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EFFECTS OF CLIMATE CHANGE ON MARINE AND COASTAL ECOSYSTEMS IN WASHINGTON STATE

FIELD HEARING

BEFORE THE

SUBCOMMITTEE ON OCEANS, ATMOSPHERE, FISHERIES, AND COAST GUARD

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED TENTH CONGRESS

SECOND SESSION

MAY 27, 2008

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EFFECTS OF CLIMATE CHANGE ON MARINE AND COASTAL ECOSYSTEMS IN WASHINGTON STATE

TUESDAY, MAY 27, 2008

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

The Subcommittee met, pursuant to notice, at 10 a.m. at the Seattle Aquarium, 1483 Alaskan Way, Seattle, Washington, Hon. Maria Cantwell, Chairman of the Subcommittee, presiding.

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

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

We are here today in Seattle to do a field hearing on the effect of climate change on marine coastal ecosystems in Washington State. So thank you all very much for being here, and my thanks to the Seattle Aquarium for their hospitality.

Today's hearing, as you can see, is the perfect venue for what we are going to be talking about, and each year, this aquarium gives hundreds of thousands of visitors a window into Washington's underwater wildlife. And so, today, we get to be here beneath that to see and understand what we need to be doing, more importantly, on the issue of climate change.

Over the last 200 years, the oceans have absorbed nearly half of the CO_2 that basically has been emitted through combustion of fossil fuels. With the ocean's absorption of CO_2, it reacts with seawater to form carbonic acid that ends up making our oceans more acidic.

What are those impacts? Well, we are going to hear in more detail from the panelists today. But the impacts are to our salmon and other fisheries, the threat to the entire marine food chain, the increased water temperatures bring about new invasive species. The spread of dead zones because of the lack of oxygen in the water are a threat to all of our marine life, and obviously, the warming of our oceans portend to make a rise in sea levels that could have devastating impacts on lowlands and wetlands here in Washington State and around the Nation.

So it is very important that we clearly understand the carbon emission impacts, what will happen in the marine environment, and the fact that they could be all too devastating here in Puget Sound. While this may not be easy to always understand the physical impacts, the warning signals are there, and we need to examine them, more importantly.

Fortunately, we know that we can have an impact on climate change, and when we return to the U.S. Senate next week, we will be having a Senate discussion on the climate change bill on the floor of the U.S. Senate. We hope to pass that legislation over to the House of Representatives for their action.

And just recently, last year, the Energy Independence and Security Act was passed, which set a new standard for the fuel efficiency of automobiles, more efficiency in lighting and appliances, and to make a mandate on alternative fuels based on a nonfood source.

All these things together by 2030 would help us displace the equivalent of one-third of our foreign oil needs, save American consumers a half trillion dollars in energy costs, and reduce our Nation's carbon dioxide emissions by that same amount.

So we know we have lots of work to do. And we know that landmark legislation is needed. The reality is, though, our government at this point in time is ill-equipped to deal with the consequences of climate change. That is why I was proud to author the Climate Change Adaptation Act bill that would direct the Federal Government to start planning for climate change and its impact on marine resources. This bill has been passed out of the Commerce Committee and is now waiting for action on the Senate floor.

We also have been working on the Federal Ocean Acidification Research and Monitoring Act legislation that was sponsored by my colleague Senator Frank Lautenberg from New Jersey and would establish a much-needed research program on ocean acidification.

The time now is for the Federal Government to take the right steps in the right direction. I believe that these two bills are important vehicles for us to move forward on the right path in helping the health of our oceans.

Planning for the future isn't just common sense. It is responsible government, and this hearing is an important step in the input that we need to continue to take those important steps of protecting our oceans and certainly in protecting Puget Sound.

So I want to thank my colleague, Congressman Inslee, who has joined me from the House of Representatives today for this Senate field hearing. He is a member of the House Energy and Commerce Committee and the House Natural Resources Committee and has spent many hours talking and hearing about these issues and certainly joins me in an effort to try to better understand the impact of CO_2 on our oceans and what we need to do to protect marine life in the Puget Sound area.

So, Congressman, we thank you for being here.

STATEMENT OF HON. JAY INSLEE, U.S. REPRESENTATIVE FROM WASHINGTON

Representative INSLEE. Thank you. Thank you, Senator.

I hope people know that we have an absolute champion in the U.S. Senate on the energy issues that are necessary to stop this depletion of the oceans, and that is Senator Cantwell. She most recently has been a champion to adopt a package for renewable tax credits for clean energy sources that could help solve this problem, and she has been doing great work in the U.S. Senate.

My comments, I wanted to share with you two memories—one piece of extremely disturbing news and one piece of good news. First, the memories.

My dad was the biology teacher at Garfield High School, and maybe even taught Jimi Hendrix biology, I am not sure. But my earliest memories are being at Carkeek Park and my dad showing me the sea lion from the shorelines of Carkeek Park. It was an absolute thrill for me at age, I don't know, 4 or 5 to go down there and see that lion.

That life has diminished now at Carkeek Park. What I saw at Carkeek Park in 1956 and 1957 isn't there as much as it used to be, and we are in a continuing decline for some of the reasons we will talk about today.

The second memory is a picture, a movie. My favorite movie of my wife is when she was 10 years old catching a salmon right here on Old Kinder Road out at Ray's Boathouse, if anybody is old enough to remember that. The best picture I have ever seen of her. Those are memories that we want our grandkids to have. And those memories today are at risk because of the constellation of issues that we are going to hear about.

Now, here is the problem. We know about sea temperature rising due to climate change. We know about sea level rising due to climate change. We know about wind and wave patterns changing due to climate change. Fairly well known.

But there has been an absolute bomb explode in the scientific community in the last 2 years, and that is the silent assassin of ocean acidification, and that is what I want to focus on today.

In May 1996, we had a doctor named Ken Caldeira from Stanford and some of his colleagues that I invited to the House. And he came and dropped a little bomb in our laps, and that was that even if we could figure out a way to stop the climate from changing and could decrease the CO_2, that all this was going into the oceans and acidifying the oceans 30 percent—30 percent more ocean acidification, 30 percent more of those ions in the ocean than in pre-industrial times.

And he went on to explain about the calcification that occurs where these little tiny zooplankton and pteropods have to take calcium to form a substrate for their life. Probably 40 to 50 percent of the bottom of the food chain is dependent on this, and this is greatly threatened by ocean acidification.

Nothing is more potentially dangerous to humanity than ocean acidification, I believe, as the first big problem that we are going to face, and that is because we receive a significant part of our protein from the ocean. And that is greatly, greatly threatened.

So the good news is, we have some of the world's best scientists today on this panel, that I am very appreciative. But there is no solution to this problem, except reduction of carbon dioxide. That is the only solution to prevent us from essentially depopulating the bottom of the food chain in the oceans.

I also want to say that this is not a problem for tomorrow, and all of this kind of thing, global warming, is a problem for the next several decades. It is a problem today. Almost 80 percent of the coral reefs in our national parks in the Virgin Islands are dead today because of a combination of bleaching associated with water temperature and perhaps ocean acidification. This is a problem today.

But it is a problem that ought to unite us. You know, I hear still some of my colleagues in Congress that are still adopting the posture of the ostrich with their head in the sand when it comes to climate change. They want to say there is some debate about this. Well, fine. But there is no debate about ocean acidification. That carbon dioxide is going into the ocean. No one debates that. This ought to be a unifying theory on this.

Now, we are starting to see some progress. I just want to leave it on a good note. Due to Senator Cantwell's great work in the Senate, we are starting to see some progress. I passed an amendment to the Magnuson reauthorization bill to require study of the ocean acidification. A year or so ago, I sponsored a bill somewhat similar to Cantwell's in the House.

But the real work we need to do is to decarbonize the energy system of America. And when we do that, we will stop the acidification of the ocean, and we will build the largest economic expansion America has seen when we go to solar thermal power, solar photovoltaic power, wind energy, enhanced geothermal power, electric vehicles, energy efficient buildings. And when we do this, this is how we are going to solve this problem. We are going to grow our economy at the same time.

So I am optimistic about doing it, and I want to thank Senator Cantwell for her leadership in being here today.

Senator CANTWELL. Thank you, Congressman Inslee, for working with me on that legislation, including getting the energy tax credits passed so that we can make sure that we have a predictable tax law for renewable energy.

Well, let us welcome our panel here today. Thank you. You are a very distinguished set of guests testifying before this Senate subcommittee. We appreciate you being here today.

Joining us is Dr. Chris Sabine, Oceanographer with the National Oceanic and Atmospheric Administration at the Pacific Marine Environmental Laboratory. Dr. Sabine is an expert on ocean acidification and the author of a recent article, "Evidence for Upwelling of Corrosive 'Acidified' Water onto the Continental Shelf." Welcome. Thank you for being here.

Dr. Terrie Klinger, University of Washington, Associate Professor at the School of Marine Affairs. Dr. Klinger is a marine biologist who looks at the effects on the environment of stressors, including climate change on marine ecosystems.

Dr. Edward Miles, also of the University of Washington, from the School of Marine Affairs. Thank you very much for being here. Dr. Miles is the Co-Chair of the Climate Impacts Group. He performs fundamental research related to the implications of climate change for national fisheries, natural resources, and economic prospects.

He has served as Chair of the Ocean Policy Committee for the National Academy of Sciences from 1974 to 1979 and has worked with the United Nations UNESCO on development of various policies.

Our next witness will be Dr. Jeff Koenings, the Director of the Washington Department of Fish and Wildlife. Thank you for being here. I guess it all gets down to you as it relates to the local level here, or I should say at least to the State and local level. And he manages marine resources, land resources, including fisheries. And so, we appreciate you being here and your background in scientific study of water quality and nutrients.

And following him will Brett Bishop, Owner of the Little Skookum Shellfish Growers. Thank you for representing the shellfish growers here today. I know you are going to give support testimony on the impact of a very vibrant industry for us in Washington State and how the changes in climate might impact that industry.

And last, but certainly not least, Kevin Ranker, who is San Juan County Commissioner. And prior to taking office, Mr. Ranker worked for 15 years focusing on coastal and ocean policies being developed with local, national, and international organizations. Mr. Ranker currently serves as a member of Puget Sound Ecosystem Coordination Board.

So thank you all very much for being here. And while this is an official hearing and I am not going to time you, but if you could keep your remarks to 5 or 6 minutes, that would help us in getting questions to you at the end of that time period.

Mr. Sabine, we are going to start with you. And thank you very much for being here today.

STATEMENT OF CHRISTOPHER L. SABINE, Ph.D., PACIFIC MARINE ENVIRONMENTAL LABORATORY, NOAA, U.S. DEPARTMENT OF COMMERCE

Dr. SABINE. Good morning, Madam Chairwoman.

Senator CANTWELL. And you are probably going to have to pull that microphone a little closer to make sure we can hear.

Dr. SABINE. Good morning, Madam Chairwoman. Can you hear me?

Senator CANTWELL. A little closer. The acoustics here might be a little challenging. So——

Dr. SABINE. Good morning, Madam Chairwoman and Congressman Inslee. I am Dr. Christopher Sabine. I am a chemical oceanographer at NOAA's Pacific Marine Environmental Laboratory located here in Seattle. I also serve as an affiliate faculty member of oceanography at the University of Washington and as a senior fellow for the Joint Institute for the Study of Oceans and Atmosphere at the University of Washington. Thank you for inviting me to be a witness at this hearing.

My colleague Dr. Richard Feely and I have conducted several research projects to improve our understanding of climate change and ocean acidification in open ocean and coastal waters, including the West Coast of the United States and the Puget Sound region.

Today, I will focus on just one aspect of that research, the upwelling of Pacific waters onto the continental shelf. The results of this research were published last Thursday in *Sciencexpress*.

Over the last two decades, NOAA and the National Science Foundation have co-sponsored high traffic and chemical surveys of the world's oceans to study the response to rising atmospheric carbon dioxide. These studies have confirmed that the oceans are currently absorbing approximately one-third of the carbon dioxide emissions from human activity.

These studies have also documented chemical changes in seawater resulting from the absorption of this carbon dioxide, which are increasing the acidity of the seawater and lowering its pH, the scale we use to measure acidity.

The decomposition of dead and sinking organisms naturally makes deep ocean waters corrosive to the shells and skeletons of calcium-carbonate creating organisms such as corals, clams, oysters, mussels, sea urchins, and pteropods. The depth at which these shells begins to dissolve is called the carbonate saturation horizon. The ocean uptake of manmade carbon dioxide has caused the saturation horizon to rise toward the surface by as much as 100 to 200 meters since the beginning of the Industrial Revolution.

In the North Pacific, the saturation horizon is naturally between 100 and 400 meters, but is getting shallower at a rate of 1 to 2 meters each and every year. Ocean model projections based on future carbon dioxide emission scenarios have suggested that the saturation horizon could break the surface of the North Pacific within the next 50 to 100 years, exposing living organisms at the ocean surface to corrosive waters.

During the 2004 survey, which went from Japan to San Diego, we noticed that the corrosive waters came very close to the continental shelf of North America. To learn more about this phenomenon, we brought together regional experts such as Debby Ianson from the Institute of Ocean Sciences in Canada, Burke Hales from Oregon State University, and Martin Hernandez-Ayon from the University of Autonoma in Mexico to help us design a survey to run from Queen Charlotte Sound in Canada to the tip of the Baja Peninsula in Mexico, with the goal of evaluating the state of ocean acidification along the continental shelf.

These experts helped us to determine the optimum sampling strategy that we needed to participate on the cruise that was conducted in May and June of 2007, last summer. I do not believe that any of us anticipated the results that we actually found.

Our measurements showed that upwelling along the West Coast of North America is now drawing water from below the saturation horizon and up onto the continental shelf. This upwelling happens during the spring and summer months when winds push surface waters away from the coast and draw carbon dioxide-rich waters from about 150 to 200 meters depth in the open ocean to much shallower depths up on the continental shelf.

In fact, we observed that some of the low pH corrosive waters had actually upwelled all the way to the surface off of Northern California.

Our estimates of manmade carbon dioxide contributions to these waters suggest that prior to the rise in atmospheric carbon dioxide, the saturation horizon was too deep to be reached by coastal upwelling. In other words, this is a relatively recent phenomenon.

Before we started this work, no one considered that the corrosive offshore waters could be affecting shallower coastal ecosystems today. However, our findings represent the first evidence that large sections of the North American continental shelf are already being seasonally impacted by ocean acidification and that shelf organisms are being exposed to corrosive waters even at the surface.

Our research focused on understanding the chemistry and did not directly evaluate biological impacts to these corrosive waters. However, the fact that extensive upwelling occurs all along the West Coast of North America and given the importance of fisheries, particularly shellfish, on the U.S. continental shelf, the potential biological consequences of these new findings need to be assessed immediately.

Where we thought we had another 50 years to figure out the consequences of these corrosive waters reaching the ocean's surface, we are finding that it is happening today right outside our back door.

Thank you again for inviting me to testify, and I will be happy to answer any questions you may have.

[The prepared statement of Dr. Sabine follows:]

PREPARED STATEMENT OF CHRISTOPHER L. SABINE, PH.D., PACIFIC MARINE ENVIRONMENTAL LABORATORY, NOAA, U.S. DEPARTMENT OF COMMERCE

Good morning, Chairman Cantwell and Members of the Subcommittee. Thank you for giving me the opportunity to speak with you today on the effects of climate change on marine and coastal ecosystems in Washington State. My name is Christopher Sabine, I am an Oceanographer at the Pacific Marine Environmental Laboratory of the National Oceanic and Atmospheric Administration (NOAA) in Seattle, Washington.

My research focuses on understanding the global carbon cycle. In particular, my work centers around interpreting inorganic carbon measurements in the oceans. On Thursday, May 22, 2008, my colleagues and I published a paper in *Science Magazine* entitled: "Evidence for Upwelling of Corrosive 'Acidified' Water onto the Continental Shelf."

The absorption of atmospheric carbon dioxide into the ocean lowers the pH of the waters. This so-called ocean acidification could have important consequences for marine ecosystems. In order to better understand the extent of this ocean acidification in coastal waters, we conducted hydrographic surveys from central Canada to northern Mexico. We observed seawater that is undersaturated with respect to aragonite upwelling onto large portions of the continental shelf, reaching depths of approximately 40 to 120 m along most transect lines and all the way to the surface on one transect off northern California. While seasonal upwelling of the undersaturated waters onto the shelf is a natural phenomenon in this region, the ocean uptake of anthropogenic CO_2 has increased the areal extent of the affected area.

The *Science* paper is appended here as the scientific basis of my testimony.

