countless important and innovative programs to promote ocean conservation and improve ocean governance. You have asked me to provide testimony on the effects that climate change is already having on our oceans, their impacts on marine ecosystems and the people dependent upon them, as well as highlighting the policies necessary to stop the decline of our oceans and what some solutions might be to enhance resilience to climate change. My testimony will focus on the impacts of global climate change on the ocean, emphasizing coral reefs and arctic ecosystems

THE VALUE OF OCEAN

We have named our planet Earth, and we call the soil beneath our feet earth. We live on earth, we grow most of our food in earth, and our homes come from great forests anchored in earth. Yet 71 percent of Earth's surface is not earth, but water – the ocean. Of the planet's living space, 99 percent is ocean. Life evolved for most of its history in water. The greatest diversity and quantity of life is found in the ocean. We came from water and we are made mostly of water. We are ocean.

Our bodies are an ocean environment. Taste your tears – they are salty like the ocean. Measure the pH of your blood – it is similar to that of ocean. Take a breath – of the uncountable oxygen molecules in your lungs nearly half were produced by microscopic plants living in the ocean. Take a drink of fresh water – roughly 90 percent of the precipitation falling on land is water evaporated from the ocean, each molecule having cycled through the ocean numerous times over the millennia.

We cannot live without ocean. With each breath we release carbon dioxide (CO_2). One day, all the carbon in your body will return to the atmosphere as CO_2 and then be absorbed, once again, by the ocean where it will be taken up by phytoplankton, and then drift to the bottom of the sea, to join 99.9 percent of all the CO_2 ever assimilated by life. While we are fond of summarizing our brief stay on Earth with the phrase "dust to dust", "ocean to ocean" is more apt.

Most of us relate to the ocean through the brief encounters we've had during our lives – a day at the beach, a fishing trip, watching whales, a cruise to distant ports. But, what most of us have encountered are merely the edge and the surface of the ocean. We understand the life that lives beneath its shiny, opaque surface only from brief glimpses—a whale surfacing, a flying fish escaping its watery bonds for a few seconds, or a fillet on a plate. Many have been enthralled by the beauty of tropical fish in an aquarium or the unbelievably diverse and dynamic seascape of a coral reef, but few know those wonders first-hand. If you have been lucky enough to snorkel over a vibrant coral reef or dive through a swaying kelp forest, then you have surely been enraptured by the thrill, the beauty, and the other-worldliness of life *in* the ocean.

That the ocean is finite—that its influence ends where it ends, at the edge and the surface—are but illusions. Our lives are intertwined with ocean. We are dependent on the ocean, though most of us are oblivious to the fact. Whether we live in Massachusetts, California, or Wisconsin, we are all linked to the ocean through vast physical cycles, the biosphere, and economics. We are all affected by the rhythms of the ocean, and the lives of millions are inexorably tied to those rhythms.

We think of climate as atmospheric – as the extremes of weather we experience from day to day – wind and storm, rain and snow, heat and cold, blue sky and clouds. Without the ocean, however, our weather would be far harsher and much less stable. The ocean is a great buffer, protecting us from extremes of heat and drought, as coastal dwellers are well aware. Seattle, Washington and Bismarck, North Dakota are at nearly the same latitude. The temperature extremes in landlocked Bismarck, however, span 159 degrees (-45 to 114^{o}F), but in Seattle just 100 degrees (0 – 100^{o}F).

The ocean stores vast amounts of heat and distributes it across the globe; far more than does the atmosphere. There is more heat in the first ten feet of ocean than in the entire atmosphere. In the Northern Hemisphere, the Gulf Stream and Kurshio Current – the Western Boundary Currents – distribute heat from the tropics northward affecting not only the ocean climate, but also our climate on land. Without the Gulf Stream, Europe would be a much colder and less productive place. The ocean absorbs so much energy from the Sun that it is largely responsible for the circulation of air and water within the atmosphere—heating the air here, cooling it there, and causing it to move by variation in pressure.

In 2005, millions in the US and Caribbean experienced first-hand, and tragically, how the ocean's heat engine can drive violent storms ashore – Katrina, Rita, Dennis, Emily and Wilma. Over 2000 lives were lost and $128 billion in damage occurred in that devastating 2005 hurricane season. The dynamics of the ocean and atmosphere are so tightly linked, and so easily overlooked, we must remind ourselves that we ignore the ocean's role in climate at our own peril.

The ocean is vast, but it is difficult to grasp such vastness. We measure the size of the ocean in terms of the area of its surface, but that is the equivalent of measuring the capacity of the Astrodome by the area of its roof. Though the surface of the ocean is certainly impressive, it is the ocean's *volume* that truly taxes the imagination — making up 99 percent of all living space on the planet. The abyss *averages* some 13,000 feet deep and the deepest point is over a full mile deeper than Everest is tall.

The ocean was, for most of human history, considered mostly barren – like Australia, an expansive desert surrounded by a thin green ribbon of life. Now we know that life teems around thermal vents in the abyss, over deep seamounts, and even in that watery 'void' between bottom and surface. Of course, we are most familiar with the grand diversity of life at the margins – on coral reefs, among mangroves, in the channels of salt marshes, within kelp forests, and in the tide pools where many of us first witnessed the likes of hermit and shore crabs, mussels and oysters, sea stars, cucumbers, anemones and urchins, and maybe an octopus staring back at us.

The ocean is home to an unbelievable diversity of life. What we do not know about ocean life far outstrips that which we do know. Humans have described perhaps 2 million species on the planet of an estimated 5-100 million (species!) thought to exist. Although, only one in ten of the described species are marine, one estimate suggests that there are 10 million undescribed species in the deep ocean alone yet to be discovered.

Coral reefs are nicknamed the "rain forests of the sea" for their amazing biodiversity, productivity, and structural and functional complexity. Coral reefs occupy just 0.2 percent of the area of the ocean, yet roughly 25 percent of all known marine fish species inhabit coral reefs. Something like ten thousand coral reef species have been described and estimates say three million may remain.

We rely on these millions of marine species, even the ones we have yet to discover, for important ecological services. The vast quantities of phytoplankton assimilate as much CO_2 as all plant life on land. Converting that CO_2 to carbon compounds fuels our ocean food webs, which in turn feed millions of humans. All of the carbon that ends up at the bottom of the ocean would, without phytoplankton, remain in the atmosphere to accentuate the global warming that we are now experiencing. Without phytoplankton we would have to rely on a diminishing quantity of terrestrial plant life to produce all the oxygen we need. Lastly, phytoplankton are the food of zooplankton that are the food of larger species, ranging in size from anchovies to the largest creature on the planet, the blue whale.

In the United States, the contribution of the commercial and recreational seafood industries exceeds $50 billion per year. Around the world, in 2005, over 85 million tons of seafood was taken from the seas, and another 19 million tons was produced by aquaculture. For many peoples, in this country and elsewhere, seafood is a staple; in some cases, *the* staple source of protein. Fish supply 16 percent of the world's protein, and 40 percent of the world's population (more than 2.5 billion people) gets at least 20 percent of its protein from fish. Worldwide, over 40 million people catch or raise fish for a living. In the tropics, there are an estimated 30 million small-scale fishers who depend almost exclusively upon the productivity and biodiversity of coral reefs.

We are coastal people. Over half of the U.S. population now lives in coastal counties. Florida has seen a 1000 percent increase in population since 1940, and a large percentage of those new residents use and rely on the ocean for recreation. The President's Commission on Ocean Policy reported that coastal communities generated over 10 percent of GDP; three quarters of those jobs are in the ocean tourism and recreation sectors alone. By comparison, agriculture employs two-thirds as many people and contributes just 40 percent as much value to the economy. A 1999 ecological valuation study[1] put the contribution of the ocean to the world welfare at a striking $21 trillion per year, 60 percent of which comes from coastal and shelf areas.

Often we emphasize industries, like energy, that exploit the resources we require for life, as those most important to the economy. It is the recreation industry, however, that contributes more to our economy that any other ocean industry. Coastal tourism creates over $160 billion in revenue annually worldwide.[2] Cruise passenger embarkations totaled 9 million in 2006 at U.S. ports alone; with $18 billion spent on goods and services by cruise lines, their passengers, and crews.[3] The direct and indirect economic impact of the cruise industry generated $36 billion in the U.S., creating just under 350,000 jobs nationwide while doling out $15 billion in wages and salaries.

Our way of life is dependent on the burning of fossil fuels. Like the metabolism of carbon compounds in our bodies, the burning of ancient carbon compounds – fossil fuels – releases large quantities of CO_2 into the atmosphere. As we are all well aware, it has been the massive release of CO_2, sequestered in the skies over the last 150 years, that has upset the balance of CO_2 in our atmosphere and led to the global warming, which brings us together today.

Often the exponential growth of the world's population is tagged as the driver of global warming, but the increase in energy consumption has been driven more by a rise in our consumption than by population growth. Consumerism, and its creep around the world, is at the heart of our problem. It is an irony, perhaps, that the extraction of oil and gas from our continental shelves

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[1] Costanza, R. 1999. The ecological, economic, and social importance of the oceans. *Ecological Economics* 31: 199-213.

[2] Nellemann, C et al. (eds). 2008. In Dead Water – Merging of climate change with pollution, over-harvest, and infestations in the world's fishing grounds, United Nations Environment Programme, GRID-Arendal, Norway

[3] http://www.cruising.org/press/research/U.S.CLIA.Economic.Study.2006.pdf

that boosts our economy today, contributes to global climate change that threatens our way of life tomorrow. There are nearly four thousand oil and gas platforms offshore around the United States, mostly in the Gulf of Mexico. Those platforms provide roughly 30 percent of the oil and 25 percent of the natural gas that we use. In an ironic counterbalance to the extraction of oil and gas, the ocean holds the promise of relatively clean, sustainable, and efficient energy production from wind, wave, tidal, and current generators.

We harvest kelp for animal feed, fertilizer, and use in beauty products. We mine the ocean for sand, gravel, dead coral, and certain metals. For millennia we have dried seawater to produce the dietary staple, salt. Biochemicals from living marine organisms have become a big business, finding use in pharmaceuticals, foods, and beauty products.

Ocean vistas, roaring surf, and kaleidoscopic coral reefs bring us peace and offer a chance to reflect on the value of wildness and nature to our health, and to our spirit. We cherish the beauty and mystery of ocean, without necessarily knowing why. Millions pay dearly and risk everything to live at its mercurial edge. Our lives are enriched by the opportunity to visit the ocean, play on its shores, or dip below its surface. The ocean provides food, materials and energy, and is an integral part of our economy. Life on this planet cannot exist without the ecological services it provides. And, yet we have failed to protect this vital resource, whether by ignorance or indifference. In doing so we have jeopardized our future. For much too long, we have treated the ocean as a dumping ground for our waste, and acted as if its bounty were limitless. We have learned painful lessons about the true costs of collapsed fisheries, dead zones, red tides, destroyed habitats, and endangered wildlife. The ocean is not limitless and it cannot absorb all that we throw its way. We have compromised its ability to resist stress and to recover from injury. We have done what many once thought impossible; we have diminished the health of our vast and generous ocean. Today, with the potentially devastating impacts of climate change just emerging and predicted to get vastly worse, our weakened ocean is in peril. To save it, we must act with conviction now.

THREATS TO THE OCEAN

For most, the standard of ocean health is the best that they can recall from their own lifetimes—regardless of how short of historical standards their personal standards fall. This concept is what scientists call "shifting baseline syndrome." In reality, 'shifting baselines' is shorthand for how, over time, successive generations narrow their perspectives from the last, gradually lowering their standards of what a healthy ocean looks like.

Our shifting baselines have contributed significantly to declining ocean health. Lack of historical perspective leads us to misdiagnose or miscalculate ocean health, and seduces us into further excess exploitation of already depleted resources. So longstanding and so profound is human exploitation of the oceans that scientists agree that there is no clear historical baseline by which to measure healthy ecosystems.

Today, many marine ecosystems have changed so dramatically that they would be unrecognizable to our grandparents. The world's ocean continues to face an onslaught of stresses, many caused by people: overfishing, pollution, marine debris, poor water quality, and coastal development. Non-climate stresses increase vulnerability of ocean ecosystems to climate change by reducing resilience and adaptive capacity to react to the physical effects of climate change. The threats to the ocean are considerable – overfishing, pollution, poor water quality, marine debris, and coastal development all have huge impacts on marine communities and ecosystems and their effects have been well documented. Climate change will exacerbate the effect of current stresses on the ocean, and the scientific community at-large is concerned that the effects of climate change, acting together with existing threats, will accelerate the rate at which we lose biodiversity.[4] We cannot fully understand or predict the impact that climate change will have on the ocean without first understanding the context – the ocean has long been assaulted by multiple, cumulative human impacts that make its ecosystems and human society more vulnerable to climate change.