ATTACHMENT

Sciencexpress—Report—22 May 2008

EVIDENCE FOR UPWELLING OF CORROSIVE "ACIDIFIED" WATER ONTO THE CONTINENTAL SHELF

Richard A. Feely,[1] Christopher L. Sabine,[1] J. Martin Hernandez-Ayon,[2] Debby Ianson,[3] Burke Hales[4]

The absorption of atmospheric carbon dioxide into the ocean lowers the pH of the waters. This so-called ocean acidification could have important consequences for marine ecosystems. In order to better understand the extent of this ocean acidification in coastal waters, we conducted hydrographic surveys from central Canada to northern Mexico. We observed seawater that is undersaturated with respect to aragonite upwelling onto large portions of the continental shelf, reaching depths of approximately 40–120 m along most transect lines and all the way to the surface on one transect off northern California. While seasonal upwelling of the undersaturated waters onto the shelf is a natural phenomenon in this region, the ocean uptake of anthropogenic CO_2 has increased the areal extent of the affected area.

Over the past 250 years the release of carbon dioxide (CO_2) from industrial and agricultural activities has resulted in atmospheric CO_2 concentrations that have increased by about 100 parts per million (ppm). The atmospheric concentration of CO_2 is now higher than it has been for at least the last 650,000 years, and is expected to continue to rise at an increasing rate, leading to significant changes in our climate by the end of this century.[1]. Since the beginning of the industrial era, the oceans have absorbed approximately 127 ± 18 billion metric tons of carbon as carbon dioxide from the atmosphere, or about one-third of the anthropogenic carbon emissions released.[2] This process of absorption of anthropogenic CO_2 has benefited humankind by significantly reducing the greenhouse gas levels in the atmosphere and minimizing some of the impacts of global warming. However, the ocean's daily uptake of 30 million metric tons of carbon dioxide is significantly impacting its chemistry and biology. Recent hydrographic surveys and modeling studies have confirmed that the uptake of anthropogenic CO_2 by the oceans has resulted in a lowering of seawater pH by about 0.1 since the beginning of the industrial revolution.[3-7] This phenomenon, which is commonly called "ocean acidification," could affect some of the most fundamental biological and geochemical processes of the sea in the coming decades and could seriously alter the fundamental structure of pelagic and benthic ecosystems.[8]

Estimates of future atmospheric and oceanic carbon dioxide concentrations, based on the Intergovernmental Panel on Climate Change (IPCC) CO_2 emission scenarios and general circulation models, indicate that atmospheric carbon dioxide levels could exceed 500 parts per million (ppm) by the middle of this century, and 800 ppm near the end of the century. This increase would result in a surface water pH decrease of approximately 0.4 pH units, and a corresponding 50 percent decrease in carbonate ion concentration by the end of the century.[5,9] Such rapid changes are likely to negatively impact marine ecosystems, seriously jeopardizing the multifaceted economies that currently depend on them.[10]

The reaction of CO_2 with seawater reduces the availability of carbonate ions that are necessary for calcium carbonate ($CaCO_3$) skeleton and shell formation for a number of marine organisms such as corals, marine plankton, and shellfish. The extent to which the organisms are affected is largely dependent upon the calcium carbonate ($CaCO_3$) saturation state (Ω), which is the product of the concentrations of Ca^{2+} and CO_3^{2-} divided by the apparent stoichiometric solubility product for either aragonite or calcite:

$$\Omega arag = [Ca^{+2}]\,[CO_3^{-2}]/K'sp_{arag} \quad (1)$$

$$\Omega cal = [Ca^{+2}]\,[CO_3^{-2}]/K'sp_{cal} \quad (2)$$

where the calcium concentration is estimated from the salinity, and the carbonate ion concentration is calculated from the dissolved inorganic carbon (DIC) and total alkalinity (TA) measurements.[11] In regions where Ωarag or Ωcal is > 1.0 the formation of shells and skeletons is favored. Below a value of 1.0 the water is corrosive

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[2] Instituto de Investigaciones Oceanologicas. Universidad Autonoma de Baja California. Km. 103 Carr. Tijuana-Ensenada. Ensenada. Baja California. Mexico.

[3] Fisheries and Oceans Canada, Institute of Ocean Science, P.O. Box 6000, Sidney, BC V8L 4B2, Canada.

[4] College of Oceanic and Atmospheric Sciences, Oregon State University, 104 Ocean Admin. Bldg., Corvallis, OR 97331–5503, USA.

and dissolution of pure aragonite and unprotected aragonite shells will begin to occur.[12] Recent studies have demonstrated that in many regions of the ocean the aragonite saturation horizon shoaled as much as 40–200 m as a direct consequence of the uptake of anthropogenic CO_2.[3,5,6] It is shallowest in the northeastern Pacific Ocean, only 100–300 m from the ocean surface, allowing for the transport of undersaturated waters onto the continental shelf during periods of upwelling.

In May and June of 2007, we conducted a North American Carbon Program (NACP) West Coast Cruise on the Research Ship *Wecoma* along the continental shelf of western North America, completing a series of 13 cross-shelf transects from Queen Charlotte Sound, Canada to San Gregorio Baja California Sur, Mexico (Fig. 1). Full water column conductivity-temperature-depth-rosette (CTDR) stations were occupied at specified locations along each transect (Fig. 1). Water samples were collected in modified Niskin-type bottles and analyzed for DIC, TA, oxygen, nutrients and dissolved and particulate organic carbon. Aragonite and calcite saturation, pH_{SW}, and pCO_2 were calculated from the DIC and TA data.[11]

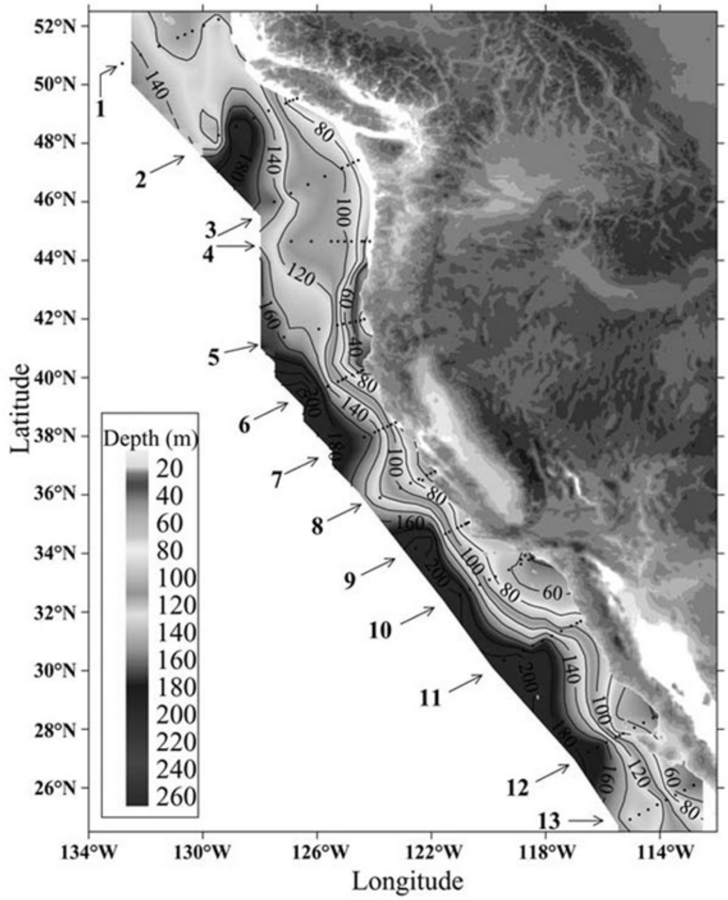

Fig. 1. Distribution of the depths of the undersaturated water (aragonite saturation < 1.0; pH < 7.75) on the continental shelf of western North America from Queen Charlotte Sound, Canada to San Gregorio Baja California Sur, Mexico. On transect lines 5 the corrosive water reaches all the way to the surface in the inshore waters near the coast. The black dots represent station locations.

The central and southern coastal region off western North America is strongly influenced by seasonal upwelling which typically begins in early spring when the Aleutian low pressure system moves to the northwest and the Pacific High moves northward, resulting in a strengthening of the northwesterly winds.[13,14] These winds drive net surface water Ekman transport offshore, which induces the upwelling of CO_2-rich intermediate depth (100–200 m) offshore waters onto the continental shelf. The upwelling lasts until late summer or fall when winter storms return.

During the cruise, various stages and strengths of upwelling were observed from line 2 off central Vancouver Island to line 11 off Baja California, Mexico. We observed recent upwelling on lines 5 and 6 near the Oregon-California border. Coincident with the upwelled waters, we found evidence for undersaturated, low pH seawater in the bottom waters as depicted by Ωarag values < 1.0 and pH values < 7.75. The corrosive waters reached mid-shelf depths of approximately 40–120 m along lines 2–4, and 7–13 (Fig. 1). In the region of the strongest upwelling (line 5), the isolines of Ωarag = 1.0, DIC = 2190 and pH = 7.75 closely followed the 26.2 potential density surface (Fig. 2). This density surface shoaled from a depth of ~150 m in the offshore waters and breached the surface over the shelf near the 100 m bottom contour, approximately 40 km from the coast. This shoaling of the density surfaces and CO_2-rich waters as one approaches land is typical of strong coastal upwelling conditions.[15-18] The surface water pCO_2 on the 26.2 potential density surface was about 850 µatm near the shelfbreak and higher inshore (Fig. 2), possibly enhanced by respiration processes on the shelf.[17] These results indicate that the upwelling process caused the entire water column shoreward of the 50 m bottom contour to become undersaturated with respect to aragonite, a condition that was not predicted to occur in open-ocean surface waters until 2050.[5] On line 6, the next transect south, the undersaturated water was close to the surface at approximately 22 km from the coast. The lowest Ωarag values (< 0.60) observed in the near-bottom waters of the continental shelf corresponded with pH values close to 7.5. Since the calcite saturation horizon is located between 225–400 m in this part of the northeastern Pacific,[19] it is still too deep to shoal onto the continental shelf. Nevertheless, the calcite saturations values drop in the core of the upwelled water (Ωcal < 1.3).

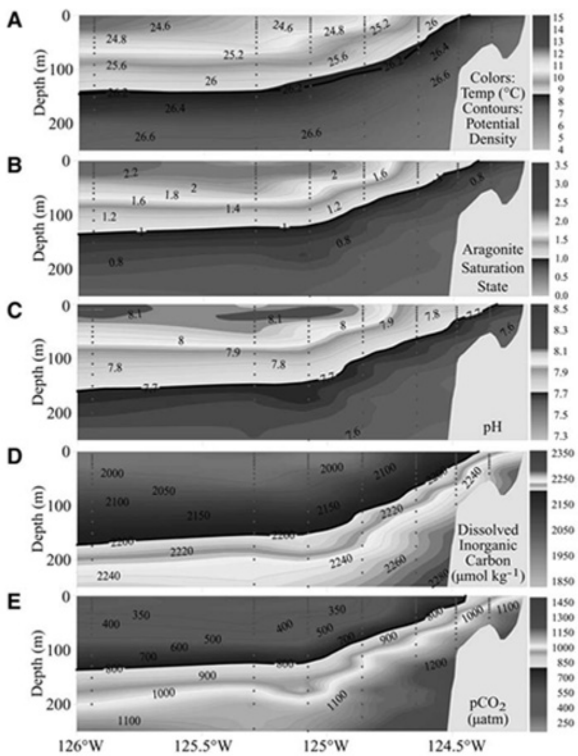

Fig. 2. Vertical sections of: (*A*) temperature, (*B*) aragonite saturation, (*C*) pH, (*D*) DIC and (*E*) pCO_2, on transect line 5 off Pt. St. George, California. Note that the potential density surfaces are superimposed on the temperature section. The 26.2 potential density surface delineates the location of the first instance of the undersaturated water being upwelled from depths of

150–200 m onto the shelf and outcropping at the surface near the coast. The black dots represent sample locations.

As noted, the North Pacific aragonite saturation horizons are among the shallowest in the global ocean.[3] The uptake of anthropogenic CO_2 has caused these horizons to shoal by 50–100 m since pre-industrial times so that they are within the density layers that are currently being upwelled along the west coast of North America. Although much of the corrosive character of these waters is the natural result of respiration processes at intermediate depths below the euphotic zone, this region continues to accumulate more anthropogenic CO_2 and, therefore, the upwelling processes will expose coastal organisms living in the water column or at the seafloor to less saturated waters exacerbating the biological impacts of ocean acidification.

Based on our observed O_2 values and estimated O_2 consumption rates on the same density surfaces,[20] the upwelled water off northern California (line 5) was last at the surface about 50 years ago when atmospheric CO_2 was about 65 ppm lower than today. The open ocean anthropogenic CO_2 distributions in the Pacific have been estimated previously.[19,4,21] By determining the density-dependence of anthropogenic CO_2 distributions in the eastern-most North Pacific stations of the Sabine et al [21] data set, we estimate that these upwelled waters contain approximately 31 ± 4 umol kg–1 anthropogenic CO_2 (fig. S2). Removing this signal from the DIC increases the aragonite saturation state of the waters by about 0.2 units. Thus, without the anthropogenic signal, the equilibrium aragonite saturation level (Ωarag = 1) would be deeper by about 50 m across the shelf, and no undersaturated waters would reach the surface. Water already in transit to upwelling centers is carrying increasing anthropogenic CO_2 and more corrosive conditions to the coastal oceans of the future. Thus the undersaturated waters, which were mostly a problem for benthic communities in the deeper waters near the shelf break in the pre-industrial era, have shoaled closer to the surface and near the coast because of the additional inputs of anthropogenic CO_2.

These observations clearly show that seasonal upwelling processes enhance the advancement of the corrosive deep water into broad regions of the North American western continental shelf. Since the region experiences seasonal periods of enhanced aragonite undersaturation, it is important to understand how the indigenous organisms deal with this exposure and whether or not future increases in the range and intensity of the corrosiveness will affect their survivorship. Presently, little is known about how this intermittent exposure to corrosive water might impact the development of larval, juvenile and adult stages of aragonitic calcifying organisms or finfish that populate the neritic and benthic environments in this region and fuel a thriving economy. Laboratory and mesocosm experiments show that these changes in saturation state may cause significant changes in overall calcification rates for many species of marine calcifiers including corals, coccolithophores, foraminifera and pteropods, which are a significant food source for local juvenile salmon.[8,22-30] Similar decreases in calcification rates would be expected for edible mussels, clams and oysters.[22,31] Other research indicates that many species of juvenile fish and shellfish of significant economic importance to coastal regions are highly sensitive to higher-than-normal CO_2 levels such that high rates of mortality are directly correlated with the higher CO_2 levels.[31,32] While comprehensive field studies of organisms and their response to sporadic increases in CO_2 along the western North American coast are lacking, current studies suggest that further research under field conditions is warranted. Our results show for the first time that a large section of the North American continental shelf is impacted by ocean acidification. Other continental shelf regions may also be impacted where anthropogenic CO_2-enriched water is being upwelled onto the shelf.

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Supporting Online Material

www.sciencemag.org/cgi/content/full/1155676/DC1/2

Materials and Methods

Figs. S1 and S2

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Senator CANTWELL. Thank you, Mr. Sabine.

Dr. Klinger, thank you very much for being here, and we look forward to hearing your testimony. I know we have some excited school children here, but that is what we want. We want them to be excited about the oceans. We want them to be healthy in the future so that they can continue to be excited.

So you might have to—I think if you pull the microphone directly in front of you, if you can, and read your testimony.

STATEMENT OF TERRIE KLINGER, ASSOCIATE PROFESSOR, SCHOOL OF MARINE AFFAIRS; ADJUNCT ASSOCIATE PROFESSOR, SCHOOL OF AQUATIC AND FISHERIES SCIENCES, UNIVERSITY OF WASHINGTON

Dr. KLINGER. Good morning, and thank you, Senator Cantwell and Congressman Inslee, for holding this hearing on this important and emerging issue. Thank you also for offering me the opportunity to testify today.

My name is Terrie Klinger, and I am an Associate Professor in the School of Marine Affairs and Adjunct Associate Professor in the School of Aquatic and Fisheries Sciences at the University of Washington. My area of expertise is marine ecology and the application of natural science to policy and decisionmaking.

I serve as the Chair and Research Representative of the Olympic Coast National Marine Sanctuary Advisory Council, as Governor Gregoire's representative on the Straits Commission, and as a member of the San Juan County's Climate Task Force.

The issue of climate change as it impacts marine ecosystems is large and difficult, and it is made more challenging by the recent recognition that much of the carbon dioxide released to the atmosphere ends up in the ocean where it causes changes in ocean chemistry, and it profoundly influences the structure and function of marine ecosystems.