The ocean drives earth's climate and is one of the first, and often unnoticed, casualties of increased emissions of greenhouse gases. The major threats facing the ocean from climate change include increased temperature, sea level rise, decreased ocean salinity, acidification, shifting ocean currents and wind patterns, and amplified extreme events such as droughts, floods, heat waves, and the intensity of hurricanes.

Ocean Warming

Carbon dioxide and other greenhouse gases have markedly increased since 1850 as a result of human activity.[5] The 35 percent increase in CO_2 over this period is primarily due to fossil fuel use and changes in land-use patterns. Human-driven increases in greenhouse gases have resulted in significant increases in atmospheric and oceanic temperatures and a significant warming trend over the past 30 years. Even if carbon emissions are substantially reduced, CO_2 levels in the oceans will continue to increase for decades. Atmospheric CO_2 levels are accelerating at rates greater than predicted because of increased carbon dioxide emissions and declining carbon dioxide sinks.[6]

Over 80 percent of the excess heat produced by the greenhouse effect has been absorbed by the ocean, as evidenced by a rise in global ocean temperatures of 0.1 degrees Celsius in the upper 700 meters between 1961 and 2003.[7] This is a small number because the ocean is so

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[4] Parmesan, C., H. Galbraith. 2004. Observed impacts of global climate change in the U.S. Pew Center on Global Climate Change, Arlington, Virginia, USA.

[5] IPCC 2007. Fourth Assessment Report: Climate Change 2007. Contributions from Working Groups I (The Physical Science Basis), II (Impacts, Adaptation and Vulnerability), and III (Mitigation of Climate Change) and the Synthesis Report to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA (http://www.ipcc.ch, accessed November 19, 2007)

[6] Canadell and 9 others. In press. Contributions to accelerating atmospheric CO2 growth from economic activity, carbon intensity, and efficiency of natural sinks. Proceedings of the National Academy of Science.

[7] IPCC 2007

huge, but the importance to ocean organisms is significant. More alarming is a widening tropical belt and the poleward movement of large-scale climate systems (e.g., jet streams and storm tracks), which could have profound effects on ocean circulation and all ocean ecosystems.[8]

Right now we are seeing some of the greatest atmospheric warming impacts in the Arctic. In fact, we are seeing warming at twice the rate of the rest of the planet. Scientists from the National Snow and Ice Data Center (NSIDC) and the National Center for Atmospheric Research (NCAR) found that Arctic sea ice is melting faster than models have projected.[9] Ice loss may accelerate if sea ice thins - an alarming concern given that older and thicker perennial ice has already been declining.[10] Scientists are concerned that a striking drop in ice in 2007 could indicate we may have reached a tipping point where sea ice loss will occur very rapidly with summer ice lost as early as the end of 2012.[11] In addition to the loss of sea ice, coastlines are losing permafrost, which provides rigidity and support to coastlines. The combined loss of permafrost and ice is causing increased erosion from late winter storms that ordinarily occur once the sea ice has set in.

Sea-Level Rise

The most recent Intergovernmental Panel on Climate Change (IPCC) report projected that global sea level will rise by 18 to 59 cm (7 to 23 inches) during this century, assuming a negligible contribution from the Greenland and Antarctic ice sheets. However, some scientists believe that with warming of two to three degrees Celsius significant melting of the Greenland and Antarctic ice sheets could occur, triggering a rise in sea level of 6 meters (approximately 20 feet).[12] Such a rise in temperature is possible within this century if current greenhouse gas emission levels continue over the next 10 years.

Ocean Acidification

The oceans play an important role in the planet's carbon cycle by absorbing large volumes of carbon dioxide and recycling it in various processes. Rising levels of CO_2 in the atmosphere have led to increased absorption of CO_2 in the ocean where it reduces the available level of carbonate required by many shell-building organisms. Increased CO_2 absorption has already made ocean surface waters less alkaline (i.e., increased the acidity) by 30 percent (or, lowered its pH by about 0.1 units) since preindustrial times.[13]

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[8] Seidel et al. in press. Widening of the tropical belt in a changing climate. *Nature*.

[9] Stroeve et al. 2007. Arctic sea ice decline: Faster than forecast. *Geophysical Research Letters* 34:L09501

[10] Serreze et al. 2007. Perspectives on the Arctic's shrinking sea-ice cover. *Science* 315:1533-1536

[11] Jay Zwally, unpublished data

[12] Hansen et al. 2006. Global temperature change. *Proceedings of the National Academy of Sciences of the United States of America* 103:14288-14293;
Hansen, J., and 46 others. 2007. Dangerous human-made interference with climate: A GISS model study, *Atmospheric Chemistry and Physics* 7:2287-2312

[13] IPCC 2007

While these numbers may seem small, the pH scale is 'exponential' – each unit of pH represents a 10-fold difference in acidity or alkalinity. Pure water is neutral with a pH of 7.0. Sea water with a pH around 8.0 is alkaline in nature. IPCC models project that global surface pH will decrease between another 40-120% (0.14 and 0.35 units) over the 21st century.[14] These estimates may be conservative. Other studies have estimated that increased CO_2 uptake by the oceans may increase pH by 100-220% (0.3 to 0.5 units).[15]

Based on modeling and archaeological records, oceanic absorption of anthropogenic carbon dioxide by the end of this century will cause the amount of CO_2 in the ocean to exceed that of any time in the last 300 million years.

Ocean Currents

The ocean drives climate. Atmospheric circulation is driven by the energy released when evaporated water condenses into clouds – which in turn drives ocean circulation by winds and changes in sea-surface temperatures. Ocean currents transport heat, most often poleward. Temperature exchange and ocean current are also dependent on differences in temperatures of the vertical water layers. Changes of temperature in this complex system could change our ocean currents and wind patterns, ultimately affecting marine ecosystem productivity, oceanic carbon dioxide uptake, and oxygen concentrations.

In the most recent IPCC review, one of these major climate-shaping currents, the North Atlantic meridional overturning circulation (MOC), which is thought to have a large effect on climate in the North Atlantic and Northern Europe, is very likely to weaken in the 21st century. A weakening of this effect could lead to a large, abrupt shift in the MOC, which, while unlikely, is possible. However, the global warming trend will likely swamp the potential cooling effect of a weaker MOC, and result in a net warming of the Atlantic region.

Extreme Events

Strengthening of the water cycle (interaction between atmosphere and ocean) could also mean increased rainfall in the tropics and high latitudes with drier conditions in the subtropics and increased frequency of extreme droughts and floods. Scientists predict that the influence of the ocean will contribute to more extreme maximum temperatures, heat waves, and heavy precipitation in greater frequency. And, as the Ocean continues to warm, the duration and intensity of hurricanes is predicted to increase.[16] There is empirical evidence of increased hurricane intensity in the North Atlantic since about 1970 that is correlated with increased sea-surface temperatures, and it is probable that hurricanes on the average will become even more intense in the future.

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[14] IPCC 2007
[15] Feely et al. 2004. Impact of anthropogenic CO2 on the CaCO3 system in the Oceans. *Science* 305:362-366
[16] IPCC 2007

Accelerated Climate Change

The latest research shows more rapid increases in CO_2, losses of summer Arctic sea ice that could lead to the complete melting of summer ice as early as 2013, breakup of Antarctic ice shelves, ocean acidification, coral bleaching, and even greater sea level rise than were predicted just a short time ago. Research published in November 2007 documented a surprising acceleration in atmospheric CO_2, driven by economic growth and the deterioration of carbon absorption on land and in the ocean. It appears that the vast Southern Ocean may be becoming saturated with CO_2 and unable to absorb as much as it once did. Another study from the same time shows that rising acidity is happening faster in the Southern Ocean where it could negatively affect the plankton that are critical to removing CO_2 from the atmosphere, further compromising the seawater's already reduced ability to absorb CO_2. Scientists recently thought it would take a century or more for the Arctic ice cap to disappear, but the timeframe is now estimated in decades. One researcher has even projected its loss in less than 10 years.

IMPACTS

Given the myriad and diverse threats facing ocean ecosystems and their marine life summarized above, it should come as no surprise that these systems and their inhabitants are strained to the breaking point, show tremendous and increasing signs of stress, and are starting to unravel and collapse. More than a century ago, the U.S. Commission of Fish and Fisheries recognized major impacts to nearshore resources associated with human habitation.[17] More than a decade ago, the National Research Council found that the diversity of life in the ocean was being dramatically altered by the rapidly increasing and potentially irreversible effects of activities associated with expanding human populations.[18] By then, it was clear that fishing, pollution, physical alteration of habitat, invasive species, and global climate change were among the most critical of these stresses and that they had already impacted ocean life from the intertidal zone to the deep sea. Many more recent scientific studies and two national ocean commission reports attest to the fact that human impacts to ocean resources continue to increase and proliferate.[19]

Even in the absence of climate change, the onslaught of other human-caused stresses would threaten ocean ecosystems and their living components. The shifting baseline syndrome previously discussed has partially masked some of these impacts to ocean ecosystems and their inhabitants. However, they are now feeling the combined impacts of climate change on top of these other stresses. Climate change may pile on the straws that break the backs of ocean

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[17] United States Commission of Fish and Fisheries. 1880. Report of the Commissioner of Fish and Fisheries for 1878. Wash. DC. Gov't Printing Office

[18] National Research Council (NRC). 1995. Understanding Marine Biodiversity: A Research Agenda for the Nation. Wash. DC. Nat'l Acad. of Sci.

[19] Pew Oceans Commission. 1993. America's Living Oceans, Charting a Course for Sea Change. A Report to the Nation. Pew Trusts; U.S. Commission on Ocean Policy. 2004. An Ocean Blueprint for the 21st Century Final Report of the U.S. Commission on Ocean Policy

ecosystems. The added burden of climate change on top of other escalating threats is creating a perfect storm of impacts that threatens the future of ocean ecosystems and life stretching from the polar regions to the tropics. To date, some of the impacts to coral reef and Arctic habitats have been especially profound, but stresses are being felt in other ecosystems, too. The most recent assessment by the IPCC indicates that many long-term changes in climate have been documented across the oceans and affect its nearshore and offshore inhabitants. These changes include increased Arctic temperatures and less ice cover, increased ocean acidity, decreased ocean salinity, shifting current patterns, amplified extreme events (e.g., droughts, precipitation, heat waves) and changes in marine biodiversity and population size, movement and phenology (i.e., the timing of events in an animal's yearly cycle, such as the time of the year during which seals would give birth).

Coral Reefs

Coral reefs provide an excellent focal point for exploring the impacts of climate change and some of the potential solutions for addressing them. As previously discussed, coral reef ecosystems, like tropical rain forests, harbor tremendous biological diversity and provide great value to humans when properly conserved. But reefs are also fragile. In addition to their great value, coral reefs provide a good lens through which to view climate change impacts due to their accessibility, and because they are among our most charismatic and well-documented ecosystems. Many of the proposed solutions for addressing coral reef impacts are also applicable to other ecosystem types.

Nearly a decade ago, the U.S. Coral Reef Task Force concluded that the world's coral reef ecosystems were in serious jeopardy, threatened by an increasing array of overexploitation, pollution, habitat destruction, invasive species, disease, bleaching, and global climate change.[20] The rapid decline of these ancient, complex, and biologically-diverse ecosystems has significant social, economic, and environmental impacts here in the U.S. and around the world. A comprehensive review of Caribbean coral reef research studies concluded that, as of 2000, live coral cover had already declined by an average of 80 percent across this region's valuable and vulnerable reefs.[21] Elkhorn and staghorn corals, two of the region's most important reef-building corals, were harder hit and are now listed as threatened under the U.S. Endangered Species Act. Another comprehensive study of coral sites across Australia's Great Barrier Reef showed similar decades-long declines in coral cover.[22] A series of collaborative "State of the World's

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[20] United States Coral Reef Task Force (USCRTF). 2000. The National Action Plan to Conserve Coral Reefs. Wash. DC. Environmental Protection Agency (EPA)

[21] Gardner TA, ICôté IM, Gill JA, Grant A, Watkinson AR. 2003. Long-term region-wide declines in Caribbean corals. *Science* 301: 958-60

[22] Hughes, TP et al. 2003. Climate Change, Human Impacts, and the Resilience of Coral Reefs. *Science* ,15 August, 2003

Coral Reefs Reports" in recent years has documented similar long-term coral reef decline across even broader areas.[23]

No single stress is solely responsible. There is strong scientific agreement that fishing and pollution, especially eutrophication (enrichment from excess nutrients) and sedimentation, are among the key drivers of reef decline in many areas, that they act synergistically, and that climate change threatens reefs on an even larger scale.[24] Climate change impacts are likely already being felt on the world's reefs. Bleaching events in which corals expel their symbiotic algae, turn white, and may die or become diseased, are linked to elevated sea surface temperatures and appear to be becoming more frequent, severe, and repetitive as sea water temperatures increase. The summers of 1998 and 2005 were among the most damaging for coral reefs in history. In 1998, about 16 percent of the world's coral reefs were lost due to severe coral bleaching in the Indian and Western Pacific oceans. If we were talking about forests this would be the equivalent of all but 1% of the all the forests in North America burning in one year. In 2005, unusually warm waters caused even more severe bleaching in the Caribbean with average mortality rates over 50 percent in some places, including the U.S. Virgin Islands.[25]

Coral reefs are more than just corals. They are myriad interwoven and interdependent habitats and associated species. The extraordinary degree of interdependence and specialization among reef species, and the intense predator-prey, grazer-producer, and competitive interactions found within and among reef dwellers rival any on earth and may be in part responsible for the remarkable diversity found on reefs. These close relationships are critical to structuring reef communities, controlling energy and nutrient flows on reefs, and the tight recycling of materials characteristic of reef systems. Consequently, fishing and other extractive activities often remove critical living components of coral reefs, destabilize reef ecosystems, and reduce the resilience of coral reefs to withstand impaired water quality, climate change and other stresses.[26] A recent study by the United Nations Environment Programme predicts that 80 to 100 percent of the world's coral reefs may experience annual bleaching events by the year 2080.[27]

Ocean acidification, on top of warming, has the potential to completely wipe out coral reefs as we know them within this century, if we do not take the necessary steps to reduce carbon dioxide levels immediately. Moreover, it is likely that the increased acid levels already being felt by reefs in some locations could be inhibiting coral growth rates. In the face of other stresses, this could tip the balance in favor of halting or reversing reef growth.

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[23] Wilkinson et al 1998, 2000, 2002, 2004. Status of the Coral Reefs of the World 2000, 2002, 2004. GCRMN and AIMS. Townsville, Australia

[24] Schuttenberg and Hoegh-Guldberg, 2007. A World with Corals: What Will It Take? *Science,* 5 October 2007. Washington, DC

[25] Wilkinson C, Souter D. 2008. Status of Caribbean coral reefs after bleaching and hurricanes in 2005. Townsville: Global Coral Reef Monitoring Network, and Reef and Rainforest Research Centre

[26] Sobel and Dahlgren 2004. Marine Reserves, A guide to science, design, and use. Island Press, Washington, DC

[27] UNEP 2008, In Dead Water

Ocean Warming

Rising ocean temperatures, shrinking polar ice caps, and sea level rise will result in a cascade of ecological effects. Water temperature is an important determinant of physiological function of ocean organisms, and is, ultimately, an important feature of distribution and ranges of species and habitats. Changes in ocean temperature will cause major shifts in the distribution of organisms and a reorganization of the interactions that determine ecosystem function and the provision of ecosystem services. These impacts will, ultimately, affect human populations.

Arctic Impacts

Climate change effects in Polar Regions will cause major physical, ecological, sociological, and economic impacts, especially in the Arctic. The rate of Arctic warming is of grave concern because it is home to the world's few remaining pristine ecosystems and to societies and cultures with close ties to their surroundings.

Ice-associated marine algae and amphipods provide the base of a productive and unique food web that includes Arctic cod, sea birds, ice seals, walrus, whales, polar bears, and Arctic foxes. Loss of sea ice may lead to the local loss or even extinction of species unable to adapt. The loss of sea ice is already projected to severely impact polar bears.[28] Scientists predict that two-thirds of the world's polar bear population will be lost by mid-century, given current rates of warming. Loss of sea ice in the Bering, Chukchi, and Beaufort Seas will impact other ice-dependent ocean wildlife (e.g., ringed seals, spotted seals, ribbon seals, bearded seals, walruses). Ringed seals have a close association with sea ice for resting, pupping, mating, molting, and feeding.

Another concern for ocean species living at the poles is how they will adapt to warming temperatures. Species are already moving poleward in response to warming, but for those species already living as far north as possible, there is no place to go but extinct.[29] This phenomenon is already being documented from species living at the tops of mountains.

Melting ice has opened up the Arctic to industrial exploitation that in turn contributes to climate change. With the retreat of sea ice, and seasonal ice-free waters, there is great potential for greater disturbance in the Arctic Ocean from increased vessel traffic and potential fisheries interactions as well as offshore development – all of which will ultimately increase emissions and warming while threatening ecosystems also being stressed by rapid changes in temperature and ice cover. More than 78 million acres in the Chukchi, Beaufort, and Bering Seas will be made available for oil and gas development in the proposed oil lease sales by the US Federal Government. This area overlaps with habitat that is biologically important for Arctic ocean species, including critically endangered North Pacific right whales, bowhead whales, ice

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[28] US Geological Survey, 2007. USGS Science to inform U.S. Fish and Wildlife Service decision-making on polar bears: Executive Summary. (http://www.usgs.gov/newsroom/special/polar_bears/docs/executive_summary.pdf, accessed Nov 19, 2007)

[29] Parmesan 2006. Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology, Evolution, and Systematics* 37: 637-669

seals, walrus and polar bear. As the ice retreats, new shipping routes will become available, such as the Northwest Passage and the Northern Sea Route, significantly increasing the volume of vessel traffic in the Arctic. Projections suggest that by 2050, the Northern Sea Route will have 125 days per year with less than 75% sea-ice cover. Increased shipping, fishing vessels, and cruise ships bring an increased chance of interactions between vessels and whales and the chance of oil spills. The US Mineral Management Service's Environmental Impact Statement on the Chukchi Sea leases estimates the chances of one or more large spills greater than 1,000 barrels of oil at between 33 and 51 percent, and states that in 'open-water to broken-ice conditions,' only 10 to 20 percent of the spilled oil would be recovered." This represents a massive threat to Chukchi ecosystems and wildlife.

One of the greatest concerns we face with global climate change in the Arctic is the impact on indigenous Arctic communities whose coastal communities rely heavily on ice-dependent resources. Of the nearly four million people living in the Arctic today, about 10% are of indigenous descent. There are over 50 different groups of indigenous peoples throughout the Arctic – each with its own distinct culture yet united by shared dependence on the health of Arctic resources and their vulnerability to global warming. Many of these cultures, for millennia, have depended on and have adapted to the environment. One of the most widespread observations independently documented across the Arctic is that residents cannot predict the weather like they used to; residents recognize that the Arctic is inherently variable, but they have been able to use knowledge passed on from generation to generation to survive in one of the harshest environments on our planet. Because Arctic residents have maintained a vibrant connection with the environment in everyday life they are able to detect unusual characteristics and patterns in wind, weather, and sea ice conditions.[30] These changes in environmental conditions, documented by scientists and described by indigenous people, are influencing ocean wildlife, as described above. Arctic peoples have subsisted on ocean resources for thousands of years and do so, even today, but the future of subsistence is uncertain. Traditional subsistence use of ocean resources is fundamental to cultural identity, social interactions, and a primary means to obtain food. While considering the impacts of climate change to ocean wildlife, we also need to think about the communities that will be severely impacted, and ensure that other stresses on marine resources such as vessel traffic and offshore development are minimized to ensure that these cultures and societies can continue to exist.

Rising Sea Level

Rising sea level is already impacting the most low-lying coastal areas with the loss of coastal wetlands and mangroves as well as increased coastal damage from flooding.[31] If unchecked, sea level rise could severely impact human populations, wetlands, and coastal ocean species and will exacerbate inundation, storm surge, erosion, and other coastal hazards.

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[30] ACIA 2005. Arctic Climate Impact Assessment. Cambridge University Press, 1042pp
[31] IPCC 2007

An international report examined global cities whose asset value would be the most threatened by sea-level rise in the next sixty years and U.S. cities ranked high – half of the top 10 cities were in the U.S. In terms of the population that would be exposed and at risk to sea-level rise, Mumbai, India topped the list, but Miami, New York, and New Orleans were in the top 10.[32]

An increase in sea level is a threat to seals, sea lions and sea turtles that haul out on land to rest and for reproductive purposes. Low-lying sand and pebble beaches will no longer be available for these important yearly cycle events. Many islands contained within the Northwest Hawaiian Islands are low-lying and very vulnerable to increased sea level. Scientists simulated potential habitat loss and determined that with a maximum sea level increase of 88 centimeters (35 inches) the loss varies from island to island, but with an increase of 129 centimeters (51 inches) from spring tides all land would be periodically inundated.[33] They predicted that endangered Hawaiian monk seals, threatened green turtles, and endangered Laysan finch would face the greatest threats from lost habitat due to seal level rise – based on their ecological, geographical and population characteristics. The estimates used in this study are conservative relative to the reality of current levels of ice melt observed in Greenland and Antarctica. Given a maximal rise of 600 centimeter (20 feet) in sea level, much of this habitat would be lost within one of our greatest national treasures, the Papahānaumokuākea National Marine Monument.

Shifting Ranges

A snap-shot of the ocean tomorrow may not resemble the ocean that we have come to know and love today. The evidence that climate change is responsible for shifting ranges and distribution of species is mounting.[34] Our picture of ocean ecosystems may be dramatically transformed due to species altering their range in response to changing environmental features such as temperature, ice cover, circulation, and salinity.[35] As population sizes change and species shift their geographic distributions, biological communities and food webs change, with consequences for biodiversity, ecosystem function, and dependent economies. It is important to note that many of these changes may not be simultaneous. Those species that are physically able to change location may do so sooner, resulting in reorganized ecosystems with different functional relationships.

Poleward range shifts have been well documented, for individual species as well as for communities.[36] Distributions of fishes in the North Sea responded to increased temperatures, with about 2/3 of them shifting in mean latitude and/or depth over 25 years of observations.

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[32] Nicholls, RJ et al. 2008. "Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates", OECD Environment Working Papers, No. 1, OECD Publishing

[33] Baker et al. 2006. Potential effects of sea level rise on the terrestrial habitats of endangered and endemic megafauna in the Northwestern Hawaiian Islands. *Endangered Species Research* 4:1-10

[34] Petersen et al. 2008. Regime shift in a coastal marine ecosystem. *Ecological Applications* 18:497-510., IPCC 2007, Parmesan 2006, Grebmeier et al. 2006

[35] Harley et al. 2006. The impacts of climate change in coastal marine systems. *Ecology Letters* 9:228-241

[36] Grebmeier et al. 2006. A Major Ecosystem Shift Observed in the Northern Bering Sea. *Science* 311:1461-1464; Parmesan 2006

Similar documentation has been made for zooplankton in the North Sea. These changes are not occurring only in distant waters, but in our own backyard, where lucrative $2 billion dollar fisheries occur. In the Bering Sea, changes in the biological community have occurred simultaneous with shifting atmospheric and hydrographic characteristics. Changes in ocean and air temperatures and reductions in sea ice have coincided with a reduction in benthic species and communities. These changes in prey base have negatively affected higher trophic species such as seabirds and ocean wildlife populations, such as Steller sea lions.[37]

Human Impacts

Coastal communities and ocean-based societies and economies will suffer substantial losses in coming decades compromising or eliminating historic human use of coasts and the ocean. Rising sea level is currently affecting low-lying nations, such as the Pacific island of Tuvalu, where tidewater floods homes and streets. Scientists determined that sea level rise has been 1.2 mm per year, and the country is currently examining relocation options along with fears about the loss of their culture.[38] These impacts on low-lying island nations foreshadow what low-lying U.S. cities might see in the not-so-distant future. Arctic villages along the Chukchi and Beaufort Seas are facing relocation due to coastal erosion, loss of permafrost, sea level rise, and the increased frequency and intensity of storms.

There is an estimated 284,300 km^2 of coral reefs in the world,[39] which have been estimated to be worth US$100,000 to $600,000 per km^2 annually.[40] That is a total value of 28.4 to 171 billion dollars per year. By this valuation, the 3,770 km^2 of coral reefs in the United States are worth 377 million to 2.3 billion dollars per year.

Roughly half of all federally managed commercial and subsistence fisheries in the U.S. are dependent on healthy coral reefs ecosystems. Those fisheries have an estimated direct value of over $100 million per year.

Human health is predicted to decline due to increased risk of mortality and injury because of climate change related causes.[41] Some of the increased deaths may be due to infectious diseases because of heavy precipitation events; food and water shortages and water and food borne diseases in areas affected by drought; death and food and water borne diseases because of intense tropical cyclone activity; and drowning in floods because of increased incidence of extreme high seas. Many of the effects of climate change on society will be worst for those people residing in economically poorer nations with limited adaptive capacity.