The projected chemical changes are likely to interact with other stressors—for example, increasing temperature and low dissolved oxygen—to produce ecological effects that are larger and less predictable than the effects of any single stressor alone.

In my testimony today, I want to do three things. I will describe a few of the ecosystem changes that are likely to occur, using examples from Puget Sound to illustrate these changes. I will then articulate some of the pressing research needs and will suggest some of the management and policy responses that could be made at a national level.

I have submitted written testimony that develops each of these points more fully. I want to give you the sense of the scope of the problem and the urgency with which action must be taken in order to minimize risk to social, economic, and ecological systems.

Changes in seawater chemistry caused by ocean acidification will make it more difficult for organisms to form skeletons and shells. Organisms are likely to grow more slowly, produce fewer offspring, suffer greater mortality in an acidified ocean. Calcareous organisms are particularly at risk, but other organisms are also vulnerable.

In Puget Sound, it is likely the following species, such as oysters, clams, mussels, crabs, salmon, and kelp all will be negatively impacted, and it is conceivable that we will lose some of these species entirely over the next century. Species of concern are also at risk such as the non-calcifying organisms. Changes in the food web structure are likely, and essential habitats provided by invertebrates and mollusks.

We urgently need strategic policy-relevant research to help us understand the changes that are likely to occur. Only through direct experimentation will we be able to parameterize models to forecast ecosystem change and to guide strategies to mitigate impacts on human health and the environment.

Research priorities include improved capacity for monitoring chemical and biological changes, experiments to determine the range of physiological responses, and the potential for biologic adaptation and experimentation to determine the food web and other ecosystem impacts.

To perform such research, we quickly need to build capacity and ocean monitoring in experimental facilities. For example, the establishment of the Friday Harbor Laboratories as a sentinel site for time series measurements, combined with the creation of a new experimental facility there, could serve the Nation as a center for research on ocean acidification and temperate ecosystems.

Substantial funds are required to support ocean and coastal monitoring, the development of experimental facilities, and the performance of the research itself. The Federal Ocean Acidification Research and Monitoring Act is a critical first step in providing the requisite funding, but additional funds must be allocated to the research community to perform the work necessary to address this problem in an effective and timely manner.

The research performed must guide management and policy. For this to occur, processes that integrate science into decisionmaking must be developed and implemented. Key management responses are likely to be more conservative harvest limits, greater consideration of food web effects, reductions in other human-induced stressors, and preservation of biological diversity and the capacity for biological adaptation.

In summary, the challenges posed by climate change and ocean acidification are unprecedented. Serious sustained effort must be made to provide policy-relevant science and to implement policies that are reflective of this science and are sensitive to the rates and magnitudes of environmental change. Substantial new funding directed to universities and Federal agencies is required to support essential scientific investigation.

Creation of a strategic national research and implementation plan constitutes a critical first step that must be followed by Federal investment that is sufficient to support the informational needs of this serious threat to social, economic, and ecological systems.

Thank you for the opportunity to speak today.

[The prepared statement of Dr. Klinger follows:]

PREPARED STATEMENT OF TERRIE KLINGER, ASSOCIATE PROFESSOR, SCHOOL OF MARINE AFFAIRS; ADJUNCT ASSOCIATE PROFESSOR, SCHOOL OF AQUATIC AND FISHERIES SCIENCES, UNIVERSITY OF WASHINGTON

1. Statement of Problem

Industrial and agricultural releases of carbon dioxide (CO_2) to the atmosphere have accelerated over the past 250 years, with the result that levels of CO_2 in the atmosphere now are higher than at any time in the past 650,000 years (Feely *et al.,* 2008, and references therein). The oceans absorb about 30 million metric tons of this atmospheric CO_2 daily. Dissolution of atmospheric CO_2 in seawater causes the pH of seawater to decline (become more acidic) and reduces carbonate saturation levels. Temperate upwelling systems, high-latitude systems, and urbanized coastal areas all are likely to be substantially impacted by changes in pH and carbonate saturation within the next few decades. Concerted, sustained efforts must be made now to improve the state of the science and to incorporate science into decisions that will minimize risk to social, economic, and ecological systems.

2. State of the Science

The biological and ecological impacts of declining pH and carbonate saturation (jointly referred to as "ocean acidification") in temperate and high-latitude ecosystems are poorly known but are predicted to affect biological processes and ecological interactions across multiple scales of time and space (*e.g.,* Hutchins *et al.,* 2007; Riebesell *et al.,* 2007; Engel *et al.,* 2005; Delille *et al.,* 2005). Ecologically important species (*e.g.,* keystone species, foundation species, ecosystem engineers) are likely to be negatively impacted, causing unforeseen and undesirable changes in marine ecosystems and in the provision of goods and services to humans. Commercially important species are among the species likely to be negatively impacted, influencing rates of harvest among wild and cultured species, ultimately reducing the availability of human food provided from the ocean.

Biological responses to ocean acidification will vary by species. Although calcifying organisms (algae and animals with calcareous shells or skeletons) are considered to be particularly vulnerable to ocean acidification, non-calcifying organisms also will be affected. Negative impacts are likely to include reductions in growth, reproduction, survivorship, aerobic capacity, thermal tolerance, and disease resistance. Direct lethal impacts will cause mortality in some marine organisms. Other organisms will experience sub-lethal impacts that could have substantial negative ecosystem effects. For example, sub-lethal responses that have been observed in recent experiments include but are not limited to:

- Changes in size: sea urchins reared under high-CO_2 conditions were smaller than urchins reared in normal sea water (G. Hofmann, UC Santa Barbara, unpublished data)
- Changes in morphology: calcified larvae of sand dollars showed subtle changes in morphology when reared under high-CO_2 conditions. The observed morphological changes impaired larval swimming behavior, suggesting that survivorship and recruitment of larvae could be reduced (T. Clay and J. Kershner, University of Washington, unpublished data)
- Reduced thermal tolerance: calcified larvae of sea urchins were able to build skeletons but were less tolerant of thermal stress when reared under high-CO_2 conditions (G. Hofmann, UC Santa Barbara, unpublished data)
- Reduced growth rates: microscopic stages of two kelp species exhibited slower growth when grown under high-CO_2 conditions. Although preliminary, this result suggests that kelps and other non-calcified algae could be negatively impacted by ocean acidification (T. Klinger, unpublished data)

3. Ecosystem Impacts

Ecosystem impacts of ocean acidification are difficult to predict given the current state of the science. Likely impacts include:

- Changes in food web structure and function (*e.g.,* changes in the distribution and abundance of prey species and their predators; increased vulnerability of prey species due to slower growth and reduced calcification)
- Changes in species assemblages. Species that respond negatively to ocean acidification are likely to be replaced by others that are less sensitive to changing ocean chemistry. New assemblages are unlikely to provide the same goods and services that we rely on now.
- Changes in the distribution and abundance of biologically-formed (biogenic) habitat. Early evidence suggests that reef-forming organisms, especially those with calcified skeletons, and canopy-forming kelps could be negatively impacted by ocean acidification, with consequences for other organisms such as fish that utilize or depend on such habitats.

4. Fisheries Impacts

Impacts of ocean acidification on commercial and recreational fisheries are poorly known. Impacts are likely to be mediated through effects on growth and survivorship of larvae and juveniles and through prey availability for all life history stages. Likely impacts include:

- Changes in the distribution and abundance of target species
- Changes in the size and condition of harvested fish and shellfish

5. Synergistic Effects

The biological and ecological effects of ocean acidification are likely to be exacerbated by increasing ocean temperature, declining concentrations of dissolved oxygen, and other physical stressors such as ultraviolet radiation. Synergistic effects can lead to unpredictable ecological responses such as non-linear dynamics, thresholds, and tipping-points.

6. Biological Adaptation and Evolutionary Potential

The potential for biological adaptation to ocean acidification is poorly known. Populations with diversity in genes that regulate response to pH and carbonate saturation are more likely to persist over time than are those with little genetic diversity. Because we do not yet know which species or populations exhibit such genetic diversity, it is essential to maintain evolutionary potential by conserving both species diversity and genetic diversity. The potential for biological adaptation will be constrained by loss of biological diversity and by the rapid rate at which environmental change is occurring.

7. Gaps in Knowledge

Although there now exists compelling evidence that the pH of the ocean is changing due to absorption of anthropogenic CO_2, our understanding of local and regional conditions and impacts is limited. Among the existing gaps are the following:

- Status and trends in seawater chemistry (pH, carbonate saturation, temperature, dissolved oxygen, and other water properties) at spatial and temporal scales relevant to regional research, management, and decision-making
- Status and trends in local populations vulnerable to ocean acidification and the combined effects of multiple stressors
- Range of responses among key ecosystem elements and commercially important species
- Potential for biological adaptation; evolutionary potential
- Non-linear dynamics, thresholds, and tipping-points in ecological responses to ocean acidification and multiple stressors

8. Research Needs

The state of the science necessitates that new research be conducted. Only through direct experimentation will we be able to adequately parameterize models to forecast ecosystem change in the ocean and guide strategies to mitigate impacts on social, economic, and ecological systems. Effective research will require that investigations be conducted across multiple scales of organization, from genes to ecosystems, and at appropriate time scales. Satisfying these research needs will require that substantial new funds are made available to the research community. Research priorities include but are not limited to:

- More intensive and extensive monitoring of seawater chemistry and associated physical properties to detect physical change as it occurs
- Improved baseline biological data to detect ecological change as it occurs, and to link ecological change to chemical change
- Establishment of chemical and biological time-series at sentinel sites
- Experimentation to characterize physiological responses and differential gene expression under changing conditions and to determine the potential for biological adaptation
- Experimentation to determine the range of biological responses among key ecosystem elements and species of commercial importance
- Experimentation to determine interactions between species, including food web interactions, under conditions of ocean acidification and multiple interactive stressors
- Investigations to identify species that are: (1) particularly vulnerable, (2) less vulnerable, or (3) capable of rapid adaptation to the combined effects of acidification and associated stressors. Such investigations could help guide strategies to shift human uses of living marine resources to species that are less vulnerable or more resistant to projected changes in seawater chemistry.

Seven national research priorities were identified by participants in a workshop sponsored by NSF, NOAA, and USGS in April 2005 (Kleypas *et al.,* 2006). These priorities, paraphrased here from the original report, are as follows:

- Determine the calcification response to elevated CO_2 in benthic and planktonic calcifiers
- Discriminate mechanisms of calcification and responses to changing seawater chemistry across taxonomic groups
- Determine the interactive effects of multiple variables that affect calcification and dissolution in organisms
- Establish clear links between laboratory experiments and the natural environment, by combining laboratory experiments with field studies
- Characterize diurnal and seasonal cycles in the carbonate system
- Monitor *in situ* calcification and dissolution of calcifiers, with better characterization of key controls on biocalcification
- Incorporate ecological questions into observations and experiments, *e.g.,* individual survivorship, population growth rate, community structure, and ecosystem function.

A subsequent workshop was convened at the Scripps Institution of Oceanography in October 2007 by the Ocean Carbon and Biogeochemistry Program with sponsorship from NSF, NOAA, NASA, and USGS. The purpose of the workshop was to further refine scoping for research investigations of ocean acidification. Important research themes were phrased as questions of importance (paraphrased here):

- What are the temporal and spatial scales of change in the carbon system of the global oceans and what are the impacts on biological communities and ecosystems?
- Will marine organisms adapt or evolve to tolerate elevated CO_2 and temperature? If so, how?
- How does elevated CO_2 influence calcification, respiration, reproduction, settlement and recruitment, and remineralization in marine organisms?
- What are the effects of high CO_2 on processes affecting ecosystem response and global feedbacks?

9. Implications for Marine Resource Managers

Projected changes in seawater pH and carbonate saturation, combined with increasing temperature and declining levels of dissolved oxygen, will require the attention of marine resource managers. Effective management requires that processes integrating science into decision-making be developed and implemented. Key management responses are likely to include:

- More conservative limits on commercial and recreational harvest to compensate for losses due to acidification and associated stressors
- Greater consideration of food web effects (*e.g.,* consideration of the abundance and distribution of prey species) in setting harvest limits and establishing rebuilding and recovery plans
- Preservation of species diversity and genetic diversity to provide functional redundancy and to enhance the capacity for biological adaptation to changes in ocean chemistry
- Protection and restoration of essential habitat features and processes to compensate for habitat losses due to acidification and associated stressors
- Alleviation of other human-induced stressors (pollution, eutrophication, shoreline development, habitat modification) to the maximum extent possible to reduce the effects of multiple interactive stressors and the likelihood of non-linear dynamical responses

10. Conclusion

Carbon emissions are causing changes in seawater chemistry that are unprecedented in the modern era. Ultimately, carbon emissions must be curbed. At the same time, serious and sustained efforts must be made now to reduce risks associated with changing ocean chemistry. Effective strategies will: (1) provide policy-relevant science regarding the effects of ocean acidification and associated stressors on marine organisms and the ecosystems they comprise; (2) implement policies that are reflective of this science and are sensitive to the rates and magnitudes of environmental change; and (3) adjust policies as new information becomes available. Substantial new funding directed to universities and Federal agencies is required to support essential scientific investigations. Creation of a strategic national research and implementation plan constitutes a first important step that must be followed by Federal investment that is sufficient to support the informational needs of this serious threat to social, economic, and ecological systems.

11. Biographical Sketch

Terrie Klinger is Associate Professor of Marine Affairs and Adjunct Associate Professor in the School of Aquatic and Fisheries Sciences at the University of Washington and an active researcher at UW's Friday Harbor Laboratories. She obtained an A.B. in Biology from the University of California, Berkeley in 1979, a M.Sc. in Botany from the University of British Columbia in 1984 and a Ph.D. in Biological Oceanography from Scripps Institution of Oceanography in 1989. Her research focuses on ecological and policy issues in nearshore areas of the Pacific Northwest and Gulf of Alaska. She serves as Chair of the Olympic Coast National Marine Sanctuary Advisory Council, is the Governor's representative to the Northwest Straits Commission, and is a member of San Juan County's Climate Change Task Force.

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Senator CANTWELL. Thank you, Dr. Klinger.

Dr. Miles, thank you very much for being here as well. I know that you have played a long role in this area of research, and we greatly appreciate your position on these issues and your testimony today.

And again, we are trying to get a microphone arranged there while you take a seat. If you can speak directly into the microphone, that will help us today. Thank you, Dr. Miles.

STATEMENT OF EDWARD L. MILES, PH.D., VIRGINIA AND PRENTICE BLOEDEL PROFESSOR OF MARINE STUDIES AND PUBLIC AFFAIRS, SCHOOL OF MARINE AFFAIRS, UNIVERSITY OF WASHINGTON

Dr. MILES. Thank you, Senator. Thank you for your leadership, and Congressman Inslee——

Senator CANTWELL. Move it directly—right in front of you. It is a little hard——

Dr. MILES. All right. Is that better?

Senator CANTWELL. Yes, thank you.

Dr. MILES. My name is Edward L. Miles, and I am the Virginia and Prentice Bloedel Professor of Marine Studies and Public Affairs in the School of Marine Affairs at the University of Washington. I also serve as Co-Director of the Center for Science in the Earth System of the Joint Institute for the Study of Oceans and Atmosphere, or JISAO, where I am the team leader of the Climate Impacts Group, the first of NOAA's Regional Integrated Sciences and Assessment, or RISA, teams. Our Climate Impacts Group was created on July 1, 1995.

In my—in what I have to say in the short time available, I agree that the major lever of solution to the problems we face lies in fundamental changes to our energy systems and energy policy. But even if you were to bring that feat about tomorrow morning in Washington, D.C., we will have to try to manage the consequences of what we have created for several centuries. And that is the focus I want to take.

I think we cannot afford to focus just on ocean acidification, as massive and as shocking as it is. I believe these problems are best dealt with by looking at them as a suite of multiple stressors so let me at least list them.

The fact is that unprotected fossil fuel emissions since they were introduced have increased the concentration of CO_2 in the atmosphere by 100 parts per million, and this rate and magnitude is higher than any experienced on Earth for at least the last 650,000 years. As a result, as has already been mentioned, ocean pH has been reduced by about 10 percent. But much more is implied in the future as a result of the total commitment of greenhouse gases to the atmosphere and the time scale of the exchanges between the ocean and the atmosphere.

We also know, as has been pointed out, that ocean acidification impacts the health of calcareous life forms, and this will affect the web of life in the ocean, causing changes to be felt all the way up the food chain and also in the other relations.

But we move on to other massive changes. Significant thermal increases in the surface and subsurface deep in the world's oceans, which will produce large-scale biogeographical shifts in the distribution of the most important species which are targeted by global commercial fisheries on which humans depend as a source of animal protein.