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[37] Atkinson et al. 2008. Anthropogenic causes of the western Steller sea lion *Eumetopias jubatus* population decline and their threat to recovery. *Mammal Review* 38:1-18.

[38] Hunter 2002. A note on Relative Sea Level Change at Funafuti, Tuvalu. Antarctic Cooperative Research Centre, University of Tasmania. Technical Report; Patel 2006. A sinking feeling. *Nature* 440:73-736

[39] The World Atlas of Coral Reefs, prepared by the United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC)

[40] UNEP-WCMC (2006) In the front line: shoreline protection and other ecosystem services from mangroves and coral reefs. UNEP-WCMC, Cambridge, UK 33 pp

[41] IPCC 2007

SOLUTIONS

Unless we change course, the ocean and humankind are at the mercy of global climate change. Global warming and increased CO_2 concentrations are already having noticeable and severe impacts on the ocean, and we humans are feeling the effects. If we thought we had time to plan, we were mistaken. Recent research along many lines has shown that the pace of ocean-climate change is accelerating. Even under the most optimistic scenarios, atmospheric CO_2 concentrations will rise significantly over the coming decades.

There are just two options for addressing climate change. First and foremost, mitigation—we must significantly reduce greenhouse gas emissions now. Second, adaptation—we have no choice but to find ways cope with the impacts of climate change. The first addresses the root of the problem and the second will lessen or minimize climate change effects on ecosystems and human society.

Mitigation

The future of our planet and quality of life for our children and grandchildren depend on the world developing and implementing a plan that will commit all nations to significant reduction in greenhouse gas emissions. Members of Congress, many states, and countries around the world understand the urgency of taking action, and are willing to take the lead in making the changes that will be necessary to turn global climate change around. The U.S. government has failed to commit to effective action or provide the leadership needed. The United States is the largest single emitter of greenhouse gases and we must take responsibility for our role in degrading the ocean—the life-support system of the planet. Other nations contribute significantly, and China may soon surpass us, but that does not absolve us from acting responsibly. Without visionary and brave leadership from Congress and the next Administration, the planet will continue on its path toward a point of no return. We believe that the courage exists within us and that we will act decisively and quickly to avert the worst of what is coming should we continue down this road, but we cannot avoid coping with the changes global warming and ocean acidification is bringing.

Can we do anything to avoid or at least reduce the worse impacts of climate change? The answer is a simple – yes, but only if we reduce greenhouse gas emissions significant and immediately. Carbon dioxide is the most important, but not the only cause of global warming. We must control other gases, such as methane, and the production of black carbon, which we are just learning may contribute nearly as much to global warming as CO_2. We must rapidly slow and eventually reverse the dangerous increase in greenhouse gas emissions of the last 50 years. The consequences of inaction are dire.

Adaptation

Even if we cap CO_2 emissions at today's level, or, even better, reduce them to 1990's level, we will not escape climate change impacts – warming will continue for decades as a result of the excess CO_2 now in the atmosphere. Although we have no choice but to cut emissions to slow the increase in global warming, we will still be forced to cope with climate-related changes.

Indeed, those changes are already being experienced by many coastal communities around the world. If you are an artisanal fisher in the Seychelles, where most of the corals around the inner islands bleached and died in 1998, then you do not doubt that climate change is happening. If you lived in the Lower Ninth Ward of New Orleans and suffered Hurricane Katrina, you do not doubt it. And, if you are an Iñupiat living in Kivalina at the edge of the Chukchi Sea—a descendant of people who have lived there for over 10 thousand years now watching your home fall into the sea—then you certainly have no doubt.

Nature itself will attempt to adapt to climate change and its effects, but because of the unprecedented magnitude and speed of change, that adaptation will be incomplete in many cases. Managers and scientists are challenged with assisting natural marine systems as they try to adapt to climate change, and society will have to adapt to the impacts of climate change on our marine industries, coastal built environments, and economies.

It is true that the only real solution to climate change lies in mitigation – eliminating the disease – but we cannot ignore the need for adaptation to lessen the damage and pain as we seek to cure the patient.

Resilience

Our ability to foster adaptation of marine ecosystems is limited by the difficulty of direct intervention in the marine environment. We should undertake the restoration of damaged marine habitats where feasible, but the approach is expensive and is not likely to be able to deal economically with the extent and area of the many habitat types that will need to be restored. In the face of the global scale and wide scope of climate change impacts, our primary tool will be to protect, maintain and restore the natural resilience of marine ecosystems and species. Biological and ecological systems have complex regulatory processes that act to maintain structure and function in response to natural environmental variability and stresses, somewhat as the human body maintains its integrity and function through the regulation of temperature, water, and nutrients and the repair of damage.

Such a system's capacity to absorb and/or recover from a harm done by an environmental stress, whether natural or human, is referred to as resilience. Marine biological and ecological systems that have been damaged through periods of abuse may suffer reduced resilience, much as someone with certain diseases might be more susceptible to, and take longer to recover from cancer. Excessive fishing and whaling, pollution, nutrient runoff, and habitat destruction have reduced ocean ecosystems' resilience to stress such as that associated with climate change.

The primary adaptation tool for marine ecosystems is to ensure that their natural resilience is not compromised. The degree of resilience shown by different coral reefs, for example, varies depending on how stressful the environment is. Nonetheless, natural resilience can be exceeded by stresses more extreme than are normally experienced on a reef. Depending on the ecosystem, habitat, or species, this will mean that our response will focus on 1) protecting and maintaining intact resilience, or 2) restoring lost resilience.

Remote ecosystems such as the Arctic Ocean or the Northwestern Hawaiian Islands are likely to be nearly intact and resilient. While the Northwestern Hawaiian Islands are almost fully protected, they may still require some attention to rebuilding resilience with efforts to reverse the effects of lobsters being overfished and bottomfish being reduced by decades of commercial fishing, as well as the restoration of endangered monk seals. On the other hand, the Arctic Ocean has been removed from most human insults by its harsh environment and the ice, and we presume that its ecosystems are fully functional and resilient. However, the rapid loss of the ice cap is opening the Arctic Ocean to impacts to which the rest of the oceans have long been exposed – overfishing and destructive fishing practices, spills and disturbance associated with oil and gas exploration, and shipping accidents leading to fuel and cargo spills, for example.

In the Arctic, adaptation to climate change will entail protecting and maintaining ecosystem resilience in the face of new uses. An opportunity exists to build ecosystem-based management systems from the ground up *before* we do serious damage to its environment. In contrast, coral reefs have been subjected to multiple impacts from human activities for a very long time. The capacity of coral reefs to resist the effects of ocean warming and acidification is going to depend on the restoration of their natural resilience, which will not have a chance to happen if the stresses that have caused the degradation continue.

Coral reefs are not likely to be the only ecosystems to suffer reduced resilience. A recent global mapping study of multiple ecosystem types (e.g. mangroves, seagrasses, salt marshes, kelp forests and rocky reefs) and 17 different anthropogenic stresses, found that less than 4 percent of the ocean is impacted "very lightly",[42] while 43 percent of the ocean is "moderately" to "heavily impacted" by multiple stresses.

Maintaining and restoring ecosystem resilience depends on the control, reduction and elimination of stresses other than climate change. Without the negative impacts of other human influences and activities, ecosystems, habitats and species will better be able to resist ocean warming, decreased productivity, shifts in ocean currents, and/or acidification. Removing the stresses on a degraded ecosystem with compromised resilience, will not guarantee recovery – the degree and type of recovery will depend in part on characteristics of the ecosystem. But, without removing the stresses there is little or no chance of recovery.

Significantly reducing the impacts of human activities on ocean environments will require greater dedication to environmental management that aims to minimize the impact of human activity at the expense of short-term benefit to individuals, industries and economies. We are faced with severely altered ecosystems, collapsed resources, dead zones, species nearing extinction, and devastation of coastal communities because we have for decades managed for immediate profit rather than ecological sustainability.

Maintaining and restoring resilience relies on different strategies. Priority should be given to characteristics and processes that are critical to resilience. The capacity of an ecosystem to

[42] Halpern, B.S. et al. 2008. Mapping the global impact of human threats to marine ecosystems. *Science* 319: 948-952.

maintain function when stressed is a factor, among others, of biodiversity. The loss of even a few species from a diminished ecosystem could have a large effect on the system's function. Conversely, the loss of many species from a rich ecosystem may have little effect because other species can occupy vacant ecosystem roles. Areas that have lost ecologically functional groups of organisms, such as predators, herbivores, or keystone species, will be more susceptible to degradation and less able to recover without intervention.

Local environmental conditions may also affect resilience to warming. Corals that are bathed by cold upwelling waters, or subject to strong currents, may be less susceptible to bleaching because warm water is less likely to persist around them. Protecting many such reefs will reduce the chance that catastrophic, local impacts will eliminate a habitat or species – in other words, putting your eggs in many baskets is a wise strategy in the face of climate change. The recovery of affected areas will be influenced by their connectivity to other areas, especially those less affected. For instance, connectivity of ecosystems through the dispersal of eggs and larvae, and the movements of juveniles or adults, will be important in repopulating depleted areas. Ecologically connected networks of habitat patches will be key to preserving ecosystems under climate change stress.

As we learned from the Atlantic hurricanes of 2005 and the Indonesian tsunami in 2004, the condition and structural integrity of coastal habitats is critical to protecting human built environments. Healthy, intact coastal habitats such as coral reefs, mangroves, salt marshes, and dune systems provide highly effective buffers to the effects of storms. Without those buffers there is greater chance of potentially catastrophic ecological, social, and economic damage to coastal habitats and built environments. Once compromised, coast buffer habitats can take a long time to recover and may require human intervention to do so. The recovery, maintenance, and protection of coastal buffer habitats are crucial for coastal communities experiencing increased storm intensity and sea-level rise.

We lag behind in developing strategies to ensure that coastal communities adapt to climate change. We should modify coastal development planning to take into account the risks associated with climate change and how they interact with buffer habitats. We should consider relocating built environments and infrastructure at risk of loss. We should reformulate polices that create economic incentives that encourage risky coastal development to discourage such behavior and reward incorporating resilience into development plans. The impacts of climate change on coastal communities will be some of the most costly effects of climate change, but proactive, informed and timely intervention can do a lot to reduce those impacts.

Management Reform

We must reform the way that we manage the marine environment if the ocean is going to have a chance to withstand the onslaught of climate change. New approaches to management include: 1) ecosystem-based management, 2) adaptive management, and 3) application of the precautionary principle.

Ecosystem-based management, in which the primary goal is preserving ecological function and with it the ecological services that we depend on, must replace the out-dated single-species, single-issue approach.

Scientific uncertainty and lack of knowledge will require a greater reliance on adaptive management – applying a scientific approach to management and adjusting strategies in response to observed changes. To a large extent, we will have to learn how to adapt to climate change as we go.

Typically, we do not undertake management to control use or exploitation until a problem appears, but often by that time considerable harm has been done and resilience has been compromised. Faced with uncertainty and risk of climate change, a precautionary approach is needed – allowing only limited use and exploitation until it can be shown that ecosystem function and integrity will not be substantially harmed.

A precautionary approach is especially relevant in the Arctic where we have the opportunity to implement innovative management strategies and methods before substantial use and exploitation begins. The Arctic offers a grand laboratory for the study of methods and approaches to large-scale ecosystem-based, adaptive, and precautionary management.

Societal Adaptation

Not only marine ecosystems and species will have to adapt to climate change. Humankind will have to adapt. Populations of exploited species are already beginning to shift in response to warming. Fishers will have to adapt to shifting stock sizes and ranges, and eventually replace them in their catches with other species. Some preferred and valuable species will decline in abundance and eventually disappear from certain areas, with potentially severe consequences for coastal communities dependent on fishing. New species will invade, requiring fishermen to use new gear and develop new fishing methods if they are going to maintain their livelihoods. Managers will be required to account for these factors in order to manage resources effectively. Fishers, the fishing industry, and fishing-dependent communities will require technological, governmental, and economic assistance to adapt. Much as human stresses have reduced ecosystem resilience, climate change will reduce the social and economic resilience of coastal communities.

Our resource exploitation and management strategies ecosystems operate within a dynamic range that doesn't change drastically, which may have been appropriate at one time, but not in an age of continual climate change. Fishermen off Cape Cod today expect that cod will be there year after year. They do not expect that because of ocean warming stocks will gradually shift northward, to be replaced by others from the south. The rates of range shift will vary, and shifts will alter interactions among species, the combined effect of which may be chaos. Fishers will have to fundamentally alter their strategies to adapt to the changing composition of fish species available to them, or to move with the fish. Similarly, related industries—processors, distributors, and retailers—will not be able to count on stable supplies, forcing them to adapt markets, distribution, and menus.

The need for all the players to adapt rapidly and continually to the changing ocean environment will be true wherever we depend upon resources that are living. It will be true for fishers, kelp harvesters, bioprospecters, dive operators, aquarists, and aquaculturists.

Ecological systems do not always change gradually in response to incremental environmental changes. They sometimes exhibit disproportionate and unpredictable shifts in response to small changes in conditions. A fish species may decline in abundance gradually as the ocean warms, but then suddenly disappear because it meets some unanticipated threshold in it's interaction with another species. Management strategies will have to cope with multiple, rapid, and unpredictable changes in ocean environments and the resources upon which we depend.

Resources for Adaptation

Making adjustments in our thinking and management strategies to adapt to climate change will require substantial investments in education and research. Our knowledge of ocean systems is comparatively limited. Even now, we struggle to understand the relationships between ocean processes and our use of resources, and to set management strategies based on that understanding. In the context of accelerating climate change, this gap puts a premium on improving our understanding of marine ecosystems and how they react to human stresses.

In an era in which the lay of the sea will change beneath our keels, there is an imperative to increase funding and support for marine research. We are entering uncharted waters, beyond the collective experience of scientists and managers and outside our scientific knowledge base. This puts an even greater imperative on increasing the resources that we invest in understanding ocean dynamics, ecosystem processes, resource dynamics, and socioeconomic dependencies. Our ability to adapt to climate change depends on our ability to understand what is happening to the ocean, to predict as much as we can of what will come next, and to craft effective adaptation strategies.

Policy Development

While there are things the Administration can do now to address the impacts of climate change, coping with the profound challenges of building resilience in our ocean ecosystems will require legislation changes our climate governance structure. While most major bills in Congress relating to climate change focus on mitigation through the reduction of global warming pollutants, there have also been proposals in both the House and Senate to develop strategies for improving ocean adaptation and resilience, and to direct funding to such activities. The energy bill passed by the House (HR 3221) contained strong provisions for developing a national ocean adaptation strategy and for assisting states in carrying out similar activities. In addition, the major vehicle in the Senate for climate change mitigation directs funding from the auction of carbon allowances to wildlife and ocean adaptation efforts.

These proposals represent strong steps in the right direction. Consistent with the principles set forth by Chairman Markey on Earth Day, April 22nd, 2008, we urge Congress to build on these proposals, and include in broader climate change legislation provisions to help our oceans and coastal communities adapt to the impacts from climate change.

National Strategic Plan – Legislation should call for the development of a national strategic plan to respond to and alleviate the impacts of global warming and ocean acidification in the United States. This strategy must use the best available science, should include a plan for implementing the strategy across multiple federal agencies, and include a plan for carrying out research, education, monitoring, assessment, as well as for specific adaptation activities. It should also include a mechanism to ensure that any federal decision- that may exacerbate the impacts of climate change on our environment take into account the added negative effects of climate change.

National Climate Office – Second, legislation should create a National Climate Office to guide the development of the national strategy, and to coordinate and facilitate federal adaptation efforts and strategies. The legislation should codify both the National Oceanic and Atmospheric Administration (NOAA) within the Department of Commerce, and the White House Committee on Ocean Policy, which was established by Executive Order 13366 on December 17, 2004. While NOAA is the principle agency with respect to researching climate change impacts on the oceans, and for overseeing management of our ocean resources, multiple federal agencies have decision-making authority that can profoundly affect our ocean and coastal ecosystems, compounded by the effects of climate change. A centralized body is needed to oversee implementation of the national strategy with respect to oceans and coasts, and to coordinate all federal decision-making related to the health of our oceans. Providing a legislative mandate for NOAA, which was established by Executive Order in 1970 and has struggled under an obsolete management structure and unclear mission, would greatly improve its ability to carry out ocean adaptation measures, particularly if charged with carrying out ecosystem-based ocean management, taking into account the effects of climate change.

Adaptation Funding – Finally, climate change legislation must direct a substantial portion of the proceeds from the auction of carbon allowances to fund the development and implementation of national adaptation strategies, and should provide grants for states for similar activities. For years, we have significantly under-invested in the protection and restoration of our ocean and coastal resources, particularly given the vital role they play in our nation's economy, and the increasing threats posed by pollution, overfishing, and habitat destruction. Now as the oceans and coasts face the additional threats posed by climate change, a dedicated funding source to improve their resiliency is critically needed.

CONCLUSIONS

We stand at a crossroads, atop a mountain, but there is no ambiguity about which road goes straight toward the cliff and which toward home. We must make the right choice if we want to survive and prosper. The emission of greenhouse gases has to be slowed and ultimately stopped, and we have to act swiftly. We in the United States and in other developed countries enjoy an unprecedented quality of life, which is the envy of the rest of the world. But, that standard of living is expensive in the currency of carbon and it is not sustainable, especially with the rest of the world rapidly trying to emulate us. It is not sustainable if we do not take care of the ocean and the biosphere. We have a moral obligation to change our relationship with the planet. If we make those changes intelligently across all sectors of society and the economy, and if we undertake a 'mission-to-Mars' like development of new technology, then the changes have the chance to be more productive than painful. We may be able to cope and adapt to the changes that we see within our lifetimes without too much difficulty, but if we do not act now our children will suffer from out indecision and their children and grandchildren may lead much less rewarding lives, experience a significantly poorer standard of living, and face a world that is fundamentally more dangerous and uncertain. I have great faith in our ability to rise to this challenge, much as we have before when faced with global challenges to our way of life.

Nonetheless, our nation, its environment, economy, and people will be harmed by climate change. We face a twin challenge to mitigate its impacts and adapt to those which we cannot mitigate. We need strategies for responding to climate change impacts that will minimize the damage and cost of those impacts. We must get much better at anticipating what climate change is going to throw at us, and when and where those curve balls are going to appear. Adaptation to climate change will require significant investments in research, education, industry, and government, but it is within our capacity as a global society.

We have never faced a challenge of this magnitude before, but if we are willing to act now in collaboration with the World, we can succeed.

Thank you for the opportunity to provide the Select Committee on Energy Independence and Global Warming information regarding the importance of the ocean and how is being affected by climate change. If I can be of further assistance, please do not hesitate to ask.

The CHAIRMAN. Thank you, Ms. Spruill, very much.

And we thank all of our witnesses.

And Ms. Spruill raises a very good point, that we have four brilliant women who are testifying here today simultaneously. And that is what happens when you have two women Ph.D.s in science, Dr. Ana Unruh Cohen and Dr. Stephanie Herring, plan the meeting. Somehow or other they find four more brilliant women to all give the testimony. So that is kind of the theme for today's hearing, appropriately so.

So let me begin with you, Dr. Earle. Just give us your summary of how your views have changed, how the world's views have changed of the science of the seas over the last 30 or 40 years. Where were we then, and where are we today in terms of the way in which we should view the seas, their health, and the danger to the planet?

Ms. EARLE. When I was a child, there was a widespread view, that many still hold that the ocean is infinite in its capacity to rebound no matter what we take out or whatever we put in. The best way to get rid of something was to deep six it, throw it into the sea. We thought that our job was to find new and better ways to extract wildlife out of the ocean, going back to the 1960s and 1970s. And some still hold to that view.

The importance of wildlife in the ocean was primarily viewed as a commodity, protein from the sea. I think we have learned a great deal—actually, we have learned more in the last half century than during all preceding human history about the ocean, about a lot of things, but certainly about the ocean. We didn't even know, and Rachel Carson was not even aware of the mountain ranges that run like giant backbones down the Atlantic, Pacific, and Indian Oceans when she wrote, "The Sea Around Us," in the early 1950s. We did not know at that time that there was life from the surface of the ocean to the greatest depths. We certainly didn't appreciate the profound impact that the living systems, particularly the microbes, have on all of us, on the nature of the ocean, the little guys that do the heavy lifting with respect to churning out oxygen and taking on carbon dioxide.

We now know much that should alert us to the importance of taking care of the ocean that takes care of us. We certainly would not like to see the demise of rainforests. We would feel the loss if something devastated them even more than they have been devastated. But in fact, if they did go, if we still had a healthy ocean, life would probably continue. But if we did away with the ocean or seriously impacted the health of the ocean, everything, everything would be impacted. The ocean really rules the world. And one of the baffling things that strikes me today is that, although that knowledge has been around for a while, it has been growing over the last half century, but we still don't take the ocean seriously enough. And it is no more apparent than in the climate change issues where great attention, at least up to the present time, has been focused on the atmosphere. But as all of us have pointed out, there are links, inextricable links to the sea. In fact, the ocean really is the governor of climate and climate change.

The CHAIRMAN. Thank you.

Dr. Lubchenco and Dr. Kleypas, what has your research shown about the pace of climate change when you kind of compare it with geologic history? What is happening now as you look back over the whole history of the planet?

Ms. LUBCHENCO. Mr. Chairman, the history of Earth is a very dynamic history. We have seen many, many changes over millennia. And what is striking about the changes that have been happening with respect to climate change over the last century is the rate of change. The changes are so much faster than the background levels. In many cases, the levels of some greenhouse gases exceed historic or previous levels, but it is the rate of change that is really particularly striking. Even knowing that, many of the models, the early climate change models that were created have predicted rates of change that reflect our current measurements. And even those predictions have been too low. We are seeing much faster changes than even our best models have predicted.

One of the best examples of that is the melting of ice in the Arctic, the floating sea ice that has always created a very dynamic, rich habitat and upon which the peoples of the Arctic have always depended as well as the rich marine life there. And that area is warming so much faster than was originally predicted. The models are just continually revised and revised. The same is true of ocean acidification. It is happening faster than we had initially thought that it would. And I believe that this theme is one that we haven't yet sufficiently paid attention to.

In light of this knowledge, we need to be even more conservative in our use of natural resources and even more aggressive in our attempts to slow down the rate of climate change.

The CHAIRMAN. Dr. Kleypas.

Ms. KLEYPAS. I would like to key in on a couple of things, the rates of change and adaptation. We often use the term adaptation a lot, particularly in terms of human adaptation. And we are an extremely adaptable species. But most of these organisms that are in the ocean have not seen these kind of changes, either the magnitude or the speed at which they are changing, for millions of years. I think the last time we have seen an ocean acidification event was about 55 million years ago. That was only 10 years after the dinosaurs were wiped out. And even then, that rate of change was probably not as fast as what we are seeing today. And during that time period, there were a lot of big changes that happened in the ocean that can be attributed to ocean acidification. So adaptation, we can count on that for a lot of humans, but I don't think we can expect these ecosystems to adapt alongside us. Not unless we do a lot of things to help them.

The CHAIRMAN. You have heard these concerns, Ms. Spruill. How can we explain this to the public? What is your recommendation in terms of having the fire alarm sound so that we ensure that this does not result in catastrophic consequences?

Ms. SPRUILL. Thank you, Mr. Chairman. I am not a researcher. I consider myself a translator and a communicator. And I represent a constituency of people across the country who are very much hungry for change. And I think today the good news is we have got a combination of increased awareness and this growing sense of urgency and momentum. We really have a golden opportunity to act.

There are actually three things that I think we would want to encourage Congress to do. First, of course, is to make that link between climate change and oceans. That process has already begun today. And that means making adaptation strategies part of every climate change bill passed by Congress. The second thing is, there are a number of good bills already in the pipeline: Oceans 21, which passed subcommittee just this past week; the Coral Reef Protection Act; the Marine Sanctuaries Act. All of these bills, if passed, will help to provide these adaptation strategies that you have heard about today. And then, third, I would say, to continue with my medical analogy, first we need to be doing no harm. We need to be looking at some of these technological solutions. They obviously have a place. But we need to be moving carefully towards any proposals and make sure that the cure isn't actually worse than the disease.

The CHAIRMAN. Thank you.

Dr. Earle, why don't people understand the relationship between the ocean and the planet? What do you attribute that huge gap to? How can such a huge percentage of the Earth's surface be something that is just not a part of public consciousness?

Ms. EARLE. It is the great mystery of the sea. I had occasion to ask that very question to Clare Boothe Luce once. And she looked skyward, and she said, well, looking at the big puffy clouds, heaven is there and you know what is in the other direction. And whatever the reason, because perhaps we are terrestrial by nature and only in fairly recent times have human beings acquired access to the sea, effective access to the sea, but we are still beginning. SCUBA divers go down maybe a 100 feet, 150 feet perhaps if they push the edge a bit. But we are still exploring the ocean. Less than 5 percent of the sea has been seen at all, let alone explored. And because of our attitude that the ocean is a place to throw things away, or it is a place just to—well, you think of fish, fish are to eat, right? Without thinking that fish are to the sea as birds are to the land, they are components of our life support systems. They are as, as has been said about components of the land, the nuts, the bolts, the cogs, the wheels that make the ocean work. And it is not just the fish, it is all of the diversity of life in the sea. We need to respect fish alive, not just fish dead. And coral reefs alive, not just ornaments for your shelf. We need to think about the ocean with a new attitude. And it is happening, but it needs to happen faster than it presently is.