There is also the significantly increased melt rates of polar ice shields in the summer as a result of the unexpected feedback between the subsurface heat increases and the subsurface ice, which produce the increased probability of intensified stratification in the water column. Stratification means a less biologically productive ocean.

So this suite of five new problems, combined scientifically with two old problems which we haven't solved—that is, that those are the increased intensities of land-based pollution of the coastal region and the weakened condition of commercial fish populations, very significant levels of overfishing have occurred.

So nobody alive is able to deal with this suite of seven stressors simultaneously. But a group of us in the community have decided to try to merge our capabilities to focus on at least two of the big ones, ocean acidification and changing ocean thermal structure.

And together, with a colleague in the School of Oceanography, Professor Chris Sabine, and Dr. Richard Feely from NOAA PMEL, we have decided to put together a larger group, a panel launched on April 23 and 24, 2007, where we came to complete agreement on the research which encompasses both the natural science and the policy and management issues.

The assets we are combining consist of NOAA PMEL, the Northwest Fishery Science Center, the Alaska Fishery Science Center, the School of Oceanography, School of Aquatic and Fishery Sciences, School of Marine Affairs at the University of Washington, the Center for the Study of Earth Science at the University of Washington, and Friday Harbor Labs, and the National Conservation Biology Institute.

Our first step is to design a mesocosm, an experimental facility at Friday Harbor Lab, and to offer it as a national facility. And Dr. Klinger will design a workshop, which will be held this summer in late August, and that is supported by the Educational Foundation of America and the Dean of the College of Aquatic and Fishery Sciences and Government.

We have begun a fund-raising effort for the construction of the mesocosm by doing the substantive research and for conducting a public education program. We cannot solve this set of problems by focusing only on the Northeast Pacific, and so we hope to relate our efforts to those in the North Atlantic, the Northwest Pacific, and elsewhere.

As for global and national focus, we are also involved with the Heinz Center in Washington, D.C., and the Joint Global Change Research Institute at the University of Maryland.

Thank you very much, Senator Cantwell.

[The prepared statement of Dr. Miles follows:]

PREPARED STATEMENT OF EDWARD L. MILES, PH.D., VIRGINIA AND PRENTICE BLOEDEL PROFESSOR OF MARINE STUDIES AND PUBLIC AFFAIRS, SCHOOL OF MARINE AFFAIRS, UNIVERSITY OF WASHINGTON

My name is Edward L. Miles and I am the Virginia and Prentice Bloedel Professor of Marine Studies and Public Affairs in the School of Marine Affairs at the University of Washington. In addition, I hold a joint appointment in the Evans School of Public Affairs and an Adjunct Appointment in the School of Aquatic and Fisheries Sciences. I also serve as Co-Director of the Center for Science in the Earth System (CSES) of the Joint Institute for the Study of Oceans and Atmosphere (JISAO), where I am the team leader of the Climate Impacts Group (CIG), the first of NOAA's Regional Integrated Sciences Assessment (RISA) teams. The CIG was created on July 1, 1995.

The Committee has asked me to address the following issues:

1. Summarize the work of the Climate Impacts Group and explain how this work enables an understanding of climate change and its effects on Washington's marine and coastal ecosystems.

2. Discuss the integrated approach that interest groups in Washington have taken to understand and adapt to climate change.

3. Describe specifically how the University of Washington, the Pacific Marine Environmental Lab, the state of Washington, and local communities are working together to address climate change issues.

4. Discuss the implications of climate change for coastal and ocean resource managers and the needs of managers to effectively respond to the resulting impacts.

Since it will not be possible to respond to all these questions orally in the time allotted to me, I shall respond in my written statement provided in the record and, for my oral presentation, I shall present the challenges which climate change poses to the region's oceans and coasts and focus on the new and very serious problem we now face in the world ocean as a whole. This is the problem of ocean acidification combined with a changing ocean thermal structure.

The Work of the CIG

The CSES consists of the Climate Dynamics Group (CDG) and the CIG as a completely integrated "one-stop-shop". The CDG studies the physical climate system relevant to the Pacific Northwest and the CIG examines the impacts of climate variability and change on the Pacific Northwest, and produces climate information products and derived predictions (*e.g.,* streamflow forecasts) for a large set of local stakeholders.

Formed as a spin-off of Miles' experience in the Second Assessment of the Intergovernmental Panel on Climate Change (IPCC) in 1994–1995, the CIG focuses on developing climate impacts science as the study of how climate, natural resources, and human socio-economic systems affect each other. This requires the integration of physical and social science research, as well as the integration of stakeholders' perspectives (Federal, state, tribal, local, private sector, and NGO's).

With core support from NOAA, we focus on four sectors: the regional hydrology/water resources management, forest ecosystems, aquatic ecosystems (primarily salmonids and the ecosystem structures and fisheries of Puget Sound and the Northern California Current System, including the coastal zones of Washington and Oregon). We study the dynamics of climate variability as a basis for making projections of likely scenarios of climate change.

The Emerging Integration of Interest Groups in Washington in Understanding and Adapting to Climate Change

How we got to where we are now can be described as a series of steps. It is an evolutionary unfolding rather than the result of a deliberate strategic plan.

1. We began with an initial focus on understanding climate variability in the PNW and impacts across the four sectors. We shared the results of our investigations with stakeholders from 1995–1997 in general annual meetings of declining utility.

2. 1997–1998 was a year of transition defined by two major experiences. These were the First National Assessment of climate change impacts on the U.S., conceived and implemented in the Clinton Administration by then Vice President Al Gore, and the most intense El Niño of the 20th century. The latter event generated intense interest in climate which was sustained by widespread media coverage. With combined additional investment from NOAA and UW to expand the outreach capacity of the CIG, we hired Dr. Philip Mote to be our 2nd climate dynamicist, focused on the general circulation models (GCMs) of IPCC and CIG specialist in charge of outreach. In addition, we shifted to custom-made workshops for interest groups across the four sectors. CIG emphasis was then equal between climate variability and climate change; currently we place a heavier emphasis on issues related to climate change. Between 2000 and 2005 we expanded our contacts with stakeholders and deepened our connections to those who had joined us early.

3. A new threshold was crossed as a result of increasingly observed effects of climate change combined with exercise of leadership by NE states, California, the Chief Executive of King Co., the Mayor of Seattle, and the Tri-State Governor's Initiative involving California, Oregon, and Washington by 2004. In 2005 we participated in a highly successful collaboration between King Co. and the CIG in the form of a workshop for >700 people in Quest Field covering eight sectors of the PNW. Collaboration with King Co. continued in the design and preparation of an adaptation Guidebook for Local Governments and on joint research projects. Research results began to support policy development at this stage.

4. In 2007–2008 collaboration occurred between the CIG, the Washington Legislature, and the Governor's Initiative on Climate Change. Agreement converged on an eight-sector assessment of likely climate change impacts (H.B. 1303 and 2860). This initiative is overseen jointly by the Division of Community, Trade, and Economic Development (CTED) of the Office of the Governor and Washington Dept. of Ecology. An increasingly close and very effective collaboration between CIG and Ecology has emerged across all areas.

Collaboration between UW, NOAA/PMEL, NMFS Northwest Fisheries Science Center, NMFS Alaska Fisheries Science Center, and Local Communities to Address Climate Change Issues

The University of Washington has very great strengths in the earth sciences and particularly so on matters related to climate dynamics, climate impacts, and climate change. This expertise is distributed across the following units:

1. The Program on Climate Change (PCC) combines as core units the School of Oceanography, Dept. of Atmospheric Sciences, and Dept. of Earth and Space Sciences. The principal foci are research, education, and outreach. PCC also involves the Quaternary Research Center, the Applied Physics Laboratory (APL), JISAO, the CIG, and NOAA's Pacific Marine Environmental Laboratory (PMEL). *http://www.uwpcc.washington.edu/*

2. JISAO is a "center of excellence" fostering collaboration between NOAA and UW on research themes which are allied with NOAA's strategic plan. These include climate, environmental chemistry, marine ecosystems, and coastal oceanography. *http://jisao.washington.edu* The CSES/CIG is also based in JISAO. *http://cses.washington.edu*

Examples of the ways in which these organizations combine and recombine to deal with problems of climate impacts would include collaboration between CSES and the NMFS Northwest Fisheries Science Center on the investigation of harmful algal blooms in Puget Sound; on improving rebuilding plans for overfished West Coast rockfish stocks through inclusion of climate information; on modeling studies to support conservation planning for Pacific Salmon; on developing quantitative tools for evaluating the effects of climate change on the population dynamics of Pacific salmon; and on predicting the responses of wild Pacific salmon to climate change.

Another area of activity which was launched in April 2007, concerns the comprehensive investigation of the impacts of changing ocean thermal structure and increasing acidification in the Northeast Pacific Ocean. This effort integrates the efforts of CSES, UW School of Oceanography, School of Aquatic and Fishery Sciences (SAFS), School of Marine Affairs (SMA), and Friday Harbor Laboratories (FHL) with NOAA/PMEL, the Northwest Fisheries Science Center, the Alaska Fisheries Science Center, and the Marine Conservation Biology Institute. The workshop established a priority for building a mesocosm at FHL as a national facility for the purpose of conducting experiments on the impacts of ocean acidification and agreed on a Steering Committee to move the programming forward. Since then the Steering Committee has secured a grant from the Educational Foundation of America combined with a contribution from Dean Arthur Nowell to hold a workshop to produce a detailed design for the mesocosm. The Steering Committee is currently engaged in developing a fundraising effort for constructing a mesocosm as well as for beginning a substantive research program, the first steps of which have been outlined. These investigations will be conducted in an "end-to-end" mode involving fundamental and applied science connected to identification and evaluation of alternative approaches to mitigation of and adaptation to the combined problem drivers of acidification and changing ocean thermal structure.

Linked to, but going substantially beyond the acidification problem is an activity that combines the strengths of NOAA/PMEL with APL at UW and King County to determine a regional carbon budget for the Seattle area. A comprehensive plan is now being developed in the form of a White Paper. However, even before the plan is finished, NOAA/PMEL has collected carbon samples from a winter cruise conducted by the PRISM Program at UW. More samples will be collected this summer to get a first look at the carbon budget of Puget Sound. As a first step in the implementation of a continuous monitoring system, PMEL has emplaced a CO_2 mooring off Aberdeen, WA, for the purpose of measuring surface water and atmospheric CO_2. This mooring has been operating for the last 2 years. These tentative steps are very important for a number of reasons. As local governments seek to reduce their emissions of CO_2 they will need to develop the capability to verify that policies enacted are reducing emissions as intended. This capability requires an in-depth understanding of sources and sinks of the gases which are targeted for reduction. That understand would be substantially enlarged by a monitoring system such as the one being designed in the collaboration between NOAA/PMEL, UW/APL, and King Co.

Of the eight sectors identified in the H.B. 1303 investigation, two involve ocean problems. These are Coasts, Estuaries, Harbors, Salmon and Marine Ecosystems. In the former category, the legislation requires CIG and its partners to estimate to what extent rising sea levels and ocean temperatures will impact the coasts, estuaries, and harbors of the State of Washington through inundation, increased flooding, and/or erosion. In the latter case, the legislation requires assessment of the extent to which climate change will alter the state's streams for salmonids, and where and under what conditions is salmonid habitat most vulnerable to direct (rising water temperatures) and indirect (habitat) effects of climate change.

The Implications of Climate Change for Ocean and Coastal Resource Managers and the Needs of Managers to Respond Effectively to the Resulting Impacts

Challenges Posed by Climate Change in the Pacific Northwest:

1. Changing ocean thermal structure (increasing surface and sub-surface heat) inducing large-scale biogeographic shifts of ecosystems, including commercial fisheries.
2. Increasing ocean acidification in both the North Pacific Ocean and particularly in the coastal ocean off the West Coast of North America with negative results for all species requiring calcium carbonate for building their skeletons and unknown effects for fisheries.
3. Increasing stratification of the water column as a result of changing ocean thermal structure, accentuated by increased input of freshwater from melting glaciers.
4. Expanding areal extent of oligotrophic gyres (*i.e.,* waters rich in dissolved oxygen, but lacking nutrients and plant life).
5. Salmon, and salmon restoration programs affected by multiple stresses connecting both terrestrial and marine dimensions of the life cycle from watersheds to the open ocean.
6. Harmful algal blooms.
7. Coastal hypoxia.
8. Changes in the frequency and predictability of fisheries recruitment events as a result of cascading changes in the marine environment.
9. Very complex, but largely unknown, changes in nearshore structural algae (eelgrass, kelp) as habitat for a wide range of coastal fish species.

10. Changes in the magnitude and type of coastal hazards generated by varying levels of sea level rise and the ways these changes will impact coastal development and public infrastructure.

Managerial Needs:

1. Increased information derived from expansions in monitoring capacity in the open and coastal ocean and Puget Sound.

2. Research and assessment tied to policy development.

3. Systematic evaluation of potential alternative suites of policy options to respond effectively to severe problems of multiple stresses in a changing environment.

In summary, over the past 13 years the CSES has engaged in a wide range of issue-driven scientific research and outreach related to the coasts and marine waters of the Pacific Northwest region. The region's needs for improved information and decision-support tools for managing marine resources is great, and threats posed by future climate change and ocean acidification will likely amplify existing decision-support needs in the very near future.

Senator CANTWELL. Well, thank you, Dr. Miles.

Dr. Koenings, I want to thank you for being here, and we look forward to hearing your views. Thank you for representing the State of Washington.

STATEMENT OF JEFFREY P. KOENINGS, PH.D., DIRECTOR, DEPARTMENT OF FISH AND WILDLIFE, STATE OF WASHINGTON

Dr. KOENINGS. Thank you very much. Good morning, Senator Cantwell and Representative Inslee.

I am Dr. Jeff Koenings, Director of the Washington Department of Fish and Wildlife. I also wear a variety of other hats as Chair of the National Pacific Salmon Commission and a Council Member of both the Pacific Fishery Management Council and the North Pacific Fishery Management Council.

I appreciate this opportunity to speak to you on the impact of climate change on Washington State's marine ecosystems. For resource managers, I can sum up this topic with one word, and that word is "uncertainty."

When we embark on a discussion of global climate change impacts, let us first acknowledge that we are heading into uncharted territory. Unlike other areas of natural resource science and management, we have no body of research to guide us, no historic models to foreshadow the shape of things to come, no proven formulas to follow.

As a natural resource manager, I depend on science to guide my decisions, and in this arena, the science is just beginning to be developed. All this translates to the need for precautionary resource management. The climate change is, indeed, upon us all.

What we do know is that climate change has the potential for enormous direct impact on delicate coastal ecosystems, as well as leaving them more vulnerable to secondary stressors. Changing ocean water temperatures, currents, stratification patterns, acidification can lead to other changes we are only beginning to contemplate.

With so much unknown, we must gather intelligence from a growing number of the abnormal and even bizarre events that signal the natural and economic catastrophe climate change could bring. A growing oxygen-depleted dead zone has appeared in the ocean off our coast. Non-native species, such as the giant Pacific squid, make sudden appearances in our waters, and this year, entire salmon runs have collapsed in Oregon and California.

We need no crystal ball to see the economic toll the salmon fishery collapse has taken on the West Coast. An unprecedented $60 million in Federal funds has been distributed since last summer to some 1,200 commercial fishermen in Oregon and California. The shadow cast on coastal communities, on operators of hotels, restaurants, charter boats, convenience stores, and supply shops is even wider.

Here in Washington State, our severely constrained fishery is projected to eat away nearly $14 million from the sport fisheries, $15 million from the other salmon-related businesses, and another $7.2 million in direct losses to commercial fishers.

This year, the Chinook salmon disaster offers a window on how the destruction of a single species, much less entire ecosystems, reverberates through our communities. It sounds like an extreme wake-up call for us all.

I would like to briefly outline three ways marine areas could be particularly affected by climate change—first, through ocean dead zones; second, through non-native invasive species; and third, from the cumulative impacts to salmon and steelhead.

Scientists have yet to determine how closely ocean dead zones are linked to climate change, but we do know the oceanic and atmospheric conditions that create these areas are consistent with climate change predictions. In recent years, these zones of oxygen-starved water off the coast of Washington and Oregon are persisting longer and becoming more severely with depleted oxygen. By last year, the coastal dead zone had spread from Washington coast to the California border.

Even absent the great uncertainties of climate change, non-native, potentially invasive species dispersed by ship ballast water are among the top threats to the world's marine ecosystems. With the emergence of modern shipping, the natural barriers have been broken down, allowing the introduction of alien species that upset the equilibrium of native ecosystems. Climate change could usher even more invasive animals and plants into our marine waters.