The CHAIRMAN. Which organisms, which ecosystems are most vulnerable right now to this acceleration of climate change?

Ms. EARLE. I can answer a bit, but we all can weigh in. The acidification is comprehensive in its impact. We can look at coral reefs because we are familiar with them, and we don't see the tiny creatures, the coccolithophores, the foraminifera, the little calcarea-shelled creatures that make up much of life in the sea and that drive much of the ocean chemistry. And we better pay attention. And it is important. With every breath we take, it is important to understand this. And it is not rocket science, as they say. This is—this is ocean science, which is really a lot of fun as well as really important.

The CHAIRMAN. Dr. Lubchenco.

Ms. LUBCHENCO. Mr. Chairman, I believe that Sylvia has given an answer I would agree with. Relative to warming, certainly those communities, those ecosystems that are in the tropics and those at the poles appear to be most vulnerable. But every community is vulnerable to the increased acidity of oceans. And that is going to be one of the biggest challenges facing all of us. Because of its consequences at all different levels, from the microscopic plants through the filter feeders, to the herbivores, predators, on up the food web. Anything with a shell or a skeleton. And so crabs, lobsters, sea stars, urchins, microscopic plants, mussels, oysters, snails, all of those are going to be affected by this acidification. And those critters are everywhere.

The CHAIRMAN. Dr. Kleypas, are there particular areas of the ocean that we should prioritize for protection?

Ms. KLEYPAS. Thank you, Chairman Markey.

I would say that the shallow oceans are where most of the life is. That is where the primary production occurs, where they use sunlight to create the bulk that feeds the rest of the ocean. So the shallow oceans I would say are the place of urgency right now. And it does extend from the tropics to the poles. That would be my answer.

The CHAIRMAN. Ms. Spruill, as Congress considers legislation to reduce our global warming pollution, what other policies in your opinion are necessary to help protect the oceans from climate change?

Ms. SPRUILL. Well, I think I named three that are actually already in the pipeline. And a little push from this committee would go a very long way. Oceans 21, I think——

The CHAIRMAN. Oceans 21. Why don't you just outline a little bit of what each one of these bills does and why they are important to pass?

Ms. SPRUILL. So, Oceans 21 really creates a national ocean policy and then a mechanism for implementing that policy across a variety of Federal agencies. It is really the coordinating function that we need across so many Federal agencies. This grew out of both Presidential commissions. And as you mentioned, Dr. Lubchenco was on the Pew Commission. She can maybe talk a little bit more about the genesis of that legislation.

Then there is the Coral Reef Conservation Act, which passed the House and awaits Senate floor action. So these are bills that are quite far along in the pipeline. That promotes community-based conservation and provides tools at the local level, a number of these adaptation strategies that we have discussed. And it empowers NOAA to respond to damaged reefs, again another adaptation strategy if you will.

And then there is the National Marine Sanctuaries Act, which certainly has the promise at least of protecting more of our ocean and making it more resilient, as we have already discussed, in the face of unforeseen climate change.

The CHAIRMAN. Thank you. Dr. Lubchenco, Ms. Spruill referred to it; how successful has the Federal Government been in implementing the recommendations from the commission?

Ms. LUBCHENCO. We had hoped to have seen much more progress by now. I think hope still remains that Congress——

The CHAIRMAN. What is the obstacle in your opinion?

Ms. LUBCHENCO. I believe that it is part of what we have been talking about at these hearings, that oceans are not on a lot of people's radar screens. And in the press, of so many other important issues, it is sometimes hard to break through. And so the reality that oceans are in trouble and that there is real urgency has not penetrated as far as it needs to go.

It is also the case that I think there are vested interests in sort of current arrangements. Many of the recommendations call for much more comprehensive ways of having different agencies, different departments be able to work together collaboratively and to work toward much more comprehensive integration of ocean decisions. That is always a tough sell.

Ms. LUBCHENCO. I believe that we are making some good, significant progress, but there is just a lot more to be done.

The CHAIRMAN. Can we just go down and explain—each one of you give us one example in your opinion of what happens to the ocean that affects those of us who are living on land? I think that kind of will help to dramatize what the storyline is for us if we continue to ignore the oceans as a part of this story.

So we will begin with you, Ms. Spruill. Do you have one example you would like to use?

Ms. SPRUILL. I have a list of examples, Chairman Markey, and I am going to include them in the context of climate change, because I think, you know, that is where we are going to feel the impacts first, and obviously, coastal communities will be influenced.

We are going to see changes in fisheries. There is no doubt about that. Climate change is going to disrupt availability. It is going to raise seafood prices. There are human health considerations. Human health is predicted to decline due to climate change-related causes.

Food and water shortages. We have already seen some of this brought about because of areas affected by drought.

Insurance rates. We are already seeing rates affected because of extreme weather events such as hurricanes.

Our infrastructure needs are only going to increase as sea levels rise. New reports have been released that show that, you know, States are going to need to be spending more money on roads and on homes and on airports, and of course, these coastal communities are going to feel these losses most in the coming decades.

The CHAIRMAN. Dr. Earle, do you have a vivid example of how we are affected?

Ms. EARLE. I think it is important to first understand the basic process and then see how the changes are influencing those processes. So think about every breath you take. Where does the oxygen come from? 20 percent of the atmosphere is oxygen. 80 percent or so is nitrogen. There is just enough carbon dioxide to make the green plants do their thing to produce more oxygen through photosynthesis and, thus, drive the great food chains. That is the way it has been now for many millions of years. It was not always that way; the earth was not always hospitable for the likes of us. I think that is something many people need to put on the balance sheet that what we have today represents the distillation of all preceding history.

Literally, hundreds of millions of years have led us to a planet that works in our favor. There was a time going way back before dinosaurs when there was not 20 percent oxygen in the atmosphere but where today there is. We have the power, the capacity to change that through what we are doing to the engine, the green engine in the ocean as well as on the land that produces that oxygen.

So, first, understand how the system works, and then realize we are really messing that system up. It is also true with the water you drink. People think it comes out of the spigot, water does, or you get it in little bottles when you go to the store. Most of earth's water, 97 percent, is in the ocean. How does it get into the bottles, into your sink, whatever? It goes up into the atmosphere as clouds, mostly from the ocean. Take away the ocean, and you just eliminate the water system. So it is to first understand that and then to realize what we are doing that is disrupting that system.

The CHAIRMAN. Back to you, Dr. Kleypas.

Do you have an example?

Ms. KLEYPAS. I think, to play on what Sylvia said, you know, these ecosystems are not separate. You do not just lose one ecosystem; you are going to have a cascading effect.

The example I had for coral reefs is that they provide the environment where we can have mangroves and seagrass beds. Those are very good fishing areas. So, if we lose coral reefs, we lose a lot of the other ecosystems that are intertwined with that ecosystem.

I agree with you. It is hard to explain to someone who has lived in Kansas his entire life who maybe has never seen the ocean in order to really make those links. That is where we fail, in the education. If we lose our economies and our coastal regions, which really depend on the oceans, we are going to affect all of the cities in the U.S. and elsewhere. It is hard to imagine that economic impacts on the coast are not going to permeate the rest of the economy.

The CHAIRMAN. Dr. Lubchenco, do you have anything to add?

Ms. LUBCHENCO. When I was on the Pew Oceans Committee, Mr. Chairman, we were told something that I actually had not thought about, and that was that half of America lives on the coasts. The other half goes there to play. I think that that is a nice touchstone.

As the Pew Oceans Commission moved around from one city to another, to another, all along the coastal margins, and also in the heartland, I asked Americans exactly the question that you posed to us: What do you want from oceans? What do you care about oceans? Why should we be thinking about changing anything?

What I heard from them were five things. It boiled down to five things: Americans told us they wanted safe seafood, healthy seafood, number 1; number 2, clean beaches; number 3, abundant wildlife; number 4, stable fisheries with no more of this boom and bust and closures; and fifth, vibrant coastal communities.

Now, I think that is a very nice summary and synthesis of the way Americans think about oceans, and I think that they truly understand that they appreciate them; they want these things. What they do not understand is that all of those things depend on healthy, productive and resilient ecosystems, and that is not what we are seeing now. We are seeing serious degradation and disruption and depletion. Climate change is going to exacerbate that very, very seriously.

The CHAIRMAN. Well, let me ask you this then. Now you have outlined the problem, each one of you. Let us talk about solutions.

Do any of you have an example that you would like to give us of something that is happening that is very positive that you can point to that would not have been happening 10 years ago? In giving that answer, are you optimistic that we can build on your example to find a comprehensive solution to the problem?

Let me go back through you again, Dr. Earle.

Ms. EARLE. I think one of the greatest causes for hope is our expanding level of communication, that any little kid can look at the world through the eyes of an astronaut now. Hold the world in your hands when you pull up Google Earth, for heaven's sake. There it is, the whole world. You can spin it around. You can see your backyard. You can see your neighbor's backyard.

The CHAIRMAN. Be careful.

Ms. EARLE. Uh-huh. Maybe someday, before long, you will be able to take dives in the ocean and will be able to see what is going on in the ocean, not only to look at the blue blob that is now the surface but to be able to actually see what is actually going on below—the good news and the bad news. I think that is not only good for kids; I think that is good for all of us to be able to have new ways to see how we are connected to the rest. I am optimistic, in part, because there is a growing concern that people—kids and all of us—are increasingly detached from nature, and there is some effort to do something about that—the last child in the woods, no child left inside, these initiatives.

The CHAIRMAN. Beautiful.

Ms. EARLE. While you learn your A, B, Cs and your 1, 2, 3s, learn that you are connected to nature and that the ocean dominates nature. Those things are beginning to happen. We need to do much more to accelerate those things.

The CHAIRMAN. Dr. Lubchenco.

Ms. LUBCHENCO. Mr. Chairman, I had the pleasure of serving on the Oregon Governor's Advisory Group, the Citizens' Advisory Group on Global Warming, which began as a group of citizens who did not know a lot about the problem. In the process of our deliberations, they learned about them and came to make some very strong, unanimous recommendations to the governor, many of which have been adopted. Others are currently being developed. Those essentially will put Oregon on a path to very significantly reduce our greenhouse gas emissions, to slow the rated growth—to cap that—and then finally to return to 1990 levels. That action of one State has been mirrored by many other States, including yours. States working together along the West Coast and in New England have been making very significant progress in drawing attention to the problem and are beginning to address it in very serious ways. I get hope from that. I believe that now it is Congress' turn to act in kind and to listen to what the States have been saying and to do for the rest of the country what these States have begun to do and to take it even further.

The reason that I draw hope from all of these issues is partly the knowledge that social systems can often change very, very rapidly.

We have seen that in attitudes toward drunk driving, towards smoking, towards women's suffrage, towards civil rights issues. So we know that it is possible to have very, very rapid change. It is my hope that we are getting closer and closer and that Congress will show very real leadership in bringing to us the tipping point and in having some very meaningful actions to put us on the right path.

The CHAIRMAN. Dr. Kleypas.

Ms. KLEYPAS. I make a habit when I am traveling on planes and putting all of that extra CO_2 in the atmosphere to interview the people next to me about what they know about climate change and including ocean acidification. I have been astounded in the last year—I would say the last year, maybe two—at how much people know. Now, this is somewhat of an elite group. These are people who fly planes. What I have noticed is so many people are becoming more aware, and they are no longer arguing with me that is this really happening. For a long time, I got the question: Is this really happening? Now I am hearing the question: What can we do?

So people are hungry for solutions. They are hungry for choices. They are willing to sacrifice. I am just seeing this momentum, and it is time to sort of seize that and to do what Jane was saying. You know, the States have become leaders in this issue. If the U.S. becomes a leader in this issue and finds real solutions either technologically or through invoking social change, then the rest of the world will follow. We have been a leader for so long.

The CHAIRMAN. Thank you.

Ms. Spruill.

Ms. SPRUILL. Well, at the risk of stating the obvious, Mr. Chairman, I, actually, think this hearing is a bright spot in that the dots that are being connected like this between ocean and climate change would not have happened even 5 years ago. I would agree with my panelists that this level of awareness brought about by the urgency of climate change is creating a formula that we have not had before, and we need to seize on that opportunity.

I am actually hopeful about coral reefs, and I want to bring it back to that in this year of the reef. I think there is some hope even in the face of this dire news we have heard today. If we act divisively now, we can save some of those reefs that still remain. I think certainly emerging science is showing us that if we can protect the integrity and the resiliency of these systems they should be able to withstand some of these climate change stresses that we cannot yet anticipate, but we have to act now.

The CHAIRMAN. So let us get here at the end of the hearing a 1-minute summation from each of you as to what you want us to remember about the oceans, about ocean policy, about the responsibility of the United States Government to be the leader in the world to protect it and to have a leadership role that commands the respect of the rest of the world when we ask them to work with us on these issues.

Let us go in the opposite order of the opening statements. So we will start with you, Ms. Spruill, if we may, in giving us your concluding 1-minute.

Ms. SPRUILL. Thank you, Chairman Markey.

I think, as the policy organization represented at the table, I am going to probably summarize with some brass tax and restate that there is a lot that we can already do that is already in the pipeline to move forward on some of these problems we have talked about today.

First, every climate change bill should support adaptation strategies. Mitigation alone is not going to solve this problem. We need to take on both the cure and the recovery simultaneously. You know, these adaptation strategies could be and, actually, should be paid for by funding from the auction of carbon allowances, so there is a mechanism there.

Secondly, this Congress should pass the three bills that I outlined previously—Oceans 21, the Coral Reef Conservation Act and the National Marine Sanctuaries Act. Oceans 21 is successfully out of the subcommittee, and it would be a major step forward in providing this comprehensive ocean management scheme that we have talked about.

Then lastly, do no harm. I think that we need to be researching some of these technological solutions.

The CHAIRMAN. Thank you.

Dr. Kleypas.

Ms. KLEYPAS. Well, first of all, I think you guys have gotten the point that the oceans are in trouble and that we really need to act rapidly. We cannot afford a doubling of CO_2 from preindustrial levels in the atmosphere. I really stress that we try to keep it below that.

The hopeful note is that we know that warming has some momentum and that, even if we cap carbon dioxide in the atmosphere, we still will have increased warming. With ocean acidification, if we can stop atmospheric CO_2 concentrations, that will stop the ocean acidification process. If we can remove CO_2 from the atmosphere, it reverses the situation. So it is a fixable problem.

We also talk a lot about the importance of ocean ecosystems to our economies. You know, we are always asked to put a dollar value on all of the things that the oceans offer to us, but there is something we are missing here. That is the aesthetic quality of the oceans. We talk about so many of these ecosystems being rain forests of the sea and so forth. I think we cannot forget that. That is something we need to leave for future generations. If anything sticks in your mind, let it be one of my favorite quotes from Jacques Cousteau, which is “People protect what they love. All of you who love the sea, please help us protect her.” So I would ask you to help us protect the oceans.

The CHAIRMAN. Thank you, Doctor.

Dr. Lubchenco.

Ms. LUBCHENCO. I guess I would highlight four quick things.

I truly believe we are at a crossroads right now. The choice that we have to make is between the path that we are on, which has been called by one scientist, Jeremy Jackson, the slippery slope to slime, which is the direction that oceans are headed in now due to all of the threats, including climate change. The other path is what I like to think of as the mutiny for the bounty. I think that we really are at a crossroads, and we need to understand that and need to have the courage to choose the right thing because it is in our interest to do so.

The second thing I would highlight is that we need to think about adaptation differently. It is not just the adaptation of human systems, but we need to understand how to create the conditions for wildlife to adapt to the changes that are inevitable. That means reducing other stresses—managing fisheries very conservatively, eliminating destructive fishing gear, reducing the flow of nutrients and chemical pollutants to the coasts, protecting habitats as much as possible.

It means creating networks of no-take Marine reserves and protected areas so that the raw material so as much genetic diversity and as many species as possible have the best chance to adapt to changes that are inevitable. So expanding the way we think about adaptation.

Thirdly, I would emphasize the importance of significantly increasing the funding for scientific monitoring and research. It is woefully inadequate for us to understand and to better advise how to do this adaptation, how to do many of the things that lie ahead.

Fourthly, I would suggest a much more comprehensive understanding of oceans, of the management of oceans through mechanisms such as those in the Oceans 21 bill, but also educating citizens is vitally important.

The CHAIRMAN. Thank you, Doctor.

Dr. Earle.

Ms. EARLE. Well, first, I want to wholeheartedly endorse all of the above. Well said.

I will add only a few little additional comments, that we have a chance to protect what remains of all preceding history that still exists in the wild places on the planet. The United States took the lead going back to the early part of the 20th century. Some say the best idea America ever had was the national park system, an idea that is now being adopted in some measure in the sea. Although, there is more of an attitude of managing instead of protecting areas in the sea. There are some 4,000 worldwide places that are known as marine-protected areas, but there is not full protection for the wildlife that is there. We can do a much better job of taking care of our own, exclusive economic zone, an area that exceeds the size of the rest of the United States put together. We have a chance to do something really bold in our own waters.

Another thing to do is to take a leadership role. Others followed the example back in the early part of the 20th century. Here we are at the early part of the 21st. What we could do is to take a role through encouraging actions on the part of other nations to look at the high seas—the 64 percent of the ocean that is beyond national jurisdictions—and to encourage through treaties, through partnerships, through our own example, to look at the Arctic and to the Antarctic.

In the Antarctic 50 years ago, a treaty was put into place, and we were among the primary instigators of that treaty to protect and to forestall the development and the destruction in many ways of that distillation of all preceding history. There is a chance right now to do something like that for the Arctic before the frozen goose is cooked, if you will. We have a chance to do something in the Arctic now, but if we wait much longer in terms of asserting ourselves as leaders and in working with others to show the advantage of protection exceeds by far the advantage of short-term exploitation, this is the moment. I think you have heard it recently from all of us. This is a moment in time when, as never before, we recognize we have got a problem. Maybe, as never again, we can do something about it.

The CHAIRMAN. Beautiful. Thank you, Dr. Earle.

Now, while you were each giving your concluding statements to the committee, unfortunately, Congressman Emanuel Cleaver from the State of Missouri, arrived. I will now recognize him for a statement or for a round of questions, whatever is his choosing.

Mr. CLEAVER. I apologize for being late.

This is certainly a panel that I wanted to hear, and your written comments are along the lines of what, I think, is needed for our country. I was thrown into some panic over the weekend when I read about the shark attack in San Diego. Being from Kansas City, Missouri—and I am a United Methodist pastor—Satchel Paige's family were members of our church. In fact, I eulogized the great Satchel Paige.

Satchel once told me that he and one of his teammates were out fishing. As they were sitting there on the bank, fishing, a water moccasin came out of the water, and his teammate grabbed a huge brick to kill it. Satchel said to him, no, we are not going to kill him because we came into his house. If he comes into our house, that is a different story, but when we are in his house, we do not kill him.

So my fear every time I hear about a shark bite is that it feeds—pardon the pun—the men and women who would suggest that, you know, the best white shark is a dead white shark, so they can do this aimless killing of these fantastic animals without regard to the fact that the shark would never go into 7-Eleven to kill anyone and that, you know, you would have to come into his house. So I am very concerned about that.

As I am reading that, I am driving by last evening here in Washington—seafood restaurant after seafood restaurant after seafood restaurant. I am deeply concerned about the overfishing in our oceans, and I think we ought to try to do more than just condemn it. At some point, we need to move legislatively and, in some instances, maybe even militarily to prevent overfishing.

I do not want to delay you. You know, you came here today and provided fantastic testimony, and I hope that in the days, months and years to come that you will continue to be resources for those of us who believe that the ocean is the key to our survival on this little ball that circles the sun. I am not at all sure that the ocean receives the respect that it should from those of us who depend on it, even those who depend on it and do not know it.

Thank you, Mr. Chairman.

The CHAIRMAN. I thank the gentleman from Missouri. He reminds us again of what a powerful combination a minister can be when talking about moral issues that actually come into the political realm, which is this responsibility that we have to protect the planet.

We thank each of you for testifying here today. The planet is running a fever. There are no hospitals for sick planets. We have to engage in preventative care in order to avoid catastrophic consequences. That is our opportunity, our responsibility.

Our most important Supreme Court decision regarding the environment in history was in Massachusetts versus EPA just 1 year ago, in April of 2007. It ruled that the EPA had a responsibility to make a determination as to whether or not CO_2 was endangering the planet. Massachusetts relied upon, in its argument, the danger already existing to the coastline of Massachusetts. The Supreme Court ruled that the EPA, as a result, has a responsibility to make a decision, which they have yet to do 1 year later.

So your testimony helps to, once again, dramatize how important the oceans are 1 year after Massachusetts versus EPA, Massachusetts' trying to protect itself against what is happening to its coastline and to every coastline everywhere on the whole planet. You are all incredibly important national and international leaders on these issues. This was one of the most important hearings that we have had.

Speaker Pelosi has only created one new committee during her 2 years as Speaker, and that is this Committee on Global Warming. I think that if, for no other reason, the creation of this committee is valuable because we had this hearing today with the witnesses that we have had testify before us. We thank you all.

With that, this hearing is adjourned.

[Whereupon, at 2:58 p.m., the committee was adjourned.]

THE SELECT COMMITTEE ON
ENERGY INDEPENDENCE AND GLOBAL WARMING

Dear Dr. Kleypas:
Following your appearance in front of the Select Committee on Energy Independence and Global Warming, members of the committee submitted additional questions for your attention. I have attached the document with those questions to this email. Please respond at your earliest convenience, or within 2 weeks. Responses may be submitted in electronic form, at aliya.brodsky@mail.house.gov. Please call with any questions or concerns.

Thank you,
Ali Brodsky

Ali Brodsky
Chief Clerk
Select Committee on Energy Independence and Global Warming
(202)225-4012
Aliya.Brodsky@mail.house.gov

June 21, 2008

Dear Mr. Brodsky:

I thank the Select Committee for their interest in this issue and am happy to provide you with my responses. I have tried to address all of your questions, although some were outside my professional expertise. If you have any questions or need for clarification, please don't hesitate to contact me.

All the best,

JKleypas

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1. **Do you support offshore wind turbines? What reservations do you have regarding the development of offshore turbines? Where does the most promise lie with respect to placement of wind turbines offshore?**

I am not an expert on alternative energy sources, and can only provide the principles by which I would evaluate their contribution toward solving the problem of increasing carbon dioxide (CO_2) levels in the atmosphere. While I encourage the development of alternative energy sources, particularly those such as offshore wind turbines that do not add to the CO_2 burden in the atmosphere, there is always some degree of trade-off with other concerns. Wind turbines are sometimes aesthetically displeasing, and if improperly placed, could be harmful to certain bird populations. I feel that with proper considerations of these types of concerns, offshore wind turbines would be a viable component of a suite of alternative energy solutions.

2. **What is your opinion of tidal power? Do you think tidal power can be developed with minimal impact on the oceans?**

Similar to the above question, I am not an expert on alternative energy sources, including the potential impacts of tidal power. I do not feel qualified to answer this question beyond the guiding principles stated in my answer to question #1.

3. **What are your thoughts regarding "plankton blooms" and projects that would develop plankton to sequester carbon? Do you support carbon offset projects that occur in the ocean?**

I assume that your use of the term "plankton blooms" refers to large-scale ocean iron fertilization (OIF) in certain ocean environments that would enhance phytoplankton production and speed up the ability of oceanic biosphere to sequester carbon from the atmosphere. While I do not work in this field directly, I have followed the scientific assessments of the usefulness of these kinds of projects. At this stage, there remain some important concerns about iron fertilization in the oceans, including:

(1) Does it effectively fulfill its stated goal to sequester carbon from the atmosphere (in terms of how much carbon, and for how long it remains sequestered)? There is growing evidence that the amount of carbon stored in the deep ocean is too low, and does not remain in the ocean for a long enough time to be an effective carbon sequestration process.

(2) What are the impacts of iron fertilization on marine ecosystems (for example, changes in the species composition of the phytoplankton communities may produce undesirable effects, such as an increase in species that cause harmful algal blooms, or changes in oxygen levels and other aspects of biogeochemical cycling, etc)?

A recent group of scientists that are experts in the ocean carbon cycle, including many who have participated in iron fertilization experiments, have cautioned against using iron-fertilization as a carbon sequestration pathway until "there is better demonstration that OIF effectively removes

CO_2, retains that carbon in the ocean for a quantifiable amount of time, and has acceptable and predictable environmental impacts." (Buesseler et al. 2008).

In summary, despite the fact that the surface oceans are already sequestering carbon dioxide from the atmosphere and that this is causing ocean acidification, at this time I do not support carbon offset projects of this nature because the risk for increasing impacts to the surface ocean – where the abundance of ocean life resides – remains too high.

4. **The United States already has some pretty strict anti-dumping laws and tight restrictions protecting our water resources. What countries could do most significantly improve their current water pollution policies? How can the United States Congress work to encourage those countries to take tangible steps to get cleaner water?**

This is a good question but it is outside my area of expertise. I hope that one of the other witnesses on the panel can provide this information for you.