I am pleased to report that Washington State enforces ballast water management requirements. Improper ballast water discharge in State waters is subject to civil penalties. And, yes, we have invoked those penalties a half dozen times over the past few years. The passage of Federal ballast water legislation with necessary standards will greatly help these efforts.

Besides the general threat from ballast water, we are also aware of specific invaders that threaten wide-scale havoc in our marine ecosystem and our economy. Just two invasive species, the green crab and the Chinese mitten crab, could overrun our native Dungeness crab, thus disrupting the State's most lucrative coastal fishery.

In no area of State fishery management are the potential effects of climate change more sobering than for salmon and steelhead. That is because these species move throughout our entire ecosystem to complete their life cycle, making them particularly vulnerable to flood events, competing water demands, and temperature changes, all expected to increase with the changing climate.

Given the uncertainty of what lies ahead, the common denominator in all these concerns is the need for precautionary resource management. Faced with great unknowns, our best hope is to take the best possible care of the resources we still have.

It is difficult to consider climate change impact without becoming overwhelmed. However, we can find some cause for optimism in an evolving spirit of cooperation as we face our shared burden, and you see some of that in front of you today.

There are also very collaborative people behind me that are here attending this hearing. [Inaudible] All are involved in a collaborative effort to address ecosystem problems we have here in the State of Washington.

But first, I would like to share one recent example of collaborative effort. Just days ago, the United States and Canada reached agreement on a new salmon harvest plan under the Pacific Salmon Treaty. Over the next 10 years, this ground-breaking agreement will return a million more salmon to Northwest waters. This treaty offers a unique opportunity to pursue precautionary resource management on a far-reaching and long-lasting scale.

The kind of large-scale commitment and cooperation exemplified in the Pacific Salmon Treaty among nations, among agencies, and among citizens must be the cornerstone for any concrete effort to tackle climate change. In this arena, the past is not served but is a prelude to the future. Instead, we are faced with unknown challenges of monumental proportions. We must move forward with only the tools that offer hope—our shared concern, our willingness to collaborate, and our combined commitment to conservation.

Thank you, and I will be happy to answer any questions.

[The prepared statement of Dr. Koenings follows:]

PREPARED STATEMENT OF JEFFREY P. KOENINGS, PH.D., DIRECTOR, DEPARTMENT OF FISH AND WILDLIFE, STATE OF WASHINGTON

Good morning, Senator Cantwell and honorable Committee members. I'm Dr. Jeff Koenings, Director of the Washington State Department of Fish and Wildlife. I appreciate this opportunity to speak to you on the impacts of climate change on Washington State's marine ecosystem. I can sum up this topic with one word—uncertainty!

When we embark on a discussion of global climate change impacts, let's first acknowledge that we are heading into uncharted territory. Unlike other areas of natural-resource science and management, we have no body of research to guide us, no historic models to foreshadow the shape of things to come, no proven formulas to follow.

Given this uncertainty, Washington state has embarked on several collaborative efforts to assess and begin planning for the potential impacts of climate change. The University of Washington Climate Impacts Group, part of the National Oceanic and Atmospheric Administration's Regional Integrated Sciences and Assessment (RISA) network, the Western Governor's Association Climate Initiatives work group and the Washington State Climate Challenge all offer the kind of broad-based forums that will be required to respond to climate change.

We do know that climate change has the potential for enormous direct impact on delicate coastal ecosystems, as well as leaving them more vulnerable to secondary stressors. Changing ocean water temperatures, currents, and stratification can lead to other changes we are only beginning to contemplate. As you know, impacts associated with climate change and climate variability are difficult to distinguish from other forces that stress the marine ecosystem.

With so much unknown, we must gather intelligence from a growing number of abnormal, even bizarre, events that signal the natural and economic catastrophe climate change could bring to our waters. Since 2002, a growing, oxygen-depleted ocean “dead zone” ocean has appeared and grown off our coast. Periodically non-native species such as the giant Pacific squid make sudden appearances in our waters. And this year, entire salmon runs have collapsed in Oregon and California.

We need no crystal ball to see the economic toll the salmon fishery collapse has taken on the West Coast. An unprecedented $60 million in Federal funds has been distributed since last summer to some 1,200 commercial fishermen in Oregon and California. The shadow cast on coastal communities—business lost to hotels, restaurants, charter operators, convenience stores and supply shops—is even wider. And even though we in Washington state are fortunate to have some fishing opportunity this year, our severely constrained fishery is projected to eat away nearly $14 million in revenues from sport fisheries, $15 million in lost revenue to businesses that provide goods and services that support fisheries, and another $7.2 million in direct losses to commercial fishers.

This year’s chinook salmon disaster offers a window on how the disruption of a single species reverberates throughout our communities. It also sounds a wake-up call. Because as difficult as this year’s events are for our West Coast neighbors, this state, with its miles of complex marine coastline—bays, estuaries, great coastal rivers and, of course, Puget Sound—is potentially even more vulnerable to climate change.

I’d like to briefly outline three ways our marine areas are particularly vulnerable to climate change—first, through growing, oxygen-deprived ocean “dead zones;” second, from the appearance of non-native, invasive species; and third, from cumulative impacts to salmon and steelhead as they move throughout freshwater and marine ecosystems to complete their life cycle.

Scientists have yet to determine how closely oxygen-deprived ocean dead zones are linked to climate change. But we do know the oceanic and atmospheric conditions that create these areas are consistent with climate change predictions. These zones of oxygen-starved water—historically found only on the sea floor and the outer areas of the continental shelf—in 2002 began appearing much closer to the coasts of Oregon and Washington, persisting longer, and becoming more severely oxygen depleted. We also know that the longer they persist, the greater the impact on fish, crab and other marine life. By last year, the coastal dead zone that appeared only in 2002, had spread to extend from Washington to the California border.

Even absent the great uncertainties of climate change, non-native, potentially invasive species dispersed by ship ballast water discharges are among the top threats to the world’s marine ecosystems. For thousands of years, marine species could spread only by drifting on current or debris. With the emergence of the modern shipping and growing trade between nations, natural barriers have been broken down, allowing the introduction of alien species that upset the equilibrium of native ecosystems. A recent report by the Environmental Protection Agency calls on states to consider the effect of climate change on the already-challenging issue of aquatic invasive species, to identify ecosystem vulnerabilities, and to evaluate and improve controls.

Although there is much to be done to meet this growing challenge, I’m pleased to report that Washington state has enforced ballast water management requirements on all vessels of three hundred gross tons or more, domestic or foreign. Vessel operators are required to ensure that ballast water is exchanged at sea or treated before it is discharged into state waters, and to report discharges. Improper ballast water discharges into state waters are subject to civil penalties. And yes, we have invoked those penalties a half-dozen times in the past several years.

Besides the general threat from ballast water, we are also aware of specific invaders that threaten wide-scale havoc in our marine ecosystem and our state’s economy. Just two invasive species—the green crab and the Chinese mitten crab—could overrun our native Dungeness crab, disrupting this state’s most lucrative coastal fishery.

In no area of state fishery management are the potential effects of climate change more sobering than for salmon and steelhead. That’s because these iconic Northwest species move throughout our entire ecosystem—beginning life in inland spawning streams, migrating down major river systems, sheltering along estuaries and coastlines, finally heading out to sea and then repeating their journey homeward—to complete their life cycle. With such a wide range, they are particularly vulnerable to flood events, competing water demands and temperature changes—all expected to increase with a changing climate. Because salmon and steelhead rely on clean, cool water for survival, and require undisturbed streambeds to produce offspring, entire runs can be threatened by water flow disruptions. Those disruptions include flooding such as we’ve seen this past winter and the one before it, as well as warm season low flows that can strand young fish en route to the ocean, or block the return of adult salmon headed back to their native streams to spawn. This year’s collapse of California's Sacramento River and Oregon's Klamath River salmon runs may offer the most detailed picture to date of the consequences of water-supply disruption.

Given the uncertainty of what lies ahead, the common denominator in all these concerns is the need for precautionary resource management. Faced with great unknowns, our best hope is to take the best possible care of the resources we still have.

It's difficult to consider climate change impacts without becoming overwhelmed. However, we can find some cause for optimism in an evolving spirit of cooperation as we face our shared burden. I'd like to share one recent example. Just days ago, the United States and Canada reached agreement on a new salmon-harvest plan, under the Pacific Salmon Treaty. Over the next 10 years, this groundbreaking agreement will return *a million more* salmon to Northwest waters. For example, the annual catch of chinook in southeast Alaska will be reduced by 15 percent. Off the west coast of Vancouver Island, British Columbia will lower its annual chinook harvest by 30 percent. Many of the salmon spared will return to Washington waters, furthering the recovery of fish populations listed for protection under the Federal Endangered Species Act.

I can assure you that with this conservation-based agreement we are making a substantial down payment toward recovery of Washington's weak, wild, chinook salmon populations. This is a unique opportunity to pursue precautionary resource management on a far-reaching and long-lasting scale.

We can find other models of the kind of all-hands work needed to take on climate change issues. Right here in the Puget Sound region, a partnership established by Governor Gregoire is bringing governments on all levels together to restore the health of the Sound within a decade. On another front, my agency is working with scientists, tribes and legislators to completely retool our state's aging hatchery system—one of the world's largest—to support wild salmon recovery.

The kind of large-scale commitment and cooperation exemplified in the Pacific Salmon Treaty—among nations, among agencies, among citizens—must be the cornerstone of any concrete effort to tackle the sweeping challenge of climate change. Unlike so many other concerns of government where the past is prelude to the future, in this arena we are faced with unknown challenges of monumental proportions. We go forward with the only tools that offer hope—our shared concern, our willingness to collaborate, and our combined commitment to conservation.

Thank you. If there are any questions, I'll be happy to try to provide you with a concise answer.

Senator CANTWELL. Thank you, Dr. Koenings.

Now I think Mr. Bishop maybe will elaborate a little bit more on how those invasive species are impacting a very vital industry in Washington State, obviously in the shellfish industry. Thank you for being here.

STATEMENT OF BRETT BISHOP, CO-OWNER, LITTLE SKOOKUM SHELLFISH GROWERS; ON BEHALF OF THE PACIFIC COAST SHELLFISH GROWERS ASSOCIATION

Mr. BISHOP. You are welcome. Good morning. I am honored and surprised to be here. I am a clam digger and oyster picker. My name is Brett Bishop, and today I am representing commercial shellfish growers from Alaska to California to Hawaii.

Washington State produces 85 percent of the shellfish grown on the West Coast, and we in Washington State are now the largest producer of farmed shellfish in the United States.

My family's farm is on Little Skookum Bay. We are a traditional family farm, with tides. Mom and dad live next door. Mom is 91. Dad is 93. They still take care of themselves, but I do the driving now. My two teenage boys are the sixth generation in our family to live on the homestead and grow clams and oysters in Skookum Bay. We would like to keep that going.

We are typical of other shellfish farmers, and we are all facing problems that appear to be related to a warming climate and greenhouse gases. We have a current crisis in several of the larger shellfish hatcheries. It is a new bacterium called *Vibrio tubiashii,* and it interferes with the reproduction of oysters and clams when they are in the larval stage, less than 1 millimeter.

In the hatcheries, it is devastating. The largest hatchery we have is in Whiskey Creek, Oregon, in Netarts Bay, and this year, they shut their doors and laid off employees. What they have been doing is retooling their facility. They have added ultraviolet filtration and protein skimmers, and they have shown some early success. But in the marine environment, particularly in the coastal bays such as Willapa and Grays Harbor—well, in Willapa Bay, they are in year three of little or no natural oyster setting. So they now have to rely on hatcheries, and the hatcheries have this problem. They are in dire straits.

Even if we fix the problem in the hatcheries, it still leaves unresolved the ability of oysters to reproduce in the wild. We need to be clear about this. The current situation puts not just the shellfish grower, but the entire marine ecosystem in extreme jeopardy. I am scared.

A problem of even greater magnitude is this acidification of seawater that we have heard about. I heard about it last week, and I haven't forgotten about it for a moment since. This acidity dissolves calcium carbonate, which is the thing the shells are made out of. And if diatoms, corals, or clams and oysters succumb to this, it not only wipes out the shellfish industry, but potentially the entire marine food chain.

I know that is a dark and gloomy picture we have been painting for you today. So, as a counterpoint to that, let me tell you something else. Shellfish growers are perhaps the only category of humans that might actually benefit from climate change. Here is how it might work.

Instead of having to mow my front lawn once a week, as sea levels rise because of melting ice caps, I might be able to grow clams and oysters in the front lawn. Of course, we have to survive as a business to reap the benefit from that future date. I am not so sure we are going to.

Shellfish perform vital ecosystem functions as they filter-feed. Just about every human activity that takes place on the uplands contributes nutrients to the marine environment, and when the shellfish is harvested, it represents one of the very few human activities that actually withdraw nutrients from the marine environment. So all the oceans need filter-feeding shellfish, whether it is my family growing them or not.

From the perspective of the Bishop family, it looks like this. We have invested everything that we have and everything that we are on our farm. We have a mortgage with Farm Credit Services. We employ 27 people year round, gross sales of about $2.8 million a year. If we can't grow our shellfish, the bank will foreclose on the mortgage, we will lose our farm, our homes, and six generations of hopes and dreams and investment, which is just about everything that we hold dear.

We do not intend to be passive witnesses to our own demise. Growers have thoughts. With electricity, we have boats and people out on the beach at every low tide. We are ready to supply physical locations, telemetry, and field work at no cost to researchers, who are helping us figure out our common problems. If science can supply the intelligence, we will help with the means. Please use us.

Thank you for your attention.

[The prepared statement of Mr. Bishop follows:]

PREPARED STATEMENT OF BRETT BISHOP, CO-OWNER, LITTLE SKOOKUM SHELLFISH GROWERS; ON BEHALF OF THE PACIFIC COAST SHELLFISH GROWERS ASSOCIATION

My name is Brett Bishop and today I am representing commercial shellfish growers on the Pacific Coast from Alaska to California. For the record, 85 percent of all shellfish produced on the West Coast are grown in Washington, where we've farmed shellfish for 150 years. We're actually the largest producer of farmed shellfish in the entire United States.

My family's farm is on Little Skookum Bay in Mason County. We are a traditional family farm, with tides. My parents live next door, Mom is 91 and Dad is 93. My two teenage boys are the sixth generation to live on the old homestead and grow clams and oysters in Little Skookum Bay.

We are typical of most other shellfish growers, and we are all facing unprecedented problems that appear to be linked to warming oceans and low oxygen conditions. The 'dead zone,' identified in 2002 off the coast of Oregon, has now been observed by researchers all the way up into Canada. We've been able to correlate the dead zone and upwelling events with the presence of a marine bacteria, *Vibrio tubiashii*, in many of our growing areas and hatcheries. *Vibrio tubiashii* thrives in low oxygen (hypoxic) and no oxygen (anoxic) conditions.

In the wild, it kills oyster larva and seed up to at least 1 mm. which has interrupted the natural cycle of propagation, resulting in little or no "natural set" in the bays and estuaries where we make our living. While many growers in Puget Sound, Oregon and California depend primarily on hatchery-produced seed, many growers in Willapa Bay, which produces almost 60 percent of Washington State's oysters, continue to depend on natural set seed. Growers there are reporting that they are now experiencing their third year with virtually no seed set. This forces them to rely on hatchery production of juvenile shellfish to assure adequate crops, but *Vibrio tubiashii* has infected most of our West Coast hatcheries. Our largest producer of larvae, Whiskey Creek Hatchery, has in fact had to close their doors temporarily, and lay off staff, while they retrofit their operation with a series of filtration systems in an attempt to keep the *Vibrio tubiashii* out of the water they are pumping into their facility from Netarts Bay in Oregon. Growers have been donating funds to Whiskey Creek, to aid them in their research into solutions for hatcheries. If a way is found to rid the hatcheries of *Vibrio tubiashii*, and a system can be engineered that allows us to grow seed up to at least 1 mm in size, we may be able to save our shellfish farmers.

Left unresolved is the ability of oysters to reproduce in the wild.

I need to be clear about this; the current situation puts both the marine eco-system and shellfish growers in extreme jeopardy. Diminished natural reproduction coupled with failing hatcheries puts us in a position where we stand to lose it all.

A problem of even greater magnitude is the acidification of seawater. A NOAA researcher, Richard Feely, reports finding levels of acidity along the Pacific Coast of North America that were not predicted until 50 to 100 years from now. This acidity dissolves calcium carbonate, the stuff that shells are made of. If diatoms, corals and shellfish succumb to this, it might collapse not only the shellfish industry, but the entire marine food chain. Life as we have known it might soon change.

It is a dark and gloomy picture that I just painted. In counterpoint to that, let me tell you something else; shellfish growers might be the only category of people who stand to benefit from the effects of climate change. As polar ice melts and sea levels rise, our front yards and lawns may become suitable places for growing clams and oysters.

Of course, our businesses would have to survive financially to reap any benefits from that future day. This is why we need to solve the problem in the hatcheries now, and address the acidification of the oceans.

Our shellfish crops perform vital eco-system functions as they filter-feed. Just about every human activity that occurs on the uplands contributes nutrients to the marine environment. When a clam or oyster is harvested, it becomes one of the very few human activities that result in a withdrawal of nutrients from the water. Clean and healthy oceans need filter feeding shellfish, whether it's my family that's growing them or not.

From the perspective of the Bishop family it looks like this: we have invested everything we have and everything that we are in our farm. We have been growing as we could afford to for the last one hundred and twenty four years. We have a mortgage with Farm Credit Services. We employ 27 people year-round with gross sales of $2.8 million.

If we can't grow our shellfish, the bank will foreclose on the mortgage, we will lose the farm, our homes, and six generations of our hopes and dreams and investments. That is most of everything that we hold dear.

This is what I am reporting to you folks today.

I thank you for your attention.

Senator CANTWELL. Thank you, Mr. Bishop, and thank you for being here. Very much appreciate your testimony.

Mr. Ranker, welcome to the Committee hearing. Thank you for being here.

STATEMENT OF HON. KEVIN RANKER, MEMBER, SAN JUAN COUNTY COUNCIL, STATE OF WASHINGTON

Mr. RANKER. Thank you. Thank you, Senator Cantwell and Congressman Inslee, for your incredible leadership with regard to coastal issues, policy, and restoration and conservation for your tenures in Washington, D.C.

For the record, I am Kevin Ranker. I am a member of the San Juan County Council. I am also the chair of the Coastal Counties Caucus, which represents the 14 coastal counties in Washington State. I also co-chair the Salmon Recovery Council for the Puget Sound, and I am a program officer for the Ocean Foundation. And last, I serve on the Ecosystem Coordination Board for the Puget Sound Partnership.

I want to touch on some of the ecosystem impacts, simply to bring it down to a local level in my testimony today, so I will summarize my written comments that you have already received.

The effects of climate change are dramatic for a Pacific Rim state, such as Washington State, and particularly dramatic for the coastal communities along our 2,300 miles of coastline.

I want to quote from the University of Washington Climate Impacts Group paper, "Uncertain Future: Climate Change and the Effects on Puget Sound." They wrote, "Changes caused by global warming are likely to reverberate across the Puget Sound ecosystem in complex and unpredictable ways, disrupting crucial interactions between plant, animal, and human communities." We are talking about an ecosystem problem here.

Some of the specific impacts that we will see in the future and that we are already seeing, we have heard about some regarding acidification and other issues. We are also seeing significant impacts to the snow-fed water supplies for Washington State, which will have a dramatic impact on our rivers, streams, lakes, and drinking water for millions of Washington citizens.

We have heard about sea level rise. We will continue to see sea level rise impacts. And as a coastal-elected official, those impacts are very significant. When the sea level rises, we talk about millions of dollars in infrastructure upgrades, millions of dollars in impacts to coastal development, to say nothing of the changing planning and allotting for our communities.

We will see increased and are seeing increases in air temperature and water temperature. We have heard about the impacts on salmon. This will also dramatically impact our other commercial and recreational fisheries.

We are also already seeing stronger and more frequent winter storms in the Northwest. I was elected to the San Juan County Board of County Commissioners in 2004. When I was elected, we had not declared a state of emergency in San Juan County in several decades. In 2006 and 2007, we had three major storms and had to declare emergency situations in San Juan County in a 2-year period. We had no power. We had snow and no water for our elderly out in the rural areas for several days.

These sorts of trends, and what we are reading in the research and data that have been compiled, will continue.

We have also seen increased and will continue to see increased flooding in Washington State in our watersheds. Recent flooding in southwest Washington, and particularly the Skagit, has cost human lives. It cost thousands in dead cattle and other livestock, millions of dollars in damage, and significant long-term community impacts.

There are also, as we have heard, significant economic impacts associated with these changes, with the shellfish industry, with commercial and recreational fishing, with coastal development and infrastructure. And also something that we don't always think about with regard to climate change is the direct relationship between a healthy and beautiful natural environment in Washington State and our tourism economy.

Tourism in 2006 raised $13.9 billion—that is billion with a B—dollars for our state economy and employed 146,000 people. In San Juan County, in my district, $121 million and employed 1,700 people. This is a very important piece of our economy that will also be dramatically impacted.

And I raise that just to point out kind of the—I don't necessarily want to go crazy here—but the trickle-down effect of this situation throughout our economy and throughout our environment.

Here in Washington State, under the leadership of Governor Gregoire, we have made some local and state-based changes that are very significant and need to be pointed out today. One is with regard to emissions reduction. By 2020, having cars down to 1990 standards, green car initiative standards by 2009, energy efficiency standards for appliances, and green building standards are all things that have been advocated by our Governor.

The larger issue, however, as Dr. Miles stated, is that we have an ecosystem problem. For an ecosystem problem, we must have ecosystem solutions.

I want to spent the last few minutes of my comments today talking about ecosystem-based management and why it is so very important to start looking in that direction when we face climate change issues.

There are several examples of this here in Washington State. One is the recently established—and Congressman Inslee is very involved in this—the Puget Sound Partnership. The Puget Sound Partnership is taking a look at ecosystems from the snowcaps to the whitecaps. And when we have an ecosystem problem, such as climate change, we must begin to manage our resources and our human activities in an ecosystem perspective.

The Puget Sound Partnership has six ecosystem goals—human health, human quality of life, species biodiversity and the food web, habitat and land use, water quality, and water quantity. These are critical issues. We cannot continue to manage our resources on a habitat by habitat, species by species, or in my case, as a locally elected official, individual lot by individual lot perspective. We must take an ecosystem focus.

In San Juan County, we launched the San Juan Initiative. We brought together the heads of all of our state resource agencies—thank you, Dr. Koenings, for participating—the heads of all of our Federal agencies for the region, and tribal and local leaders to begin addressing how we can actually do this on a local level.

The recommendations of the San Juan Initiative will be completed this year. Those recommendations will go to our state and Federal and tribal partners with regard to specifically how we can begin to look at climate change and other ecosystem problems facing us.

On a Federal level, something else that is very important to pay attention to when it comes to these issues is the Federal Joint Ocean Commission Initiative. That body is providing coordination for state efforts, such as the Puget Sound Partnership, local efforts such as the San Juan Initiative. On a national perspective, we must have a coordinated approach to these issues so that we can generate these wonderful successes on a local level that can be replicated on a national or statewide perspective.

Specific recommendations, in my conclusion here, we are aware that the Federal Government has some recommendations on what needs to be happening. First of all, continued support for NOAA, academic institutions such as the University of Washington, non-governmental organizations, which provide research and modeling, is critical to addressing these issues—critical for myself as a locally elected official, critical for State managers and Federal managers. Without that data, we cannot plan appropriately.

We also must formally recognize and support local efforts, such as the San Juan Initiative, State-based efforts such as the Puget Sound Partnership, and regional and national efforts of coordination such as the Joint Ocean Commission Initiative.

And last, we need your colleagues to step up the way you have and be true champions with regard to these issues. What we sorely need is a renewal of the kind of leadership commitment, and innovation at the Federal level that in the past defined the United States as a leading force in the protection of our environment and our planet. I hope that as we move forward, we can work together to regain that position.

And the last comment I will make is, Congressman Inslee, you mentioned the next generation. I have a 5-week-old daughter. I have thoroughly enjoyed my times on the Puget Sound and my memories playing with my father and my grandfather on the beaches and on Orcas Island. And it is not a choice, but an absolute mandate, that we must take these actions now for my daughter and my daughter's generation.

Thank you.

[The prepared statement of Mr. Ranker follows:]

PREPARED STATEMENT OF HON. KEVIN RANKER, MEMBER, SAN JUAN COUNTY COUNCIL, STATE OF WASHINGTON

Introduction

Thank you, Chairman Inouye and Senators, for the opportunity to testify today. Welcome to Washington State. I am so glad to see that Chairman Inouye continues his legacy of supporting Washington State as he did in the Magnusson/Jackson era now during the Murray/Cantwell era. Senator, we have something in common we both live on islands and therefore our constituents could be the most affected by sea level rise and climate change.

For the record, I'm Kevin Ranker. I'm a San Juan County Council Member (and Chair of the Puget Sound Salmon Recovery Council, the Washington Coastal Counties Caucus, Pacific Region Program Officer of the Ocean Foundation and a member of the Ecosystem Coordination Board of the Puget Sound Partnership, which is taking an ecosystem-based approach to restoring and protecting our jewel, Puget Sound, by the year 2020).

The 2007 report from the Intergovernmental Panel on Climate Change (IPCC) says it best:

> "Warming of the climate system is *unequivocal,* as is now evident from observations in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."

Based on 20 years of research and thousands of published, peer-reviewed reports, the IPCC concluded that it is more than 90 percent likely that the accelerated warming of the past 50 to 60 years is due to human contributions.

Scientists also tell us that Washington State is particularly vulnerable to the impacts of climate change.

As a Pacific Rim state, sea level rise associated with temperature rise is a concern—especially for all of the communities along our 2,300 miles of shoreline.

- A study released in January concludes that sea levels in Puget Sound are likely to rise a half a foot by mid-century. The study (*Sea Level Rise in the Coastal Waters of Washington State,* 2008), conducted by the University of Washington's Climate Impacts Group and the state Department of Ecology, factored in global warming as well as local weather patterns and geology.
- Under its worst-case scenario, regarded as unlikely, but still a possibility, sea levels in Puget Sound could rise more than 4 feet by 2100.

Also making Washington especially vulnerable to climate change are our snow-fed water supplies. Snowmelt feeds rivers and streams, providing essential support to all kinds of ecosystems, salmon and other wildlife as well as critical aquifer recharge for drinking water for millions of Washington citizens.

The impact of these changes will also be widespread and devastating to numerous sectors of our economy. While obvious economic impacts due to climate change have been raised, such as the loss of coastal development, rebuilding of infrastructure or impacts to commercial fisheries, impacts associated with the relationship between a healthy environment and a healthy economy are less frequently discussed. Tourism for example, depends a great deal on a healthy Puget Sound and surrounding natural environment. In 2006 Washington State tourism revenue was $13.9 billion and created 146,500 jobs. In San Juan County during the same year tourism revenue topped $121.1 million and created 1,780 jobs. The economic impact of losing key ecosystem services will be severe and widespread throughout our statewide economy.

Impacts of Climate Change on Puget Sound

Another study (*Uncertain Future: Climate Change and Its Effects on Puget Sound,* 2005) by the University of Washington's Climate Impacts Group concludes that "profound changes have occurred in the Puget Sound over the past century and the next several decades will see even more change."

"Changes caused by a warming climate are likely to reverberate across the Puget Sound ecosystem in complex and unpredictable ways, disrupting crucial interactions between Puget Sound plants and animals—and their environment."

Projected changes include:

- *Continued increases in air and water temperature.* Air and water temperatures have risen more here than in other parts of the world.
  - *Increased air temperatures* have reduced spring snowpack, produced earlier spring snowmelt, increased winter flow and decreased summer flow—which can lead to altered habitat for fish and other species.

  - And even the lowest estimated warming could change the Northwest's climate significantly more than the warming of the 20th century.
  - *Warmer water temperature* has the potential to put many species at risk, including plankton, the foundation of Puget Sound's food web.
- *Continued alteration of river and stream flows.* With decreased snowpack and earlier snowmelt, Western Washington's low summer stream flows are likely to be further reduced, while winter stream flows rise, altering the timing of freshwater inputs to marine waters.
- *Increased flooding in Puget Sound watersheds.* Recent flooding has cost human lives, hundreds of cattle and other farm animals, and millions of dollars in property damage, to say nothing of the years of recovery for the local communities that were impacted. Projections show that this trend will continue.
- *Accelerated rates of sea level rise* are likely to *increase both the pace and extent of erosion and nearshore habitat loss* already affecting Puget Sound shorelines. The slightest changes in average sea level can dramatically impact the existing fragile nearshore ecosystems of the Puget Sound. Further, as the Puget Sound rises, the impact on coastal development increases. This trend leads to increased coastal armoring which devastates nearshore habitats. The nearshore ecosystems of the Puget Sound provide critical habitat for numerous species currently listed under the Endangered Species Act.
- *Salt marshes at risk.* Projected changes in water temperature, water salinity and soil salinity could change the mix of plant species in salt marshes and the viability of invertebrates that play a key role in the health of salt marsh systems.
- *Increased likelihood of algal blooms and low oxygen concentrations in bottom waters.* Increased algal productivity would lead to a further depletion of oxygen at depth.
  - Puget Sound is one of the largest shellfish-producing regions in the United States; and Puget Sound shellfish are vulnerable to contamination by the toxics produced by harmful algal blooms.

Effects of Climate Change on Salmon

Salmon are fundamental to Pacific Northwest ecology, culture and economy.

Unfortunately, in most river basins, wild populations are severely depleted. Several stocks have been listed or are being considered for listing under the Endangered Species Act.

Salmon depend on both freshwater and marine habitats. They need:

- Clean, cold water; well-connected rivers; and reliable stream flows for spawning, rearing and migration;
- healthy estuaries where juveniles can adjust to ocean conditions, and adults can rest before spawning upstream; and
- productive ocean conditions, with abundant food sources and optimal temperature regimes.

And climate change is taking its toll on salmon, too.

- *More rain and less snow* have led to a major change in hydrograph: higher high flows, lower low flows. This both *increases the vulnerability of their eggs* to flood wipe out and *decreases the rearing capacity* of rivers to support juvenile salmon.
- Because less snowpack feeds the rivers, *water temperatures are warmer in the summer,* which *lowers the survival of rearing juvenile salmon.*
- *Warmer summer temperatures increase the mortality of holding adult salmon* (particularly spring and summer Chinook and summer steelhead—as they enter rivers many months before spawning).
- *Warmer summer temperatures increase the prevalence of certain parasites, which increases in-river mortality of return adults.* (This has been a problem with Fraser River sockeye in recent years and has been noted in Puget Sound rivers, like the Stillaguamish.)
- Modeling suggests that *global climate change will modify circulation patterns resulting in microclimate changes.* For example, more rainfall is likely to occur in lower valleys making less precipitation available for upper watersheds. This will *exacerbate the effects on lower summer flows and higher temperatures, further reducing the capacity of rivers for species such as steelhead and spring Chinook, which depend on upper watershed rearing.*

- *Sea level rise will completely modify lower main stem, estuarine and nearshore rearing habitats,* which have been identified as key habitats for some species/stocks (*e.g.,* Skagit and Snohomish Chinook salmon). This means that *habitat restoration and protection actions will likely be less effective* than modeled.
- *Climate change is associated with broad changes in ocean circulation patterns.* The tendency is likely more toward the El Niño-like years, meaning *less upwelling, less productivity and poorer salmon survival in the ocean.*
- As noted earlier, *higher average ocean temperatures* will *alter the marine food web* and *reduce survivability of salmon.*

What Washington Is Doing to Adapt to Climate Change

Thanks in large part to the leadership of Gov. Chris Gregoire and the state legislature, Washington is taking bold steps to address climate change.

In Washington, nearly 50 percent of our greenhouse gas emissions come from cars, trucks, planes and ships. With this in mind:

- *Emission reduction.* In 2007, emission-reduction goals were established. In 2008, the goals were replaced by statewide emission limits:
  - To return to 1990 emission levels by 2020.
  - To reduce emissions to 50 percent below 1990 levels by 2050.
- *Emissions disclosure.* To assist consumers in making informed decisions about greenhouse gas emissions when buying a vehicle, starting in 2010, disclosure labels will be placed on new passenger vehicles.
- *Clean cars.* Beginning with model year 2009, new cars sold in Washington must meet the clean car standards adopted by California and 16 other states, which will help significantly reduce air quality pollutants.

Energy efficiency avoids the need to increase power generation, which can avoid increases in greenhouse gas emissions. Along those lines:

- *Energy efficiency standards.* Washington has adopted strong energy efficiency standards for new appliance products.
- *Green building standards.* Washington became the first state in the Nation to require that state buildings be built to LEED® silver certification.

Ecosystem-Based Management in Washington

Puget Sound Partnership: Another testament to the Governor's leadership and concern for the environment came last year, when she and the legislature created the Puget Sound Partnership to restore and protect Puget Sound.