5. **Given that you consider current CO2 emissions to be the greatest threat to our oceans, would you agree that carbon free energy such as nuclear power should be part of a diverse portfolio of power for the United States?**

I do consider our current pathway of increasing CO_2 emissions to be the greatest threat to our oceans, because of impacts associated with not only climate change, but also ocean acidification. I agree that the United States would benefit through the development of a diverse portfolio of energy sources that will reduce CO_2 emissions. As I have answered in questions 1 and 2 (relating to the alternative energy sources of wind and tidal energy), I support such energy options, including the use of nuclear power, as long as the planning for these alternatives properly take into account other concerns related to environmental risks.

6. **How sure are we about the chemistry of ocean acidification? Is there debate on this point?**

Scientific understanding of the chemistry of ocean acidification is well established. As far as I know, there is no debate about the causes or extent of ocean acidification in the ocean.

7. **Given that drastic reductions in carbon emissions are not going to happen overnight, can you talk more about the steps that we can take now to help marine ecosystems be more resilient in the face of climate change? For example, how might we change our approach to coastal zone management?**

The obvious way to increase the resilience of marine ecosystems to climate change is to reduce the other stressors in their environment, such as overfishing, destructive fishing practices, and pollution. Other ways are to ensure that these ecosystems have adequate potential for recovering if and when they experience significant damage from climate change. In coral reef ecosystems, for example, those reefs that enjoy a reliable source of coral larvae (from within its own environs or from another reef upstream) are more likely to "reseed" and recover. Coastal zone management that includes designing marine reserves with these issues in mind are certainly helpful. Coastal zone management that addresses not just downstream but ocean-end effects of land-based activities can be quite effective in reducing many of the stressors on marine ecosystems.

I must emphasize here that these actions do not replace the need to reduce CO_2 emissions; but they will buy time as we find ways to move to cleaner energy regimes. Even without the threat of carbon dioxide emissions, increasing coastal zone management in ways that restores and protects marine and coastal ecosystems is simply a good idea, as these resources provide valuable services to our society.

8. Carbon dioxide concentration is not the only variable in controlling ocean acidification. What other factors need to be considered?

I am not completely clear on this question, and it can be answered in several ways. First, increasing carbon dioxide concentration in the atmosphere is the main force that is driving ocean acidification today. To some extent, ocean warming has a secondary effect. Because warmer water can hold less carbon dioxide than cold water, the global warming of the surface ocean reduces the ability of he ocean to hold as much carbon dioxide, and hence, the result is less ocean acidification. The increasing temperature effect reduces ocean acidification by about 10-15%.

Second, carbon dioxide is not the only anthropogenic source of acids to the ocean. A recent paper by Doney et al. (2007) described how other compounds (HNO_3, H_2SO_4, and NH_3) related to fossil fuel burning and agriculture contribute to the lowering of ocean pH. These compounds tend to be rained out of the atmosphere, and can affect coastal areas close to major source regions, primarily in the northern hemisphere. Compared to anthropogenic carbon dioxide, these anthropogenic compounds have only a small effect on ocean pH, but they are important because they are concentrated in coastal waters where marine resources are so important.

9. How do your future ocean acidification scenarios and time lines related to the rates of increasing atmospheric carbon dioxide concentrations compare to the actual observed rates of carbon dioxide concentration increase?

The observed rates of ocean acidification, based on observations from several time-series stations and the repeat hydrography program, indicate that ocean acidification is proceeding at a rate and magnitude that is predicted by the models.

10. Is the current distribution of corals and coral reefs more limited by cold water or warm water? If oceans warm, won't corals expand into waters that were previously too cold? Are there any regions of the world that are too warm for corals?

Most corals are limited to the tropics because of their low tolerance for cold water. We expect that, if the annual minimum sea surface temperatures increase, then some coral species will colonize waters that were previously too cold. One example of this colonization to new areas has been documented along the west coast of Florida (Precht and Aronson, 2000). However, coral reefs and the ecosystems they support are not simply a collection of corals, they are structures built by corals and other calcium carbonate organisms. If these organisms produce more calcium carbonate than is lost through erosion and dissolution of the carbonate, then a reef will grow; otherwise, no reef will develop. Corals can occur at higher latitudes, but they do not build reefs; this is because the organisms either grow more slowly, or the calcium carbonate material dissolves more readily. With ocean acidification, we expect both the production of calcium carbonate to decrease, and its dissolution to increase. Therefore, climate change may allow corals to migrate to higher latitudes, but ocean acidification will limit reef development to lower latitudes.

We do not know of any specific regions where waters have been historically too warm for corals to grow, although at the local scale there are certainly some enclosed areas where temperatures are prohibitive to coral growth. Today, there are some regions that have recently warmed to temperatures that exceed the upper thermal tolerance of corals, leading to coral bleaching. These recent coral bleaching episodes have led to the destruction of around 10% of the world's coral reefs.

11. How did corals and coral reefs survive the rapid and large climate changes that have characterized that past 4 or 5 ice ages?

Paleoclimate studies of coral reef environments during the last 4-5 ice ages indicate that climate changes were neither as extreme nor as rapid as is occurring today. In particular, ocean temperatures in some locations may have varied by as much as 4°C, but would have increased much more gradually (over thousands of years, rather than decades), allowing corals and ecosystems ample time to adapt. Changes in ocean pH during he glacial cycles have been small for two reasons: first, the change in atmospheric carbon dioxide concentration remained between about 200 and 300 ppmv; and second, the slow rate of that change would have allowed various processes (such as weathering of rocks or ocean circulation) to act to keep the ocean chemistry in balance.

The main environmental change that would have affected coral reefs was sea level rise. For example, sea level rose some 120 m between the time of the last ice age to the present. The ability of coral reef ecosystems to produce such an excess of calcium carbonate allowed them to grow upward as sea level rose and to stay within the well-lit waters that they need. There is evidence that some coral reefs could not grow quickly enough to keep pace with this rapid sea level rise (these are often referred to as "drowned reefs"), but many did, forming the very reefs that we have today. One might think of coral reefs as an ecosystem that has "adapted" to sea level fluctuations. However they are not adapted to rapid temperature increases or to ocean acidification.

12. What percentage of the world's distribution of coral reefs are located along the U.S. coasts?

I believe that approximately 5% of the world's coral reefs exist in waters of the U.S. and its territories.

13. Aren't there are whole lot of factors that can cause coral reef decline? Factors such as pollution, sedimentation, over fishing, boating and shipping injuries—that are often the case of overdevelopment and poor land use planning and oversight?

Yes, coral reefs experience multiple stressors. Much progress has been made in reducing damage from navigational problems (ship grounding, anchoring, etc.), and in some areas, in reducing over fishing and land-based sources of pollution. Many believe that the ability of the Great Barrier Reef to recover from two major coral bleaching episodes is due to reduction of these other stressors through the efforts of the Great Barrier Reef Marine Park Authority. However, some coral reefs that have direct (non-climate) stressors have been completely destroyed by coral bleaching.

14. Some researchers have focused on the El Nino Southern Oscillation (ENSO) as a threat to corals. Isn't ENSO a naturally-occurring event that has been documented for decades? If so, why is the threat considered so critical now?

Yes, ENSO is a naturally-occurring event that has been documented for decades and probably for thousands of years (based largely on temperature records obtained from coral skeletons). ENSO events are considered a major threat to coral reefs now because:

- Climatic changes in temperature, wind patterns, cloud cover, circulation patterns, etc., can create conditions that are conducive to coral bleaching events. These conditions are further heightened by the background increase in sea surface temperature due to the greenhouse effect.
- While mass coral bleaching events are increasing in general, regardless of whether El Niño conditions exist, coral bleaching during ENSO years are more widespread and deadly. During the 1997–1998 ENSO, for example, an estimated 16% of the world's coral reefs were extensively damaged by bleaching (Wilkinson 2000).
- The ENSO events in 1982–83 and 1997–98 had major impacts on coral reefs worldwide. These two events were some of the strongest events on record. Models show that El Niño events will continue in a future warmer climate (i.e. they won't go away), but their future amplitudes and frequencies may become much less predictable.

15. Because coral reefs are such vital ecosystems, partially because they provide hiding places for other animals, can their functions be created artificially?

Replacing coral reefs with artificial structures is like replacing a rainforest with artificial trees. Yes, some birds may sit in the trees (even if there is no food for them), but the services the rainforest provides to the functioning on this planet will be lost.

The ecosystem services provided by coral reefs are often not obvious but they are many. Reefs provide not only spatial habitat for fish, but nutrition for those fish, cycling of nutrients, buffering of seawater chemistry, coastal protection (reefs are much better than man-made structures), sand production that maintains beaches and supports other important habitats such as seagrass beds and mangroves, biodiversity (which in turn supports ecosystem stability and holds promise for the discovery of many medicinal compounds), etc.

The term 'artificial reef' may be misleading in that it implies that coral reefs can be created artificially. In short, a structure can be artificially created, and at times this can stimulate natural colonization of corals and reef growth, but the structure alone does not replace the many coral reef functions.

16. Aside from the broad policy of climate change that is currently being debated in Congress, what programs can immediately assist in preservation of coral reefs?

There are some 10-15 bills being considered in Congress right now that would improve our ability to preserve coral reefs, either by establishing greater protection of our oceans, coral reef ecosystems, etc., as well as improving coastal zone management. As your questions bear out, there are many ways that Congress can take action to improve the overall quality of the ocean environment. A few of these bills are listed below:

HR21	OCEANS 21
S1581/HR4174	Federal Ocean Acidification Research and Monitoring Act
HR1205/S1580	Coral Reef Conservation Amendments Act
S1579	Coastal Zone Enhancement Reauthorization Act
HR1907/S1142	Coastal and Estuarine Land Protection Act
S2211	Global Warming and Acidification Coastal and Ocean Resiliency Act

17. What federal research do you believe should be placed at the top of the priority list as we try to learn more about and monitor coral reef issues?

In order to improve our ability to preserve coral reef ecosystems, it is most important to build on the research within existing federal research that was established under the Coral Reef Conservation Act. It is also vital that we establish a strong federal research program on the emerging issue of ocean acidification (Federal Ocean Acidification Research and Monitoring Act), as this newly identified consequence of increasing atmospheric CO_2 threatens not just coral reef ecosystems, but the vast marine biological realm.

18. Is there any sign that coral reef organisms can adapt to the changes in acidification that you described in your testimony?

No, not yet. Adaptation can be thought of in two ways here. The organisms can adapt either by: (1) diverting energy resources from other physiological functions to maintain coral growth, or (2) allowing calcification rates to decline and adapting in ways to deal with the skeletal loss (living more cryptically to avoid predation, growing more slowly, growing in areas away from damaging currents, etc.). The former has not been observed, so the latter is likely the only alternative. We do not know how corals will adapt to having less dense or slower growing skeletons. In response to your question #19 below, I discuss the field evidence that corals do not occur in nature where CO_2 concentrations are elevated.

19. The March 30, 2007 issue of *Science* contains a research article that shows calcifying coral species, in the absence of considerations supporting skeleton building, maintained basic life functions as skeleton-less forms and returned to skeleton building when conditions return to normal. Have you looked at this issue and does it provide some insight into the possible survival of corals in the long-term?

Yes, I have looked into this issue, and I briefly discussed this in my written testimony:

> "At some point growth is slowed to the point where a marine animal may no longer be able to maintain its skeleton, and the skeletal material will dissolve. This has been demonstrated in both mollusks and corals. A dramatic example of this is the work by Fine and Tchernov (2007) in which two species of corals that were cultured in highly acidified water (equivalent to atmospheric CO_2 levels around 1200 ppmv) completely lost their skeletons; then re-grew them after being returned to seawater of normal pH. These species may not be typical of most reef-building corals, and indeed appear to be closely related to those few species that survived the Cretaceous-Tertiary extinction (65 million years ago) and later gave rise to modern-day corals (over time spans of millions of years). Nonetheless, the experiment highlighted three important points: (1) coral calcification rates can essentially stop or reverse in lowered ocean pH conditions; (2) the naked, anemone-like coral polyps remained healthy, but the fitness of the organisms overall would change because of the loss of the protective skeleton; and (3) reversing the acidification process results in a reversal of the skeletal loss."

It is worth noting that another recent paper that has looked at the distributions of organisms (both calcifying and non-calcifying) near a natural CO_2 vent in shallow waters of the Mediterranean illustrated that calcifying organisms (namely corals and coralline algae) disappeared as seawater pH decreased near the vent (Hall-Spencer et al. 2008); that is, the corals did not exhibit an ability to persist in the lower pH waters.

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