Puget Sound's beauty belies its problems:

- Puget Sound orcas are the most contaminated marine mammals in the world.
- Shellfish beds are closed because their harvests are unsafe to eat.
- Beaches are closed because they are unsafe for swimming.
- The list of Puget Sound species that are threatened or endangered is long and, without action, likely to grow.

And a projected population growth of some 1.5 million people by 2020, which will put more stress on the Sound, only increases the urgency to act now.

The Puget Sound Partnership, which I have the pleasure to be involved with, is different from previous cleanup efforts in many respects.

- Its work is based on science.
- It will hold entities charged with the tasks accountable for results.
- And, it is charged with looking at the entire ecosystem—from the snowcaps to the whitecaps.

In developing its Action Agenda for a restored Sound by 2020, the Partnership is considering 6 ecosystem goals:

- human health;
- human quality of life;
- species, biodiversity and food web;
- habitat and land use;
- water quality; and
- water quantity.

This ecosystem-based approach will be essential to turning around the fate of the Sound—a task only made more difficult by climate change.

San Juan Initiative: In San Juan County, we have a local effort that will recommend changes to how local government and state and Federal agencies protect the remaining high quality habitat of the Islands and by extension, all of Puget Sound. The San Juan Initiative's assessment of protection effectiveness will mostly demonstrate that parcel-by-parcel protection has not worked to protect what we care about. The Assessment points out that the way forward is through ecosystem or reach level management that engages the community in finding ways to manage collective resources together, insuring that the values of the community are expressed in protection efforts.

The San Juan Initiative will be completed this year and will point out where our combined local, state and Federal efforts are working to protect the environment, address climate change impacts and where they need to be strengthened to fill the gaps. The process will engage citizens and governments so that the recommendations are ground-truthed and commitments are secured for actions necessary for immediate implementation.

The San Juan Initiative's model for improving protection is the best way to begin preparing for climate change at the local level. The effects of climate change will require new ideas and local solutions that change our management approach to focus less on the parcel and more on the scale of ecosystems.

Federal Support Needed for Better Understanding, Response to Climate Change's Effects on Washington's Marine, Coastal Ecosystems

In the interest of time, I will limit my remarks about necessary Federal support to salmon, as they are an excellent indicator of ecosystem health and our Northwest culture.

Perhaps Jim Martin, former Chief of Oregon Fisheries and Salmon Adviser to Oregon Gov. John Kitzhaber, says it best in the "Light in the River" report on the effects of climate change on Columbia and Snake River salmon:

> "Whether salmon can recover in the Columbia and Snake Basin depends primarily on Federal policy. Will it keep backing into the future with eyes on the past? Or will it turn forward, scout the changes coming fast and act strategically?"

The report recommends a restoration strategy with 4 primary features:

- *Immediate actions* to reduce the impacts or buffer salmon against them, with a priority focus on:
  - reconnecting salmon to headwater habitats;
  - protecting headwater flows and temperatures; and
  - reducing mainstem Columbia and Snake River mortalities to adult and especially juvenile salmon.
- *Population-specific analyses and actions* as precise as possible to the status, life histories and warming effects on each species.
- *Assured feedback* so that research and evaluation of effects on species of both chose actions and warming impacts loop back quickly and certainly to modify and add actions, on an annual or biennial basis.
- *Assured commitment to the precautionary principle under the Endangered Species Act*—which, requires human actions, not salmon, to bear more of the risks from global warming uncertainties and unknowns.

Conclusion

It is critical that the Federal Government be a leader in the efforts to address the effects of climate change on the marine and coastal ecosystems of Washington State and elsewhere in the Nation. Congress must provide increased support to NOAA, academic institutions and non-governmental organizations who are conducting important research and modeling that will be critical to coastal states and local communities as we develop strategies to address these issues. Congress must also provide more support for the state, regional and local programs already underway in Washington and elsewhere in our Nation. These "bottom-up" ecosystem-based efforts are developing local solutions and management strategies while engaging citizens at a level they understand. They will be incredibly valuable models for replication as the effects of climate change become more apparent over the coming years.

Lastly, I want to emphasize that financial support is not enough. What we sorely need is a renewal of the kind of leadership, commitment and innovation at the Federal level that—in the past—defined the United States as the leading force in protecting the environment and the planet. I hope that as we move forward we can all work together to regain that position.

Thank you very much for the opportunity to testify today.

Senator CANTWELL. Thank you, Mr. Ranker. Thank you for being here, and congratulations on that newborn daughter. And I am sure, along with Mr. Bishop, you are working hard to preserve Puget Sound and our oceans for the next generation.

Well, thank you all for your testimony. It has been very helpful. This is obviously part of the official record for the Senate Commerce Committee, and certainly to have a perspective from the Puget Sound, the Northwest, and the West Coast is, I think, particularly important for the Nation.

So I want to start, Dr. Klinger, with you on this point. Are we seeing—we certainly are seeing more of an impact in the West, on the West Coast of climate change in the sense of higher temperatures than in other places. So are we seeing the same impacts on the acidification? Are we at a higher rate of acidification on the West Coast? And if so, what are we seeing in Puget Sound specifically?

Dr. KLINGER. We know very little about the biological effects of acidification on the West Coast. But work by Dr. Feely and Dr. Sabine and others have demonstrated that there will be early and strong effects of acidification in coastal ecosystems in the Northwest and in the high-latitude systems.

So that this area—the chemistry suggests that this area is particularly vulnerable. We do not yet have the biological or ecological data to link the chemistry to the biology.

Senator CANTWELL. Explain that. Explain why the chemistry puts us in the Northwest at greater risk on this issue of CO_2 in the oceans.

Dr. KLINGER. In nearshore areas, there was a recent paper by Scott Doney and his colleagues that suggest that not only due to the absorption of CO_2, but also to other greenhouse gas emissions, urban areas such as the Puget Sound urban estuary is more vulnerable than open ocean areas to acidification. But there are other reasons, and those have to do with the age of the water and the circulation of it that make this region particularly vulnerable.

Dr. Sabine is actually more of an expert on circulation than I am.

Senator CANTWELL. Dr. Sabine, do you want to comment on that? Are we in the West at greater risk, or are we seeing a more rapid acidification than in other waters across the Nation?

Dr. SABINE. Certainly. As I mentioned previously, the deep waters of the open oceans naturally have much higher CO_2 levels than surface waters. And as the waters circulate from the North Atlantic, where they sink from the surface, down around through the Antarctic and back up into the North Pacific, we are basically the end of that conveyor belt that is moving water from the North Atlantic into the North Pacific.

During that whole transit, which takes about 1,500 years, the oceans are accumulating CO_2 from all the dead organisms falling into the ocean. What that means along our coast here, the corrosive waters are the shallowest that they are anywhere else in the world. So when you then add on top of that the anthropogenic CO_2 that is coming in from the surface that combines with those naturally acidic waters, that makes our waters much more prone to the impacts.

Senator CANTWELL. So you are saying that shallow water and runoff are combining? Is that what you are saying because we live in an urban area and have more? Is that what you are——

Dr. SABINE. No, ma'am. In the open ocean, the waters from the deep Pacific that are coming up have—are naturally very acidic. That is just the natural inversion of CO_2 across the ocean, the interface of those two waters make it more corrosive toward the organisms.

And then what we are seeing from our most recent research is that water is now being drawn up onto the continental shelves, and that is what we are concerned about. We didn't expect for these levels of corrosive waters to get shallower for another 50 years. But, in fact, it is kind of a double whammy where adding CO_2 to the oceans is bringing the saturation horizon shallower. Now they have moved into the zone of waters that are being upwelled onto the shelf, so that they are physically being dragged up to the shallower depths more so than we expected in the past.

Senator CANTWELL. Well, Mr. Bishop brought up not wanting to sound so gloomy about this. But I do think it is important to understand unabated where we are going as it relates to the food chain and the Puget Sound, particularly as it relates to the impact on salmon and to our orca population. And I don't know if you could comment on where you think this current trajectory puts us on as it relates to the food chain and the availability.

Dr. SABINE. The oceans are absorbing about 2 billion metric tons of carbon each year. That is a natural process. Whenever you increase CO_2 above any liquid, it will absorb that CO_2. That is what the oceans are naturally doing. But that is changing the chemistry. And as long as CO_2 continues to increase in the atmosphere, the oceans will continue to absorb that.

We are seeing these corrosive waters in the open ocean naturally getting shallower by about 1 to 2 meters each year. Every year, it is getting shallower and shallower and shallower until it eventually breaks the surface. That is going to continue basically no matter what. So what we are seeing is only going to get worse over time.

Senator CANTWELL. Dr. Klinger, would you like to comment on food chain and the impact on the food chain? Was it Dr. Koenings saying how it relates to salmon and the orca population? We are already obviously seeing impacts on both these species and moving a lot in these areas to try to recover and save these species. So what is the impact of this acidification, what is the trajectory we are on right now?

Dr. KLINGER. That is a very difficult question. Dr. Koenings spoke to the uncertainty on this issue, and I—there is no science that can inform that—an answer to that question at this time. There are concerns. There are early responses—sadly, responses, for example, in the very small stages of fish and invertebrates that could easily be impacted.

We would see impacts in those young recruits before we actually see impacts on adults. And what that would perhaps promise is reduced recruitment or a recruitment failure so that absence of new recruits to populations, it could apply to fish populations and to shellfish populations.

But as I said, we don't know at this point what the impacts will be. The food web effects could be very large. In my own opinion, they are very unpredictable at this point.

Senator CANTWELL. Dr. Koenings, do you just want to comment on that?

Dr. KOENINGS. As a resource manager that takes science and builds the management decisions that affect people's lives, it is a very difficult period for us to go through right now in terms of management of natural resources. I think we are seeing some very definite changes in our salmon populations in particular.

The synchronicity of the fresh water phase, the marine phase is no longer as tight as it used to be, *i.e.,* the young fish coming down from the fresh water hitting the ocean. That survival phase is not as great as it used to be. We are seeing a lot of changes in the fishing patterns of our fleets. We base our models that we use for management these days on historic fishing patterns.

Those historic fishing patterns are basically not catching the same fish that they caught before because thermal routines are changing, and we haven't been able to keep up with those kinds of changes in our mathematical models that we rely on so heavily. So there are a lot of changes that are going on that we are already seeing that management has to respond to.

And one way of responding to them is simply saying in light of all this uncertainty, we just need to cool it. We need to cut the harvest, for example, in certain species down to a level that we think is sustainable. Harvest rates on salmon that maybe in the past years were sustainable at 60 or 70 percent harvest level, probably are now in the 20 or 30 percent harvest level today simply because of productivity of those stocks aren't as good as it used to be, and I think that trend is going to continue for a number of years. So until we can solve——

Senator CANTWELL. When you say "productivity," you are referring to—?

Dr. KOENINGS. The productivity, the number of, let us say, the number of salmon produced per generation, *i.e.,* you have 1,000 fish in this generation, you expect 3,000 or more of the next generation. Right now, we are getting maybe harvest rates a little bit higher. One thousand is producing 1,000. So we are seeing the harvest has to respond to that.

So the productivity isn't as high as it used to be. And we have to respond as resource managers. So there are definitely changes going on, again, that I referred to as sort of bizarre in terms of their perspective.

Senator CANTWELL. Mr. Ranker, do you want to comment on this?

Mr. RANKER. Just specifically, with regard to the food web effects, as we see alterations in—the research is suggesting, we see alterations in estuaries and nearshore environments, and we need not only focus on the individual salmon and the out-migrating juvenile salmon which use those areas for foraging, but also the foraged fish, the herring. These small fish represent a significant majority of the salmon's diet, and then the salmon represent a significant majority of the southern resident orca whale population's diet.

So, again, when we are looking at individual alterations and specific habitats, we need to recognize that there is impact on the food source going all the way up to the orca whale.

Senator CANTWELL. Well, I think this is exactly what we are seeing already. Yes, we are seeing a major impact on the food source for both of those species.

So, Dr. Miles, I am saving all my questions for you as to the solutions. But for now, I am going to turn it over to my colleague, Congressman Inslee, and allow him to ask a few questions.

Representative INSLEE. Thank you.

You know, this is very disturbing because, unfortunately, it has confirmed what I have been hearing since May 5, 1996, when we brought these scientists up and really dropped this bomb on Congress. And Mr. Bishop, you have been worried about this for a couple of weeks. I have been worried about it for a couple of years now, and the news gets worse.

Basically, nature is seriously out of whack is what you are telling us. From an acidification standpoint, the ocean is on fire, and we need to respond as if there is a fire and we are not responding as if there is even a drizzle. And that is why I am hopeful that with your testimony, Senator Cantwell and I can make sure that others hear about it. It is very, very disturbing.

Several things I want to make sure that people understand is clear, is it not, that climate change is separate from acidification? In other words, even if the Flat Earth Society is right and there is no climate change going on or if it is not caused by humans—even if the Flat Earth Society is right—still we would have this clearly scientific consensus that the oceans are becoming significantly more acidic because of human-caused CO_2. Does everybody agree on that? Everybody agrees on it.

I want to give people a sense of how significant that is. pH, the acidic scale, is a logarithmic scale which is designed to trip up sophomore physics students. But I have been told, I was looking at the NOAA literature, and it says—make sure that I read this right. The NOAA fact sheet on this says that the oceans have absorbed 50 percent of human-caused carbon dioxide. And it says, "This has caused an increase in hydrogen ion acidity of about 30 percent since the start of the industrial age through a process known as ocean acidification."

Now could somebody just briefly describe if there is a 30 percent increase in acidification, the ions that are associated with acidification, why does it only show a tiny little change in the logarithmic pH of the ocean? Just very briefly so that the Flat Earth Society can get this.

Dr. SABINE. Why is everyone looking at me? OK. As you said, the pH scale is logarithmic. pH 7 is neutral. Numbers larger than 7 are bases like sodium hydroxide or Alka-Seltzer. Those are basic compounds. Numbers less than 7 are acidic like acids, hydrochloric acid, or lemon juice is acidic.

But it covers such a wide range that this logarithmic scale explains it. It is the concentration of hydrogen ions that actually affects the chemistry, and so it depends on where you start. The oceans are actually slightly base. They had a pH—in the pre-industrial period, they had a pH of about 8.1. Now they have got a pH of about 8.0. So that is about 0.1 of a pH. But because of the logarithmic scale, that represents about a 30 percent change in the actual concentration of hydrogen, the individual hydrogen ions.

Representative INSLEE. Now, as a layperson, if you are going to have a 30 percent change in the significant part of the acid-base relationship of the water, it would shock me if there wasn't very significant changes in the biology of the ocean. I want to ask you about what we know about that.

In the NOAA material and other material, I have read that we do know that at twice pre-industrial levels, if we get to parts per million of twice pre-industrial levels, which we are clearly headed to in this century if things don't change, and more, that there would be as much as an 80 percent reduction in calcification in some coral species and 5 to 50 percent reduction in calcification, the ability to form calcium, the structural part of these organisms associated with this? Are those about the right numbers?

Dr. SABINE. Yes.

Representative INSLEE. So if I told you that humans were going to have an 80 percent reduction in our ability to form bones, the calcification process, I think that would be pretty disturbing to people if that happened within this century.

Isn't it fair to say from the science we know today, that is a distinct possibility for the organisms that live in the sea?

Dr. SABINE. For the organisms that specifically produce calcium carbonate skeletons, yes. Now—I am sorry.

Representative INSLEE. Yes. So here is what is disturbing, the most disturbing thing to me in all this. With all due respect to clams and oysters—and I can see—around clams and oysters—the very basic bottom of the food chain are zooplankton, pteropods, and the like. All the life in the ocean is based upon this bottom life in the food chain.

And I am told that something like 40 to 50 percent of all those little organisms that are the basis, eventually up to the blue whale and orcas, have some calcification process involved in their system that could be disrupted by the somewhere 50 to 80 percent reduction in calcification. Is that right?

Dr. SABINE. Yes.

Representative INSLEE. Now, to me, that just scares the living heck out of me. We get 7 to 10 percent of our protein from the oceans. And from that, it seems to me that from what you are telling us, there is a significant chance of a collapse in the food chain in the oceans. Is that what we are looking at as a possibility?

Dr. SABINE. If I could just give you an example? We did a study a while back where we took living pteropods, these little marine snails that float around in the ocean, living pteropods out of the North Pacific and placed them into waters that coincidentally were very similar to the waters that we saw being upwelled off of the northern California coast this last summer. So, high CO_2 waters, and we actually saw the shells dissolving off of these living organisms. They were dissolving off of the pteropods as they were swimming around.

These pteropods have been shown to comprise as much as 40 percent of Pacific pink salmon diet. So, yes, if we don't know exactly how all the ecosystems are going to respond because there is a complex assembly to all kinds of different types of organisms. Some of them do not produce calcium-permeable skeletons. But we certainly will change the ecosystem structure, and that will have impacts on our food chain.

Representative INSLEE. Dr. Klinger?

Dr. KLINGER. I would like to add, in response to your question, that it is not just a problem of calcification or lack of calcification. As we change the concentration of hydrogen ions in the water, in the surface waters, and as we change the concentration of calcium ions that we haven't really talked much about that yet, that has—well, it could have profound effects on the physiology of calcified and non-calcified organisms.

So ion flux across membranes could disrupt basic biological functions even in non-calcified organisms, and this is an area of research I think we really need to pursue actively.

In regard to your comment about collapse of food chains, my own opinion is that we won't see a total collapse of food chains, but we will see substitutions, changes in the—we may end up with food chains or food webs that are highly undesirable and are not productive for the needs that we use them today.

Representative INSLEE. I can tell you that my constituents do not relish a sport season for jellyfish as a substitute for a sport season for salmon. So I share your sentiment.

Dr. KLINGER. That is right. So the food webs could be radically different.

Representative INSLEE. Well, I could tell you if Al Qaeda had some bomb that could cause a potential collapse of the food chain, the U.S. Congress would be active. And I hope that we start to act on this. I have much more questions, but I will defer to the Senator.

Senator CANTWELL. Dr. Miles, let us talk a little bit about a solution as it relates to just the fisheries management side of the equation. And obviously, there are many elements to this. But you touched on a little bit in your testimony about specific challenges, what should we do to start managing our fisheries different relative to ocean acidification?

Dr. MILES. Four things I can think of. Biology is the big hole at the moment with respect to the acidification problem. We know very little. In specificity, we know a few things. But there needs to be a really major research effort on this particular problem, looking at it in whole regional ecosystem context. And I think that is the objective behind the initiative of the National Research Council to produce a research agenda to respond to this problem. Congressman Inslee is aware of that, which is great.

In the meantime, we can't wait for that to happen. Adopt, as Dr. Koenings said, adopt a risk management approach to managing fisheries, and there are a number of ways that one can adopt a risk management approach, and I am not going to try to sell you on any single approach here. But when you look at the combination of multiple stressors, the decisions that will have to be made will have adverse effects on the way fisheries are currently—commercial fisheries are currently organized.

The third thing is reduce stressors. Take, for instance, you asked about salmon in Puget Sound. Well, we know that they will face, as a result of shoaling, an undersaturated horizon during the upwelling period, say, between April and September. That is not the only major challenge. Climate change is, (a) increasing the temperature of the streams and, (b) is reducing the water, the stream flow that they require. So that by August, September, they are in trouble. How do we deal with that problem, which is a very serious problem in Washington State, the future of the streams for migrating salmon in the summer.

Then they will get to the Sound in, say, from May to June, and they will meet additional stressors, and we have to regard then land use planning as a little different part of fishery planning. So you look at the population growth rates for some of the time, and you look at the way the coastal development is proceeding, that is another problem with salmon and other species.

Senator CANTWELL. You are saying land use planning as it relates to pollutants, stressors?

Dr. MILES. And things like temperatures will be what we, you know—all of those things will really matter. The last thing we need to do is——

Senator CANTWELL. So things of that nature that will allow water to flow directly back into?

Dr. MILES. —and the last thing we have to do is to monitor so that we know what is happening as it is happening. And the initial attempt to monitor with respect to carbon in the Puget Sound is collaboration between Mr. Sabine's group, the lab at the University of Washington, and some others. But that is just the beginning. It didn't exist before.

We have to do this systematically. It is risk management, multiple stress, awareness on action, and yes, ecosystem risk management. But we have to worry about the rate of change, and it may be as Dr. Klinger implied that the ecosystem we have now is not the ecosystem we will have 10 years from now.

Senator CANTWELL. And then when you are talking about risk management strategies, just—and I know you didn't want to focus on any one in particular, but what is different in that scenario than what we are doing today?

Dr. MILES. Oh, take, for instance, the Germans, they have proposed, their scientists have proposed a system of guardrails.

Senator CANTWELL. Of what?

Dr. MILES. Guardrails.

Senator CANTWELL. OK.

Dr. MILES. These are quantitatively defined standards that set the picture from—that imply what changes we have to make to prevent the increase in the global climate, global temperature, prevent that exceeding, say, 2.5 degrees centigrade. Whatever it takes to do that, you have to do to get——

Senator CANTWELL. So a much higher standard than what we have been talking about as far as they had legislation——

Dr. MILES. —then they have calculated what it will take to prevent the increase of acidification beyond certain levels in an annual range, and that would be another one. And there are three or four of these examples, but that is one approach to managing.

Senator CANTWELL. —guardrails sounds like a good idea to me. We should at least be pursuing that strategy as it relates to impact and evolving the legislation.

One area we haven't talked about yet in much detail is obviously the impact of the warming of our oceans and waters and the actual sea level rise and the impact that it could have on lowlands and wetlands in Washington State. Now there are some projections here for the size of the rise in the next 20 to 30 years.

Dr. Koenings, we have something—I don't know if this is your expertise, or I am not sure who on the panel has the answer to this as it relates to the impact for us as a region? What are some of the things that we should be undertaking now?

Dr. KOENINGS. Well, I think there will be some drastic impacts. For example, the agriculture industry would be susceptible to large-scale changes in water fluctuation and water levels. Myself, I took it seriously. I bought at home a 50-[inaudible] tank. So I am pretty safe on that. But it is not really my area of expertise in terms of going into the actual dynamics of what a sea level rise may be other than backing up the areas.

But if I could make one comment on some previous testimony? The big fear that I have as we go into this whole reaction to the acidification, global warming changes, et cetera, is you get into the paralysis by analysis. There isn't enough connection. There isn't enough certainty. There isn't enough data populating our models to make accurate predictions of what may, in fact, be in front of us.

But yet we are already, I think, seeing changes that are going on that lead us to believe that we need to take action. That is what I said before. We need to be really precautionary in terms of our resource management because we don't know what the future has in front of us. But we do know something is going on, and we can't wait to take action until our models are populated, until we validate our predictions and those kind of things.

That is a hard thing for people to accept. It is a hard thing to make change when you don't have the basic science to say that here is the causal connection.

But yet things are happening that lead us to believe we have got to take the steps, and that is one thing that the government wants us to do is to go ahead and make sure there is environmental sustainability here in Washington for the future by being bold and taking those steps.

Senator CANTWELL. Dr. Klinger, Dr. Sabine, do you want to comment on sea level rise or what we need to do to plan for that? And obviously, we have quite a few areas here in Washington State that would be impacted.

Dr. KLINGER. I am not an expert on the sea level rise. From a biological standpoint or an ecological standpoint, it is likely that we will see a shift in nearshore habitats and in the distribution of those habitats. Those—at least some of those shifts are likely to negatively impact communities—marine communities that we value.

So I think we have to be smarter. I think we have to engage in protection of the habitats that we have now. And we may have to come up with some really innovative restoration strategies that are sort of more forward-thinking than those that we have implemented so far.

Dr. SABINE. I am also not an expert on sea level rise, but I would just like to add the fact that the oceans actually contain the majority of the heat at the surface of the Earth. The increasing temperatures, most of that heat is being absorbed into the oceans, and the oceans have tremendous momentum.

So even if we were to make changes today that would change the temperature of the planet, there is so much momentum in the absorption of the heat and consequences of that are thermal expansion—the expansion of the oceans, which increase the sea level—that the ocean sea levels will continue to rise over centuries to perhaps millennia as a result of what we are doing right now, today, even if we were to stop it.

So I think we need to study and evaluate what the consequences of this will be because there is such a tremendous momentum that once you have got that ball rolling, once sea level is rising, it will continue, and you can't stop it.

And I just also would like to comment on the previous statement about the acting while we still have large uncertainties. And that is just to reiterate the point that I believe you made, Congressman Inslee, that while there are many uncertainties associated with the ecosystem responses to ocean acidification, ocean acidification is a very clear consequence of rising atmospheric CO_2. And the chemistry is irrefutable.

We are measuring those changes, and we know that they are happening and that will also continue as long as CO_2 is. So that is not really a matter for debate.

Senator CANTWELL. But then we should be planning appropriately and particularly you are saying no matter what we do, if sea level rises, the temperature is going to continue, I don't know. Some statistics I have seen say 40,000 to 50,000 Washingtonians could be displaced by this, to say nothing of the impact it could have on Mr. Bishop and other shellfish growers in the industry. But it seems to me if that is inevitable, no matter what we do moving forward, we ought to have better plans in place to address that.

Dr. SABINE. That is right. But I also go back to what Dr. Koenings pointed out, which is the rate of change is also critically important here. That while we can't at this point stop the sea level rise, and it is likely to take a long time to deal with rising CO_2, that even just reducing the rate at which we are changing can have a tremendous impact on the resulting consequences.

Senator CANTWELL. Thank you.

Congressman Inslee?

Representative INSLEE. Mr. Ranker, do you have something more to add?

Mr. RANKER. Just very quickly, specific to your original question, Senator Cantwell, regarding the impact of sea level rise, something that we haven't discussed as much that was mentioned briefly in a couple of testimonies is the changes in fresh water flows which dramatically impacts our aquifer recharge. So when we start looking at sea level rise, there are two other impacts that we need to consider and consider very seriously.

One is the ability of our fresh water systems from our snow packs, rivers, and lakes with regard to aquifer recharge, which is the drinking water supply for most Washington citizens. The other thing that we are experiencing in the San Juan Islands now is the very harsh reality of salt water intrusion on our wells. Except for central Puget Sound, the majority of our homeowners have their own wells, and in south Sound, north Sound, and particularly out on the open ocean coast. And if you see even the slightest sea level rise, you significantly raise the chances of salt water intrusion on your wells.

As a past member of my county board of health, the harsh news is if you go above a certain percentage regarding salt water intrusion, you have got to shut down. There is not an alternative, except for the bottled water and bring it in. We have some people on the outer Sound who are doing that by the truckload. It is costing them 29 cents a gallon for their own water. So that is another impact that hasn't been touched on today.

Representative INSLEE. Thanks. I am reading a book called "The Most Important Fish in the Sea." It is about the collapse of the Manhattan stocks in the Atlantic. And it was pointed out that New York Harbor used to have a really productive—biologically, it was very, very productive. All kinds of, I think there were——

And listening to these multiple stressors, increased temperature in our streams and the Hood Canal dead zone, increase in acidification, changes in the hydrological cycle, if things do not change, if we continue on this course of acidification, the warming, changes in our hydrological cycle, would there come a point or could there become a point where we suffer the same biological decline as New York Harbor, eventually?

Dr. KOENINGS. I think that is a very good question, and that is one of the things that certainly we here in the State of Washington are trying to avoid by setting up a whole new agency dealing with—under Governor Gregoire's leadership, a whole agency that deals with Puget Sound. And you are very familiar with that. You are one of the leaders of that as well.

So one of the things we are trying to do, of course, is to set up so we avoid that kind of fate, and we somehow can restructure, reshape, and reform what we do in Puget Sound so that we don't get into the fix that we are in in terms of the New York Harbor and some of the other industrial areas around the country, the Chesapeake Bay, down in Florida, Louisiana, California. They have all suffered sort of the same kind of fate. And we are determined here in Washington to avoid that.

Representative INSLEE. We appreciate the Governor's leadership on that. I want to talk about on a larger basis what we have to do to skin this cat. I really appreciate that you have very prudent resource management. We have got to guard against uncertainty. But I am going to lay the cards on the table. As long as we are putting out megatons of carbon dioxide, we are just sort of doomed in these biological systems no matter how good a job we do in the fishery and the management and the like.

And I just want to talk about what we have to do to solve this problem. I had said earlier that we could have an 80 percent reduction in calcification if we get to twice the parts per million as in pre-industrial times. That is about 450 parts per million, which we are headed to in this century if things do not change.

I have been told that to stop at that level, to stop the rise at twice the pre-industrial levels, we in the industrialized world have to reduce our carbon dioxide emissions by about 80 percent per capita simply to stop the runaway freight train before we are past the point of twice pre-industrial levels that we know is going to have adverse consequences.

And so, I mean each of us have to reduce our carbon footprint by four-fifths by the year 2050 to prevent going past twice pre-industrialized levels. Is that a fair assessment on what we need to be shooting at to really solve this problem, or should we have different targets of emission?

Mr. BISHOP. Trying to come to grips with this huge problem of ocean acidification strikes me is like trying to fight a beach ball that is so big you can't get a grip on it. You likened it to a bomb. The knowledge of what is coming is like a bomb. The old saying is that the pen is mightier than the sword. I would like to think that ideas can be more powerful than laws. This is how it would have to work.

Shellfish growers measure progress on design, and that is the way this problem has to be dealt with—land use regulations, daily behavior changes. We have to grind away at it. You have to know what you are doing and which direction you are going to go, but it can't be solved in one fell swoop.

What it means to me personally is that we have 7 years left on our mortgage. I would like to be able to grow shellfish for at least 7 more years.

Representative INSLEE. Anyone else? Dr. Miles, are those numbers about right?

Dr. MILES. Yes, but a world of 500 ppm is a world of enormous environmental disruption.

Representative INSLEE. So even if we reduce our emissions by 80 percent by 2050, we are still going to suffer significant environmental damage? Is that right?

Dr. MILES. Yes. Yes.

Representative INSLEE. Which, to me, is not a reason for inaction, it is a reason for hastening the action. The fact that we are in difficult straits means that we should be acting sooner rather than later. And I can tell you that I am optimistic in our ability to do that.

I have been working on something called New Apollo Energy Project, which basically says that we need a new technological base rather than our carbon-based system. I believe we can achieve that. Senator Cantwell has been doing incredible work in the Senate to develop one.

And if we do that, if we use the optimistic attitude of Americans and the intellectual capital that is available to us, we are going to solve this problem. I believe that. If the U.S. Congress acts. And I just want to thank you for your efforts. We are going to share this information as widely as possible. We will get that Flat Earth Society to wake up yet.

Thank you.

Somebody wants to—Dr. Klinger?

Dr. KLINGER. I would just like to comment. Dr. Sabine brought up the concept of rate and rates of change, and although we can't likely reverse the changes that we have set in motion, if we slow the rate at which we are changing the environment, then we give the organisms a chance to evolve and adapt to those changes.

So adaptation may be a potential where genetic evolution is very rate dependent. The slower you go, the more likely we are that some organisms may be able to adapt and adjust to these new environmental conditions. So rates are important, and we should slow down.

Representative INSLEE. So our theory or our sort of motif should be give the clams a chance.

Senator CANTWELL. Well, I would thank again the staff of the aquarium and John Braden for hosting us being here, and obviously my colleague, Congressman Inslee, for being here and adding his expertise and knowledge to this. And certainly, this information is free to be shared with the House of Representatives as well.

And I want to thank the Commerce Committee staff for traveling here and staffing the hearing this weekend. As you can see, we produced a little Northwest sunshine as part of that.

I want to thank the witnesses especially. Thank you for illuminating this issue, which for many people today have been hearing about the impacts of global warming and the climate change, and yet I feel that the oceans have been missing in the discussion or at least not in the limelight that they really need to have, given the significant impact and damage that has already been done today, the challenges that that puts forth in front of us to save these various fisheries and to save the health of our oceans.

So I want to thank you for being leaders in your fields and helping us illuminate this issue. Mr. Bishop and Mr. Ranker, thank you for your uniquely local perspective. I know these are big challenges. I know that given the consequence of what could happen to our oceans' food chain, what could happen to the health of the oceans overall, it does seem quite daunting.

But, Mr. Bishop, you remind me, we had an FCC Commissioner who just died recently, Newton Minnow, who, when he was taking John Kennedy around NASA, the President said to him, "how come we aren't launching men into—astronauts into orbit instead of satellites?" And Mr. Minnow said, "well, we are launching the satellites because ideas last longer than people do."

And I think your notion that there are ingenious ideas that could help us and that we have to put the American scientific community to task at that, I think, is really the focus of this hearing.

While we have introduced legislation on adaptation, on acidification, and we will be having a debate next week when we come back on global climate change and legislation moving forward, I think that the health of our oceans are in such peril that it takes much more aggressive action than we have currently put forth in the U.S. Senate.

So I thank the Northwest for helping me to paint a picture of this that is very clear and very challenging, but we are a place of ideas, and we should not be daunted by this task. We look forward to working with all of you in the future.

And again, thank you for being here to testify in this important Subcommittee hearing.

This Committee is adjourned.

[Whereupon, at 12 p.m., the hearing was adjourned.]

